Energy Infrastructure and Industrial Data: Between Global Data Policies and an Evolving iIoT Environment

Final Report

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1 Executive Summary

This paper identifies the factors shaping Industrial Data (ID) use and sharing among Southeastern energy firms. The research questions underlying this study are:

1. What factors affect an energy firm's decision to use and share ID
2. To what extent does ID use entail strategic or collaborative sharing arrangements with other firms
3. What are the procedures by which these arrangements take shape

Contrary to other research findings, agglomeration economies and locational advantages based on Information Technology (IT) infrastructure were not drivers of ID development in the Southeast. Data localization and data protection laws were also not found to influence how Original Equipment Manufacturers (OEM) handle transnational data flows. The decision-making procedures by which ID arrangements take shape instead depend on strategic choices around data management and the evolution of the cloud services market.

Business model adaptation among OEMs has significant impacts on data management practices. While diversified energy service offerings remain sparse among Investor-Owned Utilities (IOUs), OEMs are experiencing an increased complementarity of demand between goods and services as they start to divest from central power generation. For example, demand for gas turbines or transformers coupled with demand for analytics services to minimize failure and downtimes was indicative of a shift from isolated products to services built around products. In the ongoing convergence environment between IT and legacy Operational Technology (OT), access to data is more relevant than ownership. The ownership of intellectual property in software and algorithms that enable the continued use and reuse of data for various business ends drives firms' competitive advantages. However, despite the flexibility afforded by the latest open-source developments in data management, such as container platforms, we found no evidence of energy firms sufficiently leveraging these tools.

Our analysis of the role of standards in the ID ecosystem's evolution shows no risk of serious harm due to vendor lock-in, particularly in the smart grid. The path-dependent inertia of IEEE 1815/DNP3, lack of awareness and perceived benefit of IEC 61850, and strategic OEM preferences for DNP3 involve the kinds of switching costs that are to be expected in a competitive market environment. These costs are dependent on the economic and organizational barriers defining the position of the utility in question along its technological migration path (legacy infrastructure, hybrid systems, or fully digital substations). Costs for deployment may progressively shrink as legacy infrastructure continues to be replaced.

We recommend that Investor-Owned Utilities better leverage the capabilities that data science has to offer and foster ongoing relationships with large OEMs or third-party energy service providers with proven track-records of providing added business value. As a matter of regional economic policy, methods to facilitate market entry for third-party energy service providers should be explored.

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2 Introduction

‘Big data’ is at the heart of an ongoing, industrial paradigm shift often touted as the fourth industrial revolution (1). Industrial Data (ID) increases efficiency and allows the innovative bundling of products and services (2). The increasing rate of efficiency by which energy and raw materials are being converted into useful work — while nothing short of revolutionary — has significant implications for the future of the energy sector as business decision-makers continue to leverage ID to drive their firms’ competitive advantages (3). In 2015, the US Department of Energy (DoE) stated that:

> *The popular transition to smart, data-driven technologies (...) has been introduced at an unprecedented rate relative to the history of the industry, and injects uncertainty into grid operations, traditional regulatory structures, and utility business models (4).*

This study focuses on the energy sector strategies towards Industrial Data (ID) production and sharing in the Southeastern region. The overarching research question that initiated this study is: what are the sources and uses of ID, and under what conditions do energy firms evolve into the ID ecosystem? We consider the Southeastern energy sector an instructive case-study that reveals why and how firms get involved in ID sharing and monetization. Due to data economics’ sector-agnostic nature, the findings may apply to other sectors involved with ID.

This project was initially conceived by EPICenter as building on the work of Clark et al. (2018) and its conceptualization of an “ID production circuit” (5). As the second stage of the project, we narrow the analysis to firm strategy, i.e., we study the factors affecting firms’ decisions related to the use and sharing of ID in the Southeastern energy sector. The research explores the extent to which these strategic decisions stem from a hypothesized set of factors we derived from the organizational decision-making and service economy literature. As outlined throughout this whitepaper, the level of access, quality of ID, and pre-existing market position primarily determine a firm’s decisions about their mode of use and monetization. This decision will, in turn, vary according to different strategic orientations that an energy stakeholder chooses to occupy on the value-chain.

The research questions underlying this study are:

1. What are the factors that affect an energy firm’s decision to use and share ID
2. To what extent does this capacity entail strategic or collaborative ID sharing arrangements with other firms
3. What are the procedures by which these arrangements take shape

Section 2 of this report describes Industrial Data in the energy sector. Section 3 describes the methodology of the case study. Section 4 outlines our findings. Section 5 sets out our policy recommendations. Three Appendices contain [6] a summary of our findings in a matrix format, [7] some detailed definitions and references to formal technical specifications in data and power engineering, and [8] a discussion of transmission quality as a (non)factor in the energy iIoT.

3 Industrial Data and its Use in the Energy Sector

Industrial data (ID) are produced by industrial equipment in their operation to fulfill various mixed-integer optimizations allowing for reliability monitoring and other automation functions. ID are proliferating with the availability of inexpensive, commoditized sensors, and by learning algorithms that can exploit their value. Increasingly, businesses can leverage data communication protocols to gather and transmit ID, such that we can now talk of an industrial Internet of Things (iIoT). ID is used in various industrial sectors to improve operations' performance including efficiency, reliability, productivity, safety and the like. This data can, for example, be used to detect the need for repairs, avoid downtime outside of established parameters, and improve general operational efficiency. More transformative, it can also be used to develop new services.

Electrical energy systems are spread over vast geographical areas and benefit greatly from Supervisory Control and Data Acquisition systems (SCADA), which power utilities use consistently throughout operations from generation, transmission, and distribution of electrical energy. We briefly discuss these ID-generating systems insofar as they help inform the research questions. The following section provides a generic SCADA topology that diagrams ID flows and how energy firms can use them. The availability and transfer of data will depend on many factors, as discussed throughout this paper.

3.1 SCADA Systems

SCADA systems provide an operator at a remote location with "sufficient information to determine the status of particular equipment or a process and cause actions to take place regarding that equipment or process without being physically present" (6). SCADA systems essentially enable remote monitoring and control and involve various operational hardware and software distributed across three architectural levels connected by communications systems (as detailed in Figure 1).

- **The Master Station Control Center:** Computers and various input/output (I/O) systems that enable monitoring and control of processes. Includes a User Interface (UI), which is the sphere where human-machine interaction occurs. Utilities differ in how they grant control center access to relevant user groups
- **Bay level:** Bay level components are the "eyes, ears, and hands" of SCADA (6). The bay level connects to a process level where various field devices are physically or logically separated from the Bay level for shielding and protection
    - » Remote Terminal Units (RTUs) (legacy systems)
    - » Intelligent Electronic Devices (IEDs) (hybrid and new fully digital systems)

3.1 SCADA Systems (continued)

- **Process level:** Involves the primary field equipment such as switchgear, current, and potential transformers, circuit breakers. While legacy hardware often exists at this level, these components increasingly include embedded digital sensors. Process level devices also often involve direct client-server communication such as urgent Generic Object Oriented Substation Events (GOOSE) messaging for critical actuation

The Communications System is typically distinguished along with three relevant categories:

» Communications topologies: whenever two or more nodes are connected in a network, they form a topology that can be defined both in terms of how the wires physically connect and how information is logically transmitted through the system. Network topologies include ring, bus, mesh, or various combinations and vary in efficiency and redundancy requirements

» Communications protocols defining data interchange formats and procedures[1]

» Communications architecture defines the overarching structure and modularity of communication layers. While often used in combinations, they serve as a reference framework to understand the overall utility communications model. The Enhanced Performance Architecture (EPA) is an International Electrotechnical Commission (IEC) reduction of the OSI model down to a three layer model: physical, data link, and application layers. EPA is often used in conjunction with TCP/IP, which allows complete modularity of layers as well as a mix-and-match approach to protocols

Figure 1 represents a generic SCADA topology for substation automation divided by the categories mentioned above and describing functionalities[2]. The illustrated model has been simplified. SCADA sub-components can be further categorized into three operational ecosystems characterized by various combinations of architecture and components listed above. These categories are generally distinct, but as systems upgrade and evolve, they co-exist on a spectrum ranging from:

- **Legacy Systems Infrastructure:** implies an electromechanical SCADA architecture that leverages electronic sensors and analog-to-digital converters

- **Hybrid systems** involve most power utilities with high sunk costs in legacy operational technology but are upgrading their components ending up with Intelligent Electronic Devices (IEDs). Involves elements of two-way smart communication

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[1] For example, SEL Mirrored Bits, Modbus, or DNP3 are common in the US, while IEC 61850 (GOOSE, MMS, SCL) is more common in Europe. Other relevant categories also include distinguishing routable networking protocols such as LAN/Ethernet as distinct from serial communications such as RS-232 and RS-485.

[2] The U.S. grid consists of around 52,000 distributional substations two-thirds of which have automation installed. For the remaining one-third, utilities would not know of an outage unless their residential customers reported them.

3.1 SCADA Systems (continued)

- **New iIoT systems** leverage microprocessor-based control to perform enhanced functions and involve fully digital and automated substations. Involves complete two-way smart communication between nodes

The energy sector's ability to make use of ID within this environment is contingent upon several factors outlined in our study. Figure 1 bears on these factors depicted in the modified ID production process (figure 4) and discussed in the findings.

3.2 Types of ID and their Beneficiaries

Many user groups in a power utility can benefit from ID: operations, planning, maintenance, asset management, power quality, marketing, and customer support. Based on discussions and interviews with practitioners in the energy industry, we distinguish between operational data (OpD) and nonoperational data (NonOpD). Both are machine-generated and exchanged within and across energy firms and manufacturers. Operational data (OpD) consist of time-critical values generated by SCADA and routed in real-time such as volts, amps, bars, breaker status, and others. The use and routing of OpD follow different industry standards depending on the process level (7).

As the name implies, NonOpD are not required by SCADA to monitor and control a power system. They consist of time-stamped, event-based records used for post hoc analysis. This type of data is more often handled by asset management, maintenance, and power quality departments within an energy firm. Examples of NonOpD data include maintenance information on circuit breakers, interval meter data, digitized waveform fault event, performance criteria for synchrophasors, volt-var control, and self-diagnostics (8). This definition also includes metadata, including static data that contains component information and dynamic data accumulated throughout a component's lifecycle. NonOpD allows a utility to switch from time-based to condition-based asset management. Data analytics relies heavily on NonOpD in allowing maintenance divisions to optimize repair and replacement schedules by knowing, for instance, when a breaker is due for service based on the device's functional history.

Both OpD and NonOpD do not include data about the identity and behavior of individual households, businesses, or people, known as Personally Identifiable Information (PII) or "behind-the-meter" data. PII are generally not considered to be ID.

3.2 Types of ID and their Beneficiaries (continued)

While OpD are traditionally solely made available for authorized personnel within an energy firm due to the underlying security implications, NonOpD are now increasingly leveraged across different energy firm user groups. Table 3 below summarizes the various overlapping beneficiaries of ID in an energy firm:

Types of ID	Beneficiaries
Operational Data	Planning, engineering, asset management, and maintenance
Non-Operational Data	Planning, engineering, management, asset maintenance, and power quality groups
Unstructured Enviromental Data	Maintenance, planning, asset management, and maintenance

Table 1: Overlapping Beneficiaries of ID

Intelligent Electronic Devices (IEDs) are distinct from analog, serial devices in that they consist of microprocessor-based devices with multiple functionalities and data generation capabilities (operational and nonoperational). IEDs range from commodity sensors to substation protection and control devices such as protective relays, load tap changers, voltage regulators, and others. There are different approaches to the storage of ID. We generally distinguish between in-house capabilities and outsourcing to cloud service providers as well as various hybrid arrangements. This aspect of data management is explained in more detail in later sections. While operational data are typically sent to SCADA master stations, NonOpD are sent to a data warehouse, which, as will be discussed in the coming sections, can be either on-premises or provided by a vendor's cloud service. As explained in the findings section, the analysis of data is often offered as a bundled service alongside storage and aggregation.

3.3 The Convergence of IT and OT

With the introduction of microprocessor-based digital relays in the 1980s, Edmund Schweitzer initiated technological convergence between Information Technology (IT) and Operations Technology (OT) in the energy sector. That convergence continues to this day (9). The proliferation of microprocessor-based devices is congruent with accelerating technological advancements, from Moore's law to powerful new data management techniques and algorithmic scalability. These advancements are powering networked sensors, or 'things,' which provide firms with insights to enable process optimization. Energy firms can use these insights for their own purposes or sell them as services to other firms. The industrial processes can be governed by algorithms like the machine learning techniques that adapt a home's lighting to its owners' behavioral patterns: iIoT has similar roots to IoT. However, with its focus on manufacturing and industrial control processes, iIoT does not become entangled with the data protection and privacy concerns associated with Personally Identifiable Information (PII).

Generic SCADA Topology

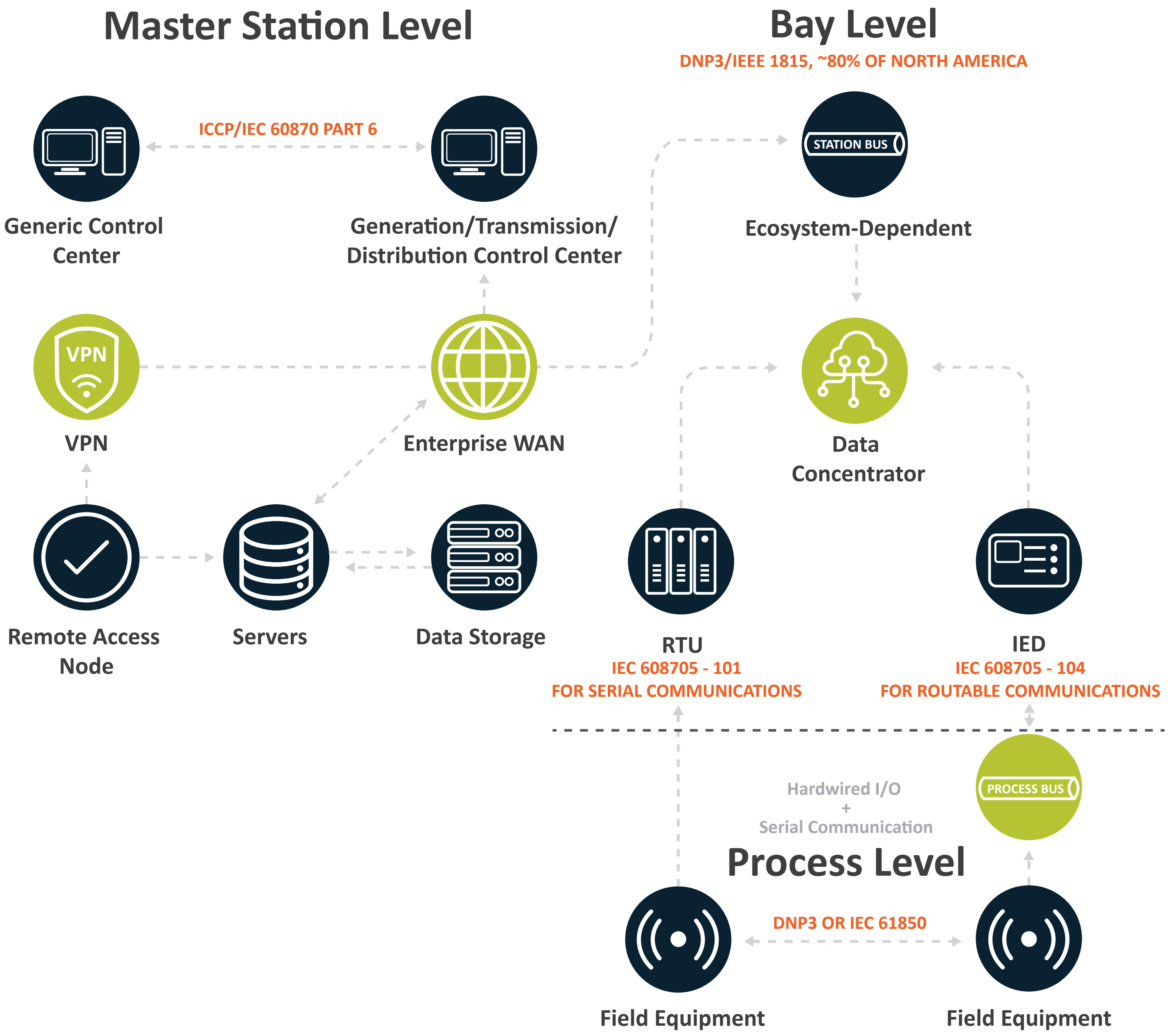

Figure 1: Generic SCADA Topology. Synthesizes work by Thomas, M. and McDonald, J. (6)

3.3 The Convergence of IT and OT (continued)

Based on interviews and a literature review, the strategic decision-making stemming from ID was limited to two categories of business innovation fitting Henderson and Clark's innovation model (1990): incremental and architectural. Incremental innovation uses the insights gleaned from access to ID to minimize operational expenditures and capital expenditures. This category of innovation enables reactive yet responsive Asset Performance Management (APM). Most power utilities today reside in the legacy-to-hybrid operational ecosystems; they are reactive in that a response is mobilized after a fault occurs, yet responsive enough to have situational awareness and precise fault diagnostics capabilities (10). Architectural innovation refers to the desired future-state where utilities can engage in predictive, prescriptive, or fully autonomous APM (11).[3] The automation of various SCADA monitoring and control functionalities achieve better load balancing and optimization of resource utilization, thereby deferring capital expenditures and minimizing operational expense. Architectural innovation enables the integration of OpD, NonOpD and other unstructured data sources that may be relevant to energy firms such as weather, vegetation trim cycles or outage information (12).[4] We also discuss service innovation more generally in the next section.

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[3] The industry refers to this innovation enviroment by the label Advanaced Distribution Management Systems (ADMS) which can mean any software solution that integrates diffrent distribution systems for automation.

[4] Vegetation accounts for 24% of Exelon's outages.

Utility Migration Path

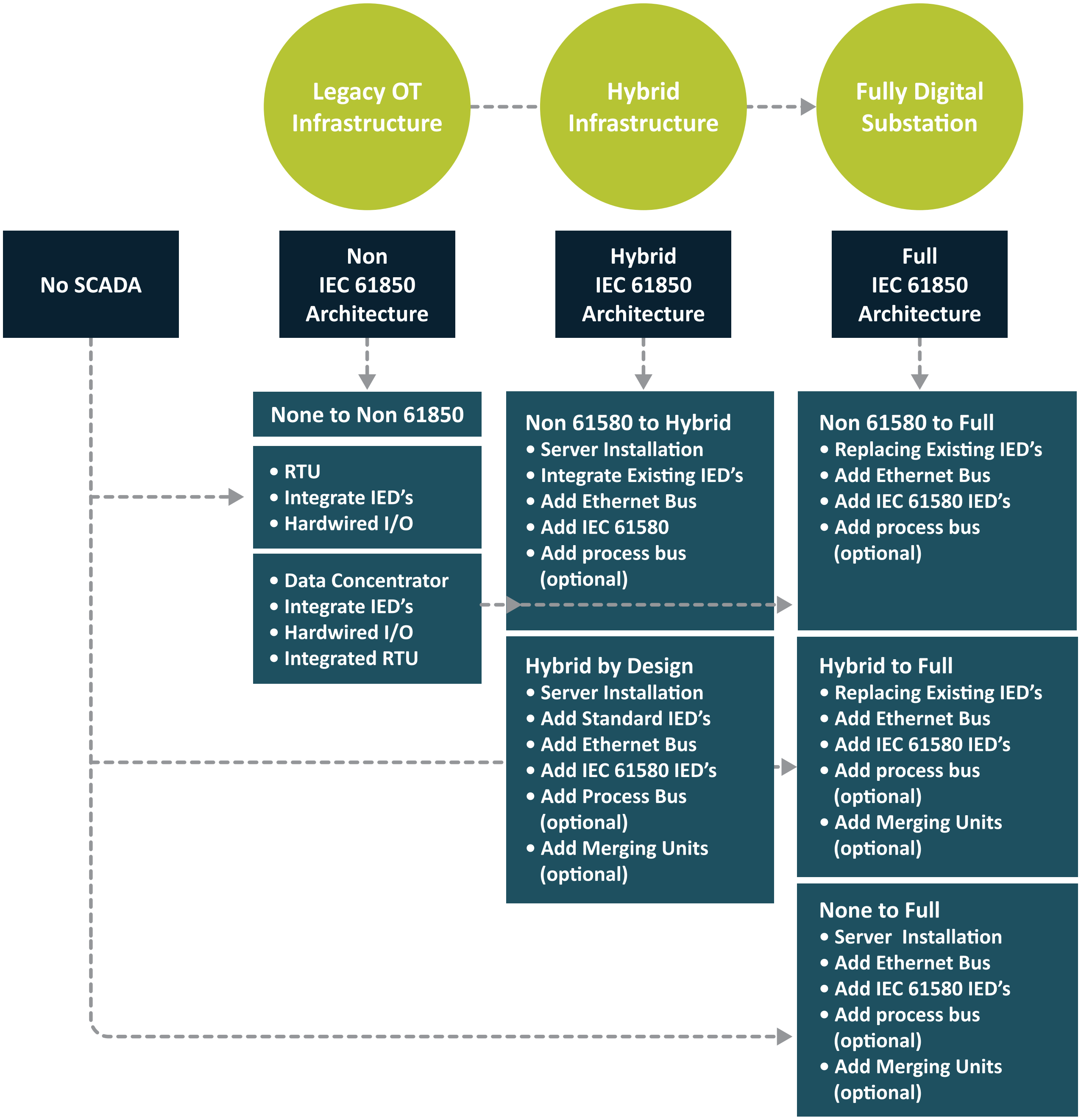

Figure 2: Utility Migration Path (adapted from Thomas, M. and McDonald, J. (6)

4 Theoretical Framework

This section analyzes how Information and Communications Technology (ICT) combine in the service economy to create new ways to capture and generate value. We argue that the most profound disruptions in the energy sector brought about by the iIoT reside at the level of service innovation. The framework is based on strategic management theory, which operates at the organizational level of analysis, and on economists' explanation of the massive shift of economic activity into service provision (13-14). The theoretical framework used by Clark et al. was developed to explain the emergence and consolidation of new industries within designated regions. This study requires a different theoretical grounding due to its firm-level analysis and declining relevance of territory and proximity in the production and exchange of ID. The next section briefly describes the iIoT and the service economy, and the subsequent section relates the two.

4.1 A Service-Based Model of Exchange for the Industrial Internet of Things (iIoT)

Experts in business and technology have published extensive literature on the Internet of Things (IoT) as a revolutionary digital ecosystem that spurs innovation and upends market incumbents (15).[5] The industrial Internet of Things (iIoT) is a more recent, narrower version of this claim rooted in industrial control systems. In this theoretical review, we argue that the iIoT is best understood through the service economy literature, and the process of "servitization," a shift from simple sale of goods to an integrated product and service offering. While traditionally the business models of power generators and Remote Terminal Unit (RTU) manufacturers such as Siemens or GE was based on the sale of equipment, the opportunities to internalize efficiencies through ID use, along with the changing environmental conditions in the broader energy sector, has turned equipment sales into a vehicle by which to disseminate tailored services. These business model changes also led utilities to lease such equipment and search for new monetization schemes based on the provision of services powered by ID.

Early on, economists explained how services are information-based ways of dividing labor in more specialized and competitive forms (14). Stanback argued that as physical work becomes increasingly supplanted by automated technology, value shifts towards services; in our case, industrial and manufacturing services. Initial service-based thought evolved from a goods-based manufacturing model of exchange and was centered on demarcating goods from services based on defining services as anything goods were not. The demarcation was based on four alleged characteristics for services: their intangibility, heterogeneity, the inability to separate their production from consumption, and their perishability. Vargo and Lusch mostly

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[5] The Wharton School's Jeremy Rifkin backs the idea that society is on the dawn of a new industrial revolution brought about a convergence between energy and communications.

4.1 A Service-Based Model of Exchange for the Industrial Internet of Things (iIoT) (continued)

dispelled this understanding of services in their seminal article (16). These authors inverted the dominant logic around the specific markers of services. Services are now defined as “the application of specialized competences (skills and knowledge), through deeds, processes, and performances for the benefit of another entity or the entity itself (self-service) …[S]ervice is sometimes provided directly, and sometimes it is provided indirectly, that is, through the provision of tangible goods” (16). In other words, goods are often the vehicle by which services are disseminated.

As anticipated by Stanback, specialization, and division of labor are evolving so that a firms’ supply becomes increasingly based on service offerings. As of 2009, services accounted for about 80% of both U.S. private-sector gross domestic product and private-sector employment (17). The drivers of service innovation now instead stem from consumer demand for new services and management’s desire to find new market niches for existing service offerings. The intensifying competition and commoditization of industrial manufacturing supply have also led to downstream ‘servitization’ strategy: services are fostering vertical integration through firms’ strategic access to information resources (18). Firms use their traditional resources such as capital and labor, and leverage their specialized skills, knowledge, and data to create competitive services among shared institutional arrangements that allow for mutual value co-creation.

This process of ‘servitization’ entails a shift from a product offering into an integrated product and service offering. For example, instead of selling computer hardware, cloud firms sell the availability of compute cycles; instead of selling compressors, firms provide compressed air as a service. The service logic remains the same: a firm, whether an Original Equipment Manufacturer (OEM) or a demand-response intermediary, leverage their skills and knowledge (e.g., sensor-based analytics, or network visibility) to deliver a service, either by optimizing their leased components or by providing analytics. Other notable examples range from IBM’s business transformation from hardware producer into ICT consulting services or Apple Computer’s switch from a hardware-centric business model to bundled hardware and software as a basis for subscription-based services such as iCloud or Apple Music. More recently, the software-as-a-service business model was adopted by technology firms instead of licensing and now constitutes an integral part of the energy service ecosystem. A natural byproduct of ICT innovation in the service economy is the disintegration of value chains (by re-intermediation or disintermediation) with the rapid growth of new service providers. In their study of different German industry sectors, Kiel and Voigt (2016) found that 89% of firms across various industrial sectors reported changing service offerings due to the iIoT (19).

4.1 A Service-Based Model of Exchange for the Industrial Internet of Things (iIoT) (continued)

The sheer complexity of the iIoT makes it a daunting challenge from a business-strategic standpoint. However, the challenges of vertical and horizontal integration predated the iIoT and started occurring with increasing servitization. The organization theory and strategic management literature distinguish between raw data (ID), information resources, and organizational knowledge (20). While ID may, under certain circumstances, be referred to as a commodity, the more valuable information resources often cannot be reified in tangible ways and are instead contextually dependent on organizational strategies. The focus on information flows stems from its capacity to facilitate and contribute to the exchange of value.

In assessing the organizational changes required to profitably leverage ID, we consider two perspectives that address the role of information resources. First, the Resource-Based View (RBV) asserts that firms' competitive advantage is upstream and based on distinct, hard to imitate resources (such as information or trade secrets) possessed by the firm. In the energy industry, this perspective reflects the exclusive access that an OEM has historically maintained over their device data; therefore, in this perspective, the entirety of the information systems to be protected Intellectual Property (IP). In contrast, Turunen's and Hakanen's study of new entrants to the industrial services market adopts the Dynamic Capabilities View of the firm. This view highlights the notion that a firm's competitive advantage "depends on a firm's capabilities to adapt, integrate, and reconfigure skills, resources, and functional competencies in a dynamic environment" (21). Their analysis connects how managerial decisions around iIoT, notably collaborative arrangements, relate to the strategic supply of tailored services. Their survey of various industrial services markets confirms the strong coupling between specialization in the division of labor and service offerings. Second, they highlight how strongly tailored services depend on mutual information sharing, enabling the co-creation of value.

Most importantly, their study of industrial services markets dispels the RBV notion that firms adopt a resource and position-protection perspective. Within this industrial paradigm, data is not about ownership and enforcing property rights on scarce resources but instead about gaining strategic access to information through collaborative arrangements. For example, Georgia Power has partnered with smart home technology firms in Atlanta to create a "Smart Neighborhood" involving individual rooftop installations and in-home battery energy storage solutions. This arrangement allows Georgia Power to access detailed behind-the-meter energy demand data. Following conventional wisdom, regulated IOUs are expected to leverage their asymmetric data access to promote rate design changes to offset their risk of DER penetration (22). This example highlights a different aspect of strategic firm behavior whereby a regulated IOU gains data access to a previously unmonitored portion of the grid by contractually meting out data-sharing arrangements among participating partners. Given the relationship between ID, information resources and services, it also stands to reason that the ability to provide a service is inexorably linked to the quality of available data.

4.2 Technical Standards and Industrial Data

Standards act as coordinating mechanisms in large organizational fields of diverse stakeholders. The theoretical literature on technical standards explains how they provide a market with the necessary compatibility or interoperability to enable economies of scale and scope, on both the supply-side and the demand-side (23). Lock-in, expanding network externalities, and various competitive dynamics are prominent effects of the economics of standardization (24). These features of standards adoption and competition among standards can work to the benefit or detriment of a sector.

Standards have a critical role in the energy sector's attempts to utilize ID; it is becoming increasingly relevant due to the IT/OT convergence discussed in Section 2.3 above. When it comes to the iIoT and the smart grid, convergence on common standards may help catalyze innovations, support consumer choice, reduce costs, highlight best practices, and globalize markets for devices and systems. At the same time, when new and incompatible technologies struggle for dominance in a market, the resulting standard war can delay efficient market adoption until the positive feedback of market adoption normalizes on an outcome. The aftermath of a standards war generally results in three scenarios, either a truce is declared (as some IoT technologies merge and form cross-licensing alliances); a winner-takes-all scenario (as Microsoft Excel dominates the spreadsheet market); or a market-segmented duopoly (as is currently the case with US-based DNP3 and EU-based IEC 61850). As outlined in the NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0 (NIST 3.0), the broader energy sector is grappling with issues of standards fragmentation and overlap, especially as IT and OT converge. Further, given the ties iIoT has to other sectors, systemic complexity may cause further delays in adoption (25).

4.3 Exogenous Considerations

Several exogenous factors are also playing a role in the transformation of the energy sector. Challenges such as declining demand for energy driven by efficiency, environmental concerns, and shifts to decentralized grid architectures and DER integration, are affecting the US energy sector, and the Southeast is no exception. Further, the pace of innovation in technology markets which is driving the proliferation of ID, evolves faster than regulatory and business models can cope (26). Changing technological circumstances, including emerging ID capabilities, should help inform ongoing discussions over rate-making procedures as regulators struggle to balance the interests of IOUs, the public good and broader policy objectives. While reporting on these elements in the findings when relevant, this study considers these factors as exogenous to the analysis, and focuses more narrowly on how ICT/OT standards, cloud services, and organizational strategy affect ID use.

5 Methodology

This study is designed as a single instrumental case study on the conditions affecting Industrial Data (ID) production and sharing in the Southeastern United States. Conducting a case study is the preferred method as the focus is on the how and why of ID dynamics, a contemporary (rather than historical) phenomenon where no control over behavioral events is possible (27). The Southeastern U.S.is chosen as an illustrative region because of its diverse mix of energy supply and heterogeneous demand, as well as the presence of multinational energy sector OEMs and large, vertically integrated, regulated utilities. Additionally, the SE region provides opportunities for dialogue with regional partners that collaborate with the sponsor of the research study, namely the Georgia Tech Strategic Energy Institute (SEI), specifically its Energy, Policy, and Innovation Center (EPICenter). This organization focuses on Southeastern regional economic development through innovations in energy policy. This boundary condition helped to narrow the scope of the region and industry under investigation. Due to the substantially sector-agnostic nature of data, some of the findings in this case study may apply to other sectors and regions.

5.1 Choice of the Unit of Analysis

The unit of analysis is set at the firm level rather than the industry level. This level of study provides a more fine-grained understanding of the strategic choices regarding usage and monetization of ID. Insights at different research levels may also allow us to understand system-wide emergent properties through better convergent validity and therefore enable more accurate prescriptive recommendations for regional economic development.

The unit of analysis is the energy firm with a geographical presence in the Southeastern US. The Southeastern energy sector consists of a universe of around 6920 energy firms distributed as shown in the Figure 3 'heat-map.' For analysis purposes, we group these firms into four categories: 1) Investor-owned utilities (IOUs); 2) third-party energy firms; 3) Original Equipment Manufacturers (OEMs), and 4) Cooperatives (co-ops) and public power ('munis'). These categories reflect different positions in energy production that may affect a firm's interest in or ability to capture specific qualitative dimensions of ID use.

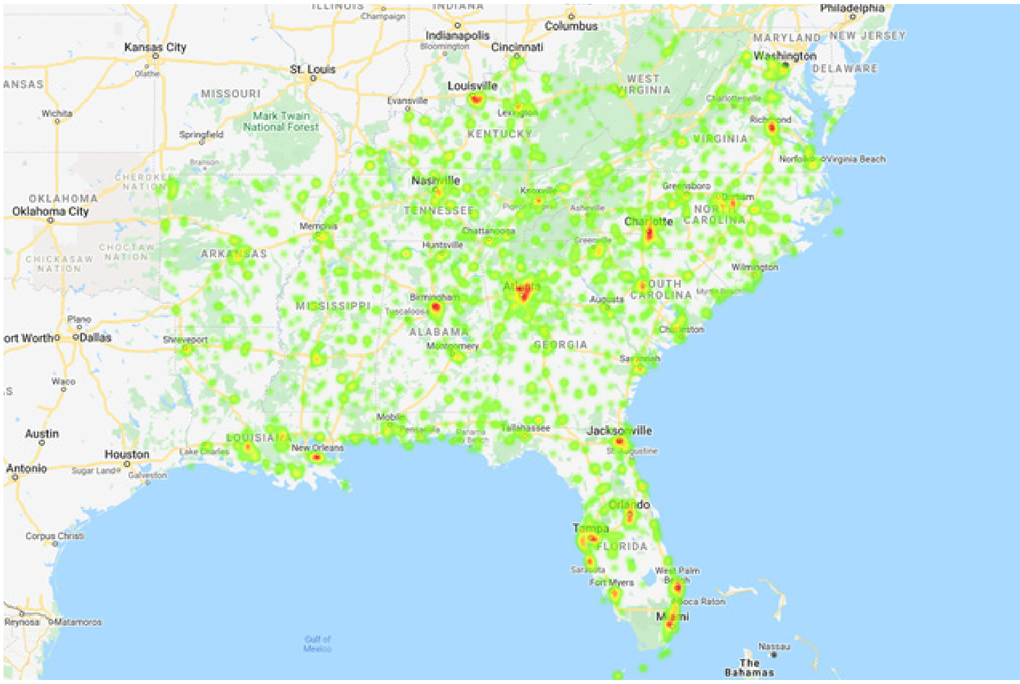

Figure 3: Heat map of energy firms in the Southeast. Source: ReferenceUSA database

In the first category, IOUs, The Southern Company is the primary proxy.[6] The second category, third-party energy service providers, includes firms that engage in energy services but not generation. This category includes firms specializing in demand-response and data analytics such as Urjanet or ProsumerGrid. Third, we consider large equipment manufacturers as key stakeholders in the energy value chain given their role in ID production, analytics services provision, and their ability to influence the standards-setting process. Firms such as General Electric (GE), Siemens, Schneider Electric, Mitsubishi Heavy Industries, Eaton, and ABB have a global presence yet maintain a strong influence in the Southeast energy sector. Finally, generation and transmission cooperatives such as Oglethorpe are amalgamated under the label Cooperatives.

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[6] The Southern Company holding company incorporates different state-level utility companies, including Alabama Power, Georgia Power, Gulf Power, and Mississippi Power

5.2 Data Collection

Data collection relied on a two-pronged method: [1] an analysis of secondary data sources, including technical standards and relevant literature, followed by [2] in-depth, semi-structured interviews with energy firm executives and academics. The first prong involved reviewing relevant documents, such as position papers, laws, and regulations, iIoT and power engineering standards and market indices. Second, interviews provided additional insights, validation of significance, and triangulation. A semi-structured interview guide was used as a template for interactions with the subjects. Following an interview protocol loosely facilitates structured data collection while allowing for openness to assimilate new and unstructured knowledge (28). As a condition, energy firm interviewees had to possess a middle or top management position in IT or OT, relevant technical and business experience, and understanding of the companies' characteristics. The interviewees were encouraged to provide informative and accurate statements by promising to treat their accounts confidentially. Participants were assured that public distributions of this whitepaper will give generic references. Energy stakeholders were systematically asked to provide templates or samples of ID exchange contracts whenever possible or to comment on their knowledge of such legal documents. Interviews with academics were used as supplemental material to corroborate evidence derived from interviews with industry stakeholders.[7] The matrix below provides a category that allows for their commentary on various identified themes and serves as a check on industry stakeholders direct insights.

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[7] Interviewed academics consist of faculty and researchers from the Georgia Tech department of Industrial and Electrical Engineering.

5.3 Summary of Factors

The set of hypothesized factors constitute the primary objective of this analysis and are summarized in the following table (2):

Research and Factors	
Research Questions	What factors affect an energy firm's decision to use and share ID? To what extent does use and sharing of ID entail collaborative or strategic arrangements with other firms? How do these arrangements take shape?
Factor 1	Rate of convergence between legacy Operations Technology (OT) infrastructure and Information Technology (IT), notably the industrial Internet of Things (iIoT)
Factor 2	Data and energy regulations
Factor 3	iIoT and power engineering standardization including levels of interoperability, embedded distributional characteristics, and network effects
Factor 4	Strategic choices around ID management (internal, external or hybrid)
Factor 5	Organizational structure and strategy

Table 2: Research and Factors

6 Findings

In this section, we report on the results of our research. We begin with a reconceptualization of the data production "circuit" and move on to energy firms' data management options, ICT/OT convergence, standards considerations and other topics. A matrix summarizing the findings can be found in Appendix 9.3.

6.1 Modified Industrial Data Process

One of our most important results is a necessary reconceptualization of Clark et al.'s "ID production circuit". We consolidated Clark's ID five-part production circuit into a three-stage linear ID production process by converging storage, aggregation, and analysis into a single ID management stage. (Figure 4) This model reflects a more accurate representation of the data management choices and strategic trade-offs faced by energy firms, given current developments in the cloud services market.

6.1 Modified Industrial Data Process (continued)

The first category, ID collection, depends on pre-existing legacy ICT and OT infrastructures, as outlined in Figure 1. The nature and scope of ID collection are subject to the migration paths for power utilities summarized in Figure 2. Figure 4 incorporates the different migration stages into the ID process model. The development of standards and protocols defining grid infrastructure operations is also a key determinant of how energy executives opt for these migration paths. We discuss these considerations in the following section.

The second category, ID management, collapses the storage, aggregation and analysis categories identified by Clark et al. These categories are unified using the label "data management" because they now constitute diversified options of cloud features available for adoption as a service bundle., As outlined in the blue circle, choices of options are a function of strategic IT decisions that vary according to a firm's business model and decision-makers' risk aversion. An energy firm can opt to use third-party cloud services, conduct on-premise data management or various hybrid arrangements as detailed in the following section and Figure 5. One of the critical findings in the updated ID production process was that data policies and regulations did not directly affect industrial data collection, but rather factor into the decision-making process in the second silo as exogenous constraints.

The third category, ID use and monetization, is about the intended use and monetization of ID (contingent on constraints set by data regulations). Though organizational strategy is addressed in the following discussion in the context of exogenous considerations mentioned earlier, we excluded it from the cycle to maintain the focus on ID. ID was found tied to two major innovation categories intended to either incrementally improve existing processes or to benefit from more profound changes by a fundamental redesign of architecture at the component and organizational level, as mentioned in the introduction.

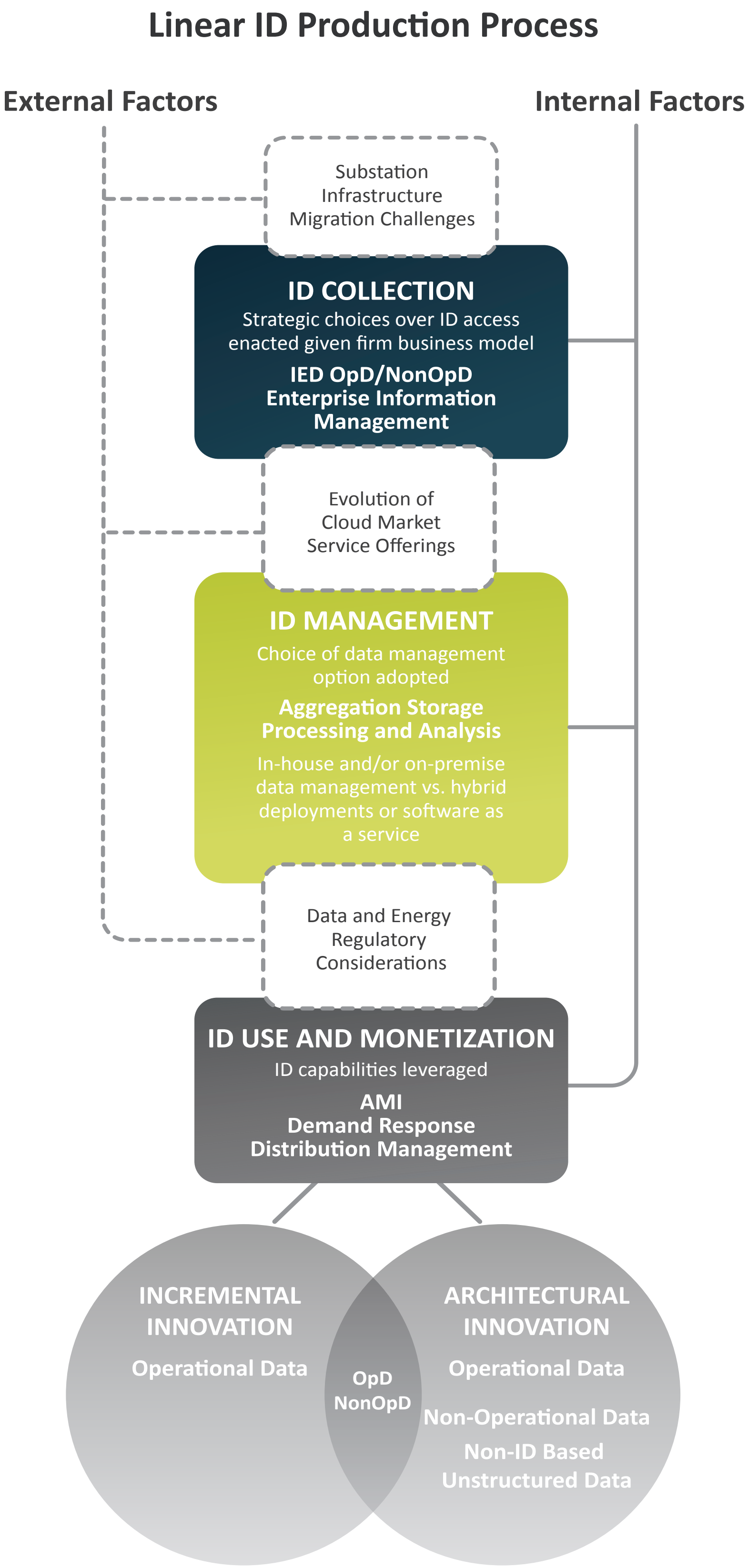
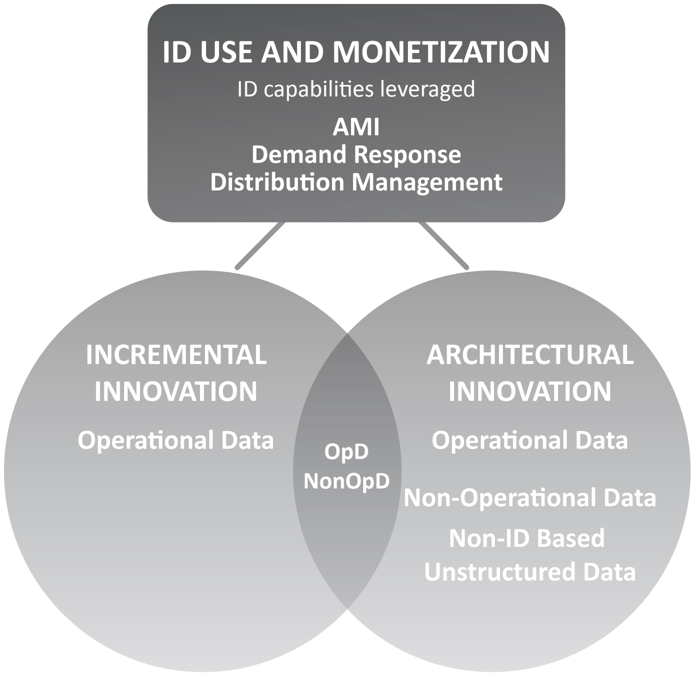


Figure 4a: Linear ID Production Process

Linear ID Production Process



ID USE AND MONETIZATION

ID capabilities leveraged

AMI
Demand Response
Distribution Management

INCREMENTAL INNOVATION

Operational Data

OpD
NonOpD

ARCHITECTURAL INNOVATION

Operational Data

Non-Operational Data

Non-ID Based
Unstructured Data

Competitive Advantage

HINDSIGHT

What happened?

INSIGHT

Why did it happen?

What will happen?

What is to be done?

FORESIGHT

Given uncertainties, how should we automate a prescription for optimal decision-making?

Production Process

Figure 4b: ID Based Competitive Advantage

6.2 Other Key Findings

6.2.1 Factor 1: IT/OT Convergence

IT/OT convergence continues to create innovation potential in power engineering and energy services. Some OEMs are replacing legacy machinery to enable preventative maintenance as an added service. Other more advanced OEMs aim to further leverage IT/OT convergence through organizational restructuring, e.g., by combining staff from business and IT. In this way, internal data sharing is aided through organizational changes rather than technical mandates. As technology consolidates, functions that used to require separate hardware components are unified in one box. However, this convergence may cause problems with unionized workers who have fixed mandates and shifts labor demand towards skilled workers.

IT/OT convergence is also considered a factor that enables high-margin service and technology innovation through faster adoption; however, that is only the case with certain high-end OEMs that can make the requisite structural changes and adjust their business models to match changes in technology. Evidence for IT/OT convergence includes IED proliferation, as well as the continuously expanding scope of standards such as IEC 61850 to include hydropower plants, DER integration, and substation interoperability. The expanding scope of 61850 has occurred over 25 years due to an industry need (mostly in Europe) to include elements of this convergence such as wind power plant modeling, distribution automation and DER integration.

6.2.2 Data and Energy Regulations

The introduction of distributed renewable energy sources (DERs) with intermittent load generation creates data visibility problems for the distribution part of the grid. The presence of DERs often means that portions of the grid are unobservable to power utilities. When this happens, interconnection agreements (which are not mandated by law) become more challenging to implement due to intermittent loads and cybersecurity risks. The lack of a Regional Transmission Organization (RTO) in the Southeast means that individual utilities do not have complete access to generation data typically available through Market Management Systems (MMS) in deregulated markets. This problem creates a market opportunity, as third-party energy service firms are contracted to provide solutions that fill the gap. Some smaller firms reported that the current rate-of-return regulation does not provide enough incentives for further DER deployments. They also disclosed a need for DER policy diffusion, for example, by including hosting capacity maps as a regulatory requirement. These maps show where it is most beneficial to deploy DERs within a given area.

We found no evidence that data localization requirements impede ID. Data localization relates to the trend to align data flows and storage along national borders. From a technical standpoint, these requirements may be an obstacle to efficient networking, especially when it comes to deploying large scale algorithms, but are said to have workarounds available.

6.2.3 Standardization in iIoT and Power Engineering

The most essential standards consideration in the utility space is path-dependence, supplier lock-in, and switching costs. These concerns are dependent on the position of the utility in question along its set migration path (legacy, hybrid or fully digitalized) as detailed in the discussion section [6].

6.2.4 Strategic Choices around ID Management

Data storage presents no scaling challenge anymore. Algorithmic scalability, however, remains challenging, competitive, and contingent on access to clean ID. OEMs usually practice in-house data management (computing and analysis), although they occasionally host functions with Amazon Web Services (AWS). OEMs that depend less on co-creating value from services deploy on-premise solutions such as local SAP deployments. As far as we could tell, the location of GE's data centers is not based on specific policies or regional advantages. Instead, it is reported to be path-dependent: the GE Monitoring and Diagnostics center in Marietta, Georgia grew out of hubs previously developed to process financial transactions. A choice was later made to further invest in data centers at that location.

IOUs run a security-constrained unit commitment optimization solution that determines how much it will cost to serve electricity at a specific node given their ability to do so; however, lack of data visibility across the grid reduces optimization quality implying that scale and data are closely correlated. The larger the IOU, the better it can perform system-level optimization. Recent trends indicate large IOUs are making repeat partnerships with third-party energy services firms to provide analytics for a single suite of assets to further bridge the data visibility problem.

Generally, IOUs are torn between their desire to maintain complete control over critical data and the added value that ID-based services can provide. Similarly, the criticality of the data to be managed makes for risk-averse decision making when it comes to cloud services adoption. While the demand for cloud services is rising in the energy sector, resistance still exists as utilities and OEMs weigh the potential loss of control over critical data against the added value that cloud services might provide for their business. Some OEMs are engaging in divisional restructuring and consolidation to foster a bottom-up data sharing culture. OEMs like GE have also created thousands of data science-based positions as they search for the right combination of computer science, statistics and power engineering expertise needed to leverage ID analytics. IOUs are lagging in this trend however, given the lack of a historical requirement for them to do so and their increasingly divergent incentives from OEMs. Data-science-powered innovation has different implications for OEMs looking to expand their service-based portfolios compared to risk-averse utilities seeking long-term returns on large capital expenditures.

Among the most significant impediments are the cost of data 'cleaning'. OpD tends to be better formatted and organized than NonOpD and most unstructured data. Cleaning up data constitutes a substantial cost of data analysis in power as in most industries. According to one informant, when it comes to IOUs "if the data is being used for billing, it's usually pristine. If the data's not being used by billing, it's usually bad."

6.2.5 Organizational Strategy

The current transformations in energy - IT/OT convergence, reduced energy demand, DER integration, and servitization - are causing shifts in the energy value chain. Emphasis is moving from generation to distribution. While a utility 'death-spiral' is considered unlikely, the strategic threat for power utilities intermediation. Firms with a competitive advantage in data can insert themselves between the utility and the consumer, undermining IOUs' data access and opportunities to add value. As an example, Intel is partnering with AWS to provide demand optimization. More empirical evidence will be required to estimate the extent of that threat to IOUs.

A prevailing view is that IOUs must provide more value to end-users, for instance via home automation services. This strategy is regarded as a mechanism to ward-off intermediation by gaining data collection access points. However, IOUs are starting to react to potential value-chain intermediation through strategic partnerships with 'behind-the-meter' service companies such as smart thermostat makers or energy storage firms. Notable examples include Georgia Power's smart neighborhood and Alabama Power's Neighborhood of the Future initiatives.

Some OEMs, such as GE, opt not to venture into consumer-level monitoring and control despite the potential access to data. Large industrial customers are considered more profitable. On-going business model shifts imply that OEMs are shifting the balance from centralized generation, turbine generators, and Peaker plants towards more reliance on high- margin services for their revenue streams.

GE consolidated internal divisions into GE Digital to provide Monitoring and Diagnostics services as added value for their turbine sales and even supplying services to hardware competitors. GE is also leveraging the existing cloud services market to create software such as Market Management Systems (MMS) to better manage reserve markets and DER integration in deregulated markets. ABB and Siemens are also divesting from central power generation to better focus on the IED manufacturing space.

6.3 Data Management and the Cloud Services Market

"… So now rather than owning your PLC you are paying a lease on your device (…) the company basically takes over the data and pushes it to the cloud, and so it's a reinvention of the same use-case but with different infrastructure"- Leading Industrial Engineer

Clark et al. asserted that ICT infrastructure is a driver of ID development across industries. Given today's ubiquity and commodification of bandwidth, the notion of "reliable connectivity" cannot be considered a significant factor that differentiates regions or firms' propensity to use or share ID. Our research found no evidence that geographical constraints are substantial impediments to "reliable connectivity." High Availability network services are readily available in any central metropolitan area and did not come up as a source of concern in our interviews. Therefore, geographic considerations of networking infrastructure should not be considered relevant.[8]

More interesting than the availability of connectivity is the cloud services market's impact on how energy firms and ID users manage their data. The cloud market (Figure 5a and 5b) offers a suite of different services to suit various business models. Computing deployment models are meant to convey the difference between data management arrangements internal or external to the enterprise network and hybrid deployments that mix both categories.

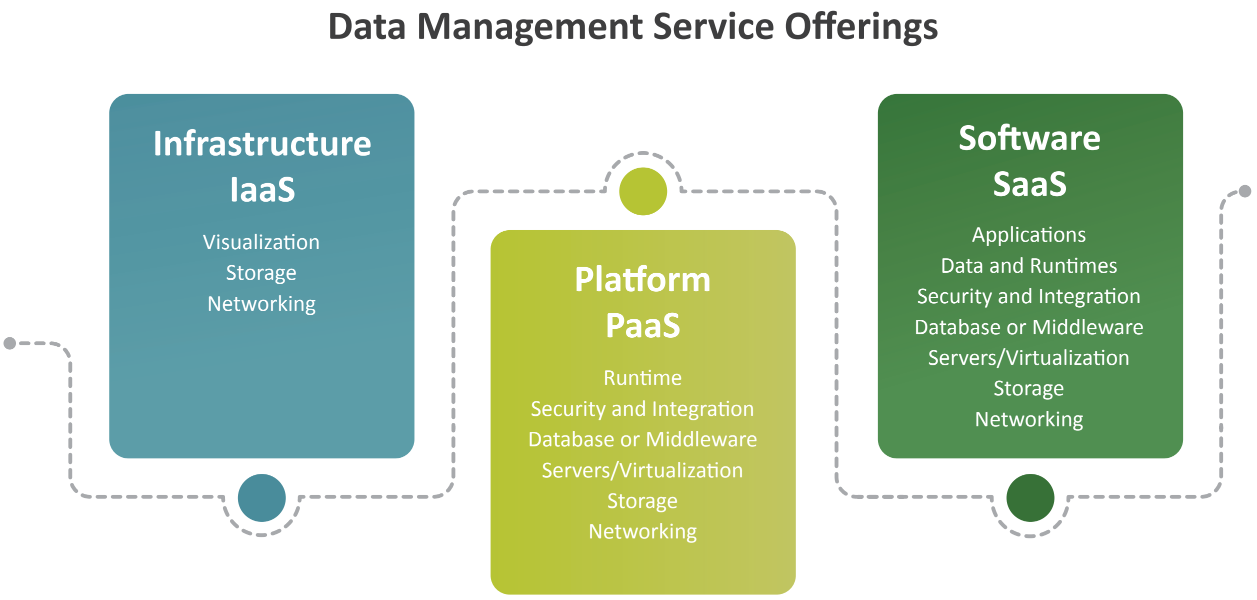


Figure 5a: Data Management Service Offerings

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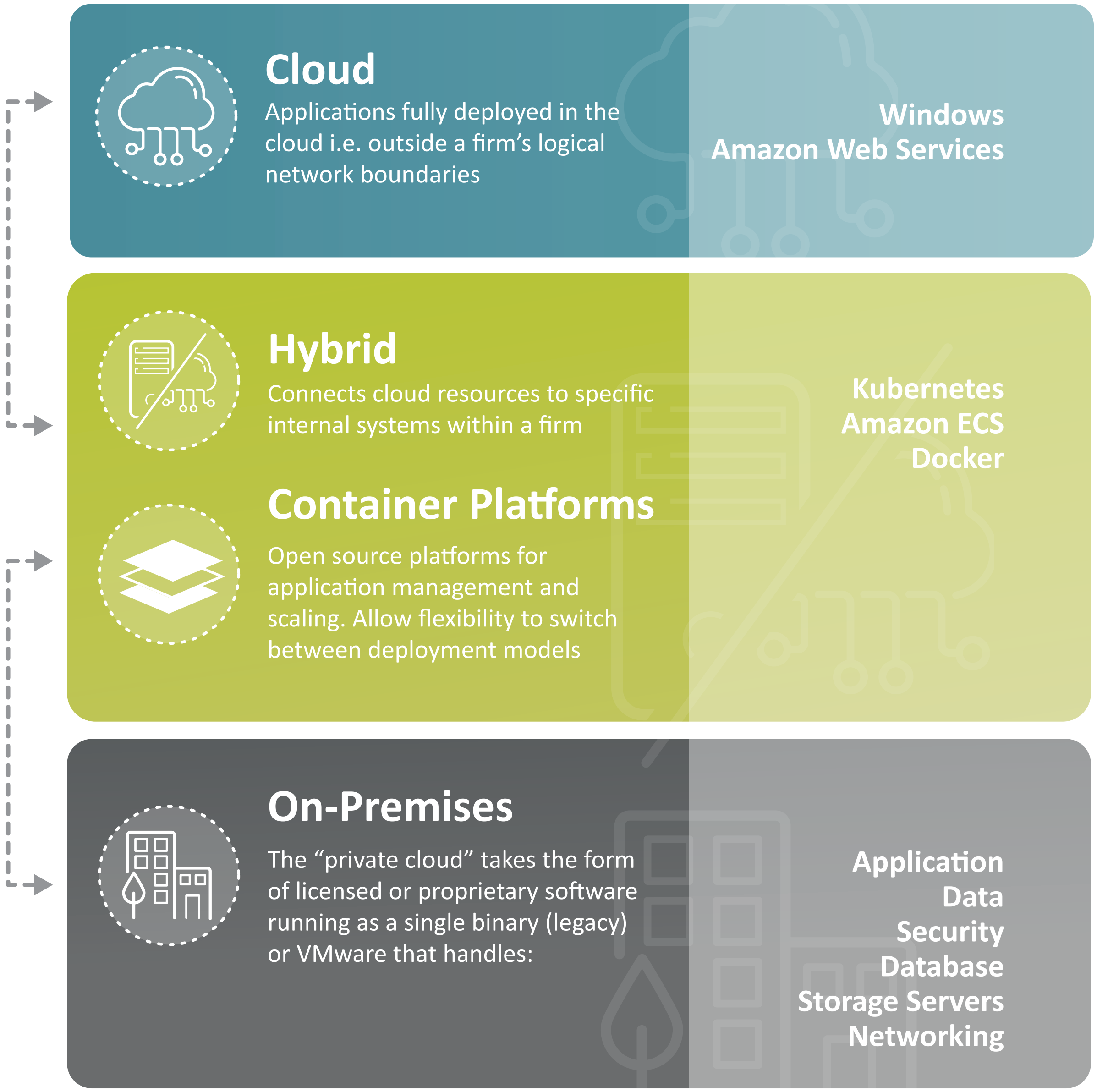
[8] See Appendix 9.3 for a more detailed discussion.

Computing Deployment Models



Cloud

Applications fully deployed in the cloud i.e. outside a firm's logical network boundaries

Windows
Amazon Web Services

Hybrid

Connects cloud resources to specific internal systems within a firm

Container Platforms

Open source platforms for application management and scaling. Allow flexibility to switch between deployment models

Kubernetes
Amazon ECS
Docker

On-Premises

The "private cloud" takes the form of licensed or proprietary software running as a single binary (legacy) or VMware that handles:

Application
Data
Security
Database
Storage Servers
Networking

Figure 5b: Computing Deployment Models

6.3 Data Management and the Cloud Services Market (continued)

As the name implies, on-premises data management operates strictly within a firm's enterprise network. Depending on the service in question, whether the software is licensed (more common) or developed in-house (less common with IOUs), all data management responsibilities would be firm handled. While this approach may have certain advantages in terms of reduced dependencies, from a software development standpoint, updating or fixing one component in the chain would be an exercise on the whole codebase, a risky process that may involve taking critical services offline.

Hybrid deployments connect cloud-based resources to enterprise resources not located in the cloud. These arrangements can offer the best of both worlds: access to affordable storage scaling options while preserving sensitive enterprise systems' integrity. This type of deployment is standard among OEMs such as GE. GE's competitive advantage is their know-how their and historical data on turbine manufacturing which they leverage to develop and sell APM or MMS software as a service. This hybrid deployment entails leasing various IaaS from Amazon AWS, Microsoft Azure, or Equinix in China, allowing IT to scale up storage and other functions while focusing the GE digital workforce where their competitive advantage lies. We expect the trend of OEMs venturing into the licensed software space to increase in the future. Applications that are fully deployed in the cloud can be created or migrated, but they benefit from deployment speed and lack of troubleshooting. Some of the drawbacks of this model involve cost and lack of flexibility.

The 'cloud vendor service offerings' section on the right of the graph presents a generic assortment of tailored data management responsibilities and the service offered. Each category, such as "Application" or "Data & Runtimes" represent a service rendered by a cloud vendor as part of a holistic solution such as SaaS.

- Infrastructure as a Service (IaaS) provides access to networking features, virtual runtimes, and storage to deploy a holistic IT solution
- Platform as a Service (PaaS) provides all the IaaS services, and it removes the need to manage hardware and operating systems so that the focus is on application management
- Software as a Service (SaaS) is a complete all in one software package that is run and managed by a cloud vendor

6.4 The Convergence of IT/OT standards

“Standards are more important today than ever” - Senior GE executive.

The convergence of IT and OT is becoming more apparent as SCADA communication shifts from legacy, serial-based protocols to standards based on interoperable Internet Protocol (IP), notably with the increased use of IEDs.[9] The proliferation of these field devices presents new business opportunities for OEMs and improved operational possibilities for power utilities. We consider this convergence as synonymous with the smart grid, which NIST defined as a cyber-physical system combining “computer-based communication, control, and command with physical equipment to yield improved performance, reliability, resilience, and user and producer awareness” (25). According to NIST, the smart grid’s dominant architectural values are in interoperability, including backward compatibility with legacy OT to facilitate the aging North American grid’s forward migration path. While technical and design migration challenges are crucial, the economic constraints on possible migration paths are challenging. Standards development in the energy sector involves around 25 Standard Setting and Standard Defining organizations listed in the NIST framework, which also contains an almost exhaustive list and description of technical standards in energy.[10] The following section addresses strategic considerations regarding competing standards in the energy sector. For a better understanding of path-dependent conditions in standards, a short history of DNP3 and IEC 61850 is included in the appendix.

Our discussion of SCADA communication standards is narrowed to IEEE 1815/DNP3 and IEC 61850. According to most of our interview participants, these two standards are mostly responsible for defining substation automation’s current and future operations. While there is no general framework for making normative claims on which standard should be given priority for adoption, it is essential to highlight how competitive trade-offs between standards are dependent on economic and organizational considerations based on a utility’s position along its migration path (legacy, hybrid or fully digital).

DNP3 constitutes the de facto communications standard for automation of electrical systems and competes with IEC 61850 for deployment at the field level. North American engineers prefer a ‘best-in-class’ view of each component where clients use multiple vendor components to optimize their systems. According to a 2012 Worldwide Study of the Protective Relay Marketplace in Electric Utilities 2016-2018, early adopters of IEC 61850 in the North American market find GOOSE messaging to be its most useful feature. While half of the new substations are said to be opting for IEC 61850, adoption rates remain low for legacy utilities, as retrofitting old equipment with 61850 capabilities is expensive.

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[9] Consumer IoT standarization processes for “behind-the-meter“ devices are in a parallel development process where various competing consortia and are in the early stages of standards wars. While beyond the scope of this analysis they deserve to be considered for their indirect upstream effects on SCADA ID due to the winner-take all characteristics of network effects.

[10] For a catalog of standards mapped onto NIST’s conceptual domains, refer to the Smart Electric Power Alliance (SEPA)’s website.

6.4 The Convergence of IT/OT standards (continued)

Migration between standards is exceptionally costly for smaller utilities, who face CapEx in equipment, installation, configuration, and training (29). As mentioned earlier, around two-thirds of North American substations are automated. For those substations, changes are undertaken incrementally rather than wholesale replacement. When IEC 61850 systems are introduced, it is more likely to require an interconnection to a SCADA system using DNP3 as its communication protocol. Cost considerations typically revolve around the use-case. For example, a 'greenfield' installation of a new substation that requires interfacing a DNP3 master with an IEC 61850-based server allows for more flexibility in the allocation of DNP3 data mapping. However, a 'brownfield' or retrofit replacement of existing DNP3 outstations with a new IEC 61850 station requires preservation of the DNP3 data map previously used (to minimize overall reconfiguration) will be more costly and is less likely (30).

One reason cited by utilities for not adopting IEC 61850 was their preference for IEEE-based standards, especially given recent efforts to formalize DNP3 through IEEE 1815, which was perceived by operators as an endorsement. Our research found further evidence of a more concerted effort to preserve this tug of war between the two standards at a more global level. Some OEMs use DNP3 as an entry barrier to European competitors at the substation level due to the tight coupling between IEC standard-setting and European OEMs.[11] However, when it comes to the manufacture of field equipment and hardware, one interview participant claimed that there is "less of a reluctance to harmonize with IEC standards" implying that IEDs are increasingly dual-compatible.

One interviewee also claimed it might be strategic on the part of certain US-based OEMs such as Schweitzer to offer dual support as a form of risk-hedge while nudging utilities in favor of DNP3. Knowing that the costs of maintaining and operating IEC 61850 will be prohibitive, Schweitzer may be opting to capture the remaining market share for newer substations. Schweitzer owns a large market share, yet one participant reported that they are lagging on their innovative capabilities. It seems their reluctance to work with IEC is based on a perceived need to maintain their advantage despite being out-innovated, yet they are forced to comply with IEC standards at the level of field equipment due to market forces.[12]

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[11] Process engineers involved in the standards-writing process overlap significantly between North American and European markets through their involvement in similar organizations such as the International Council on Large Electric Systems (CIGRE Working Groups).

[12] According to Schweitzer's online product offering page most products signal a clear preference for DNP3 as IEC/GOOSE are listed as "Optional".

Type of Lock-In	Switching Costs	Relevance to the S.E Energy Sector
Standard-specific training	Learning a new system involves direct costs and lost productivity; these potential costs tend to rise over time as tacit knowledge is embedded.	The aging energy-sector workforce was reported to have high tacit knowledge in electromechanical equipment. Greenfield substation installations may benefit from a 'leapfrogging' advantage to IEC 61850.
Data Integration	Costs of information transfer from one standard to the other. Open considerations include whether the information can easily be ported and what aspects of the information would be lost in a transfer.	As of 2016, IEEE 1815.1 specified a mapping configuration between DNP3/IEC 61850 using XML. This extension was set to fulfill NIST's requirements for smart grid interoperability, as DNP3 was not regarded as capable of enabling sufficient smart grid functions (31). Portability fundamentally reduces the risk of integration-based lock-in.
Search Costs	Search costs are incurred by buyers and sellers to find each other and establish a business relationship.	Despite a general lack of awareness regarding capabilities of IEC 61850 and its potential to facilitate sustainable smart-grid deployments, seminars that showcase IEC 61850 capabilities are on the rise. IEC 61850 is not well advertised in the US; however, tutorials, workshops and other instructional fora are currently ongoing such as interoperability demonstrations organized by the UCA International Users Group.

Table 3: Types of lock-in, switching costs and relevance to the Southeastern energy sector. Based on a typology by Shapiro and Varian (23)

7 Discussion and Conclusions

This paper has addressed factors shaping ID use and sharing arrangements among Southeastern energy firms. Decisions around ID are shaped by i) strategic choices around their management and trade-offs in the cloud services market; ii) partial standards vendor lock-in and the ongoing convergence between IT and OT; iii) Low rates of data science knowledge diffusion among IOUs. Exogenous considerations such as the transformation of the whole energy sector by Distributed Energy Resources (DER)s and the impact of this transformation on energy regulatory models were included in the findings but excluded from the analysis.

In this section we relate our findings to questions posed in the Phase 1 study by Clark et al. This second phase of the project followed a similar research agenda but used a different methodology and theoretical framework.

7.1 Regional Economics

While Clark et al emphasized agglomeration economies and locational advantages based on ICT infrastructure differences, we found no evidence for any unique regional characteristics that facilitate the intersection of data, innovation, and Southeastern energy. The one exception is the diffusion of domain knowledge (see discussion under policy recommendations). Therefore, data connectivity tied to regional IT infrastructure can be dismissed as a driver of competitive advantage for the Southeast.

7.2 Emerging Technologies for Data Collection and Sharing

The report by Clark et al. asked how emerging technologies for data collection and sharing affect energy companies' competitive dynamics and strategic choices. Energy firms are faced with a trade-off between significant deployment complexity versus high-speed software abstraction and flexibility on the IaaS side of the spectrum. On the SaaS side, firms benefit from an environment with low complexity, and low cost at scale versus low flexibility and less control over functionalities. Delegating to other firms such as with SaaS also involves data access and sharing implications.

Larger OEMs such as GE that benefit from scale opt for hybrid deployments that maximize their competitive advantage. GE offers PaaS for client utilities and other industrial customers (through the Predix platform) while partnering with Microsoft to provide them with infrastructure services. While GE retains data usage rights from its customers it remains unclear whether Microsoft benefits form the same terms through their Azure IoT platform.[13]

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[13] We learned this from analysis of data service agreements provided to us by OEMs. Contract clauses specifying use and ownership of data collected through a monitoring system maintain joint ownership of data by stating that the "Owner [shall maintain ownership of the data collected by the Monitoring System about the Facility" while also stating that "Owner [service customer] hereby grants to Operator [service provider] a perpetual, irrevocable, worldwide, royalty free right and license to use information and data collected through the Monitoring System."

7.2 Emerging Technologies for Data Collection and Sharing (continued)

Emerging technologies such as container platforms are designed to house software in sandboxed environments allowing for great flexibility in migrating deployment models and scaling specific responsibilities modularly.[14] This technology constitutes a significant innovation in data management that promises to offset the lock-in associated with IaaS investments that typically involve higher service and switching costs. Though initially open source, many technology startups have launched container engines as a service to offer support for such deployments. Together, containers, dockers, and tools like Kubernetes ease migration to and from on-premises, hybrid, and cloud, preventing lock-in to a specific environment. These technologies are also said to facilitate scalable algorithms and the stateless applications required to handle the constant influx of ID and unstructured environmental data. However, despite the flexibility afforded by the latest open-source developments in data management, we found no evidence of energy firms leveraging these tools.

7.3 Access to ID is More Important Than Ownership

Phase 1 of this study identified “distributional issues associated with data governance” which are said to exist around “contractual agreements that define who owns data, who has access to this data…” We found that the competitive landscape is more concerned with data access concerns than data ownership. Perceptions around ID are generally shifting from treating it as an exclusive private resource towards regarding it as a special type of raw material to be processed and refined.

The value of ID to energy firms is contingent on integrated access to OpD, NonOpD, and unstructured environmental data, especially in their varying capacity to power data analytics. Our study found that the perceived strategic role of ID ownership varies according to the firm’s category (IOU, OEM, third-party energy service provider) as well as the intended end use of ID.

The alignment of incentives seems to parallel firm scale: large OEMs benefit from synergies with large and medium-sized IOUs for large power assets’ efficient operation. Smaller third-party energy services firms operate in a challenging environment. Future research should consider how the competitive dynamics between IOUs and OEMs will evolve if the latter pivot to the manufacture of ‘smart’ behind-the-meter IEDs. Future research should also investigate the extent to which IEC 61850 may provide a competitive advantage for the deployment of DERs.

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[14] For example, as each cloud-native microservice is coded separately and resides in its own container, changes can be made with little compromise to the codebase, implying no downtime and a capability to scale up or down at will.

7.3 Access to ID is More Important Than Ownership (continued)

While diversified service offerings remain sparse among IOUs, OEMs are experiencing an increased complementarity of demand between goods and services. For example, demand for gas turbines or transformers coupled with demand for analytics services to minimize failure and downtimes was indicative of a shift to a service-dominant logic. In this environment, ownership of intellectual property in software and algorithms that enable continued use and reuse of data for different business ends are the technological factors providing a firm with its competitive advantage. (See Figure 5).

7.4 Internal Data Sharing and Organizational Structure

Addressing Clark et al.'s questions about "the nature of data-use agreements within firms," it became clear that the outcome hinges on the incentives of different user groups and the ability of upper management to allow them to leverage NonOpD in a way to fulfill internal divisional goals without creating conflicts. User groups within a utility or OEM have different objectives to achieve that may not always align. The availability of NonOpD may be made available enterprise-wide through federated data marts developed in-house or through cloud-based service providers. Organizational structure seems to be the most significant determinant of internal data sharing following a high-level data governance strategy instituted by upper management.

7.5 National Data Governance

Phase 1 of the study highlighted "the nature of data-use agreements within firms whose operations are located in different countries, and issues around the influence of national data policies, as well as governance regimes within industries." Surprisingly, we found that data localization and data protection laws were not mentioned as important factors by any of our interview subjects. This may be because ID does not typically incorporate PII covered by regional data regulations.

7.6 Standards

The technological challenges cited by Clark et al. in their recommendations included "lack of common standards, data availability, and market value for data across different stakeholders" were not found directly applicable to Southeastern energy. The open standard ecosystem currently in effect is facilitating overall compatibility. While different stakeholders may have preferential access to OpD and NonOpD, ID are abundant. Unstructured data are challenging to 'clean' and incorporate into analytic models, but they remain equally plentiful. When it comes to DER integration and the smart grid, despite being one potential solution among many, IEC 61850 remains the closest formalized overarching standard that allows building towards an iIoT-based energy by working in conjunction with other standards to provide the requisite data semantics for complex deployments.

7.6 Standards (continued)

While impediments exist to its deployment, the more concerning forms of structural anti-competitive behavior were relegated to economic and organizational barriers such as inertia of DNP3, lack of awareness and perceived benefit, and OEM preference signaling for DNP3. Our analysis of standards shows no current risk of technological lock-in for the ID ecosystem's evolution, particularly in the smart grid.

To sum, our analysis of standards shows no risk of serious harm due to partial forms of lock-in on the ID ecosystem's evolution, particularly in the smart grid. The path-dependent inertia of DNP3, lack of awareness and perceived benefit of IEC 61850, and strategic OEM preferences to DNP3 involve partial supplier lock-in and switching costs that are expected in a competitive market environment. Partial supplier lock-in and the ensuing switching costs are dependent on the economic and organizational barriers defining the position of the utility in question along its technological migration path (legacy infrastructure, hybrid systems, or new iIoT systems).

While costs for deployment may progressively shrink as legacy infrastructure continues to be replaced (Newton-Evans predicts increased adoption of IEC 61850 in the future), competing OEM producers in a single value chain are now cooperating on standards to benefit from the network effects of open systems. The question remains whether increased specialization complemented by focused R&D will be consistent with a pro-competitive and pro-innovation OEM landscape. Future research should also investigate the extent to which IEC 61850 may provide a competitive advantage for the deployment of DERs.

8 Policy Recommendations

The goal of this work was also to provide energy executives and policy makers with a direct basis for action as it relates to ID use in the Southeast energy sector. Based on our findings, we provide summary recommendations that will help maximize the usability and production of ID in Southeastern energy, followed by commentary:

8.1 Private Firms

IOUs should better leverage data analytics.

Given regulatory constraints, low demand growth, and variable demand-response, IOUs need to better leverage data analytics for a more efficient delivery of innovative services. Depending on the business case, these improvements should foster healthy partnerships with data analytics firms or build in-house capabilities. While IOUs are exhibiting relatively low rates of innovation in the smart grid space, their capacity to fill those knowledge-gaps is contingent on their ability to foster ongoing relationships with large OEMs or third-party energy service providers with proven track-records of providing added business value. That said, most of the third-party energy service providers are coming from out of state or overseas.

8.1 Private Firms (continued)

IOUs need to be more involved in the standards space.

IOUs have discharged standards considerations to OEMs and should be more involved in the standards deliberation process. IOUs should procure dual-compatible equipment in IEC 61850 and DNP3 to benefit from harmonization efforts led by the NIST Smart Grid Interoperability Panel and future-proof against changing business models. Where possible and as business-cases for DER integration and overall 'smart grid' deployments are possible, cost-benefit analyses should be performed for retrofitting substations with IEC 61850 compliant hardware.

8.2 Policy Makers and Academic Researchers

Facilitate market entry for third-party energy service providers.

The current ecosystem is likely to continue encouraging out of state business to engage in repeat contractual engagements with IOUs. Fostering local industry to take advantage of existing knowledge networks also requires incentives for entry. Therefore, we recommend exploring ways for policy makers to facilitate market entry for third-party energy service providers in the Southeast.

NERC Critical Infrastructure Protection regulation needs better formulation.

Current NERC Critical Infrastructure Protection (CIP) audit processes may have the unintended effect of discouraging investment in advanced IEDs. NERC Critical Infrastructure Protection (CIP) security standards are part of a series designed to protect critical energy infrastructure. If a utility circulates enterprise NonOpD using routable (non-serial) protocols e.g. IEC 608705-104, then NERC CIP requirements apply. As a result of this rulemaking, specifically, CIP-005-5 — Cyber Security – Electronic Security Perimeter(s), security incentives were misaligned as some utilities tended to either not invest in routable equipment or turn off NonOpD data-generating capabilities, thereby reverting to analog capabilities to bypass NERC audits. This finding confirms similar results by Clark-Ginsberg & Slayton (2019) who found that CIP requirements have at times worsened cybersecurity risks. NERC CIP audit processes should be investigated to ensure the grid's critical portions are still compliant with security controls. CIP — 005 should also be revised to include security requirements for all forms of communications to not create incentives to turn 'smart' capabilities off.

The Southeastern energy sector should focus on data science knowledge diffusion.

The knowledge spillover and diffusion literature often attribute innovation to a combination of dedicated resources from public research organizations with the responsiveness of private firms. The Tech Square area of midtown Atlanta and the Research Triangle in North Carolina are designed to provide a healthy interdependence between public research organizations and private sector initiative. These networking hubs provide the essential collaborative structure by which research institutions, firms, and policymakers support the diffusion of domain knowledge in the Southeast. These hubs should continue to be characterized by open regimes of information disclosure, i.e. open fora of discussion and collaborative arrangements. Based on our research, however, we question the responsiveness of private sector innovation hubs based primarily on incumbent activity.

8.2 Policy Makers and Academic Researchers (continued)

Data science is more than a combination of statistics and computer science; it requires training on how to weave statistical and computational techniques into a broader contextual framework starting with its subject matter, in this case, power engineering. Therefore, we recommend a collaborative initiative among Georgia Tech Interdisciplinary Research Institutes, e.g., the Strategic Energy Institute (SEI), the Institute for Data Engineering and Science (IDEaS), Georgia Tech Research Institute (GTRI) and other relevant centers housed within the academic units with an explicit focus on data science and energy. Appropriately scoped, such collaboration could further accelerate the adoption of data science technology in the energy sector, allowing it to leapfrog intermittent problem stages as IT agglomeration economies of Silicon Valley did, instead of walking through barriers one at a time.

Finally, further empirical work should build on research by the Electric Power Research Institute and Edison Electric Institute to determine how utilities share ID management best practices while operating under different regulatory conditions.

9 References

(1) Schwab, K. The fourth industrial revolution; Currency, 2017.

(2) Nagy, J.; Oláh, J.; Erdei, E.; Máté, D.; Popp, J. The role and impact of Industry 4.0 and the internet of things on the business strategy of the value chain—the case of Hungary. Sustainability 2018, 10, 3491.

(3) Ayres, R. U.; Ayres, E. H. Crossing the energy divide: moving from fossil fuel dependence to a clean-energy future; Pearson Prentice Hall, 2009.

(4) Clark, J.; Gilstrap, M.; Amin, S.; DeCorla-Souza, K. United States Electricity Industry Primer. Department of Energy 2015, 6.

(5) Clark, J.; Sudharsan, S. Firm strategies and path dependencies: an emerging economic geography of industrial data. Regional Studies 2020, 54, 634–646.

(6) Thomas, M. S.; McDonald, J. D. Power system SCADA and smart grids; CRC press, 2017.

(7) McDonald, J. D. Big Data Application in Power Systems; Elsevier, 2018; pp 3–27.

(8) Adamiak, M.; Kasztenny, B.; Premerlani, W. Synchrophasors: definition, measurement, and application. Proceedings of the 59th Annual Georgia Tech Protective Relaying, Atlanta, GA 2005, 27–29.

(9) Haas, D.; Leoni, M.; Zimmerman, K.; Genz, A.; Mooney, T. The Useful Life of Microprocessor-Based Relays: A Data-Driven Approach. 2019, 1–5.

(10) McDonald, J. D. Asset Performance Management Comes of Age. 2018, 1–7.

(11) Henderson, R. M.; Clark, K. B. Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms. Administrative science quarterly 1990, 9–30.

(12) Madwesh, A. Applications of Advanced Analytics. Smart Grid Edge Analytics Work- shop. 2019.

(13) Quinn, J. B. Managing innovation: controlled chaos. Harvard business review 1985, 63, 73–84.

(14) Stanback, T. M. Understanding the service economy: Employment, productivity, location; Baltimore: Johns Hopkins University Press, 1979.

(15) Rifkin, J. The third industrial revolution: how lateral power is transforming energy, the economy, and the world ; Macmillan, 2011.

(16) Vargo, S. L.; Lusch, R. F. The four service marketing myths: remnants of a goods-based, manufacturing model. Journal of service research 2004, 6, 324–335.

(17) Ward, J. The Services Sector: How Best to Measure it? Internet Archive Wayback Machine 2016, 1.

(18) Wise, R.; Baumgartner, P. Go downstream. Harvard business review 1999, 77, 133–141.

(19) Kiel, D.; Arnold, C.; Voigt, K.-I. The influence of the Industrial Internet of Things on business models of established manufacturing companies–A business level perspective. Technovation 2017, 68, 4–19.

9 References (continued)

(20) Choo, C. W. The knowing organization: How organizations use information to construct meaning, create knowledge and make decisions. International journal of information management 1996, 16, 329–340.

(21) Eloranta, V.; Turunen, T. Seeking competitive advantage with service infusion: a systematic literature review. Journal of Service Management 2015, 394–425.

(22) Bentham, P. The Growth of Distributed Energy, Implications for California. Next10 2018, 1–36.

(23) Shapiro, C.; Carl, S.; Varian, H. R., et al. Information rules: a strategic guide to the network economy ; Harvard Business Press, 1998.

(24) Katz, M. L.; Shapiro, C. Technology adoption in the presence of network externalities. Journal of political economy 1986, 94, 822–841.

(25) Greer, C.; Wollman, D. A.; Prochaska, D. E.; Boynton, P. A.; Mazer, J. A.; Nguyen, C. T.; FitzPatrick, G. J.; Nelson, T. L.; Koepke, G. H.; Hefner Jr, A. R., et al. Nist framework and roadmap for smart grid interoperability standards, release 3.0 ; 2014.

(26) Lehr, R. L. New utility business models: utility and regulatory models for the modern era. The Electricity Journal 2013, 26, 35–53.

(27) Yin, R. K. Case study research and applications: Design and methods; Sage publica- tions, 2017.

(28) Cannell, C. F.; Kahn, R. L. Interviewing. The handbook of social psychology 1968, 2, 526–595.

(29) Newton, C. IEC 61850: A Research Perspective. Transmission Distribution World 2019, 1.

(30) West, A. Integrating IEC 61850 and IEEE 1815(DNP3). CIGRE US 2016, 1–10.

(31) IEEE Standard for Exchanging Information Between Networks Implementing IEC 61850 and IEEE Std 1815(TM) [Distributed Network Protocol (DNP3)]. IEEE Std 1815.1-2015 (Incorporates IEEE Std 1815.1-2015/Cor 1-2016) 2016, 1–358.

(32) Clark-Ginsberg, A.; Slayton, R. Regulating risks within complex sociotechnical systems: Evidence from critical infrastructure cybersecurity standards. Science and Public Policy 2019, 46, 339–346.

(33) Owen-Smith, J.; Powell, W. W. Knowledge networks as channels and conduits: The effects of spillovers in the Boston biotechnology community. Organization science 2004, 15, 5–21.

(34) Blei, D. M.; Smyth, P. Science and data science. Proceedings of the National Academy of Sciences 2017, 114, 8689–8692.

(35) Morel, Q.; Coste, T. IEC 61850 to the service of power system flexibility. CIRED-Open Access Proceedings Journal 2017, 2017, 1792–1794.

10 Appendices

10.1 Acronyms

ADMS: Advanced Distribution Management System

APM: Asset Performance Management

DER: Distributed Energy Resources

EPA: Enhanced Performance Architecture

EPICenter: The Energy, Policy, and Innovation Center

GOOSE: Generic Object Oriented Substation Events (control model of IEC 61850)

ID: Industrial Data

IEC: International Electrotechnical Commission

IED: Intelligent Electronic Device

iIoT: Industrial Internet of Things

NIST: National Institute for Standards and Technology

IOU: Investor-Owned Utility

IT: Informations Technology

LAN: Local Area Network

MMS: Manufacturing Message Specification (often used along with the TCP/IP stack)

NonOpD: Non-Operational Data

OEM: Original Equipment Manufacturer

OT: Operations Technology

OpD: Operational Data

PII: Personally Identifiable Information

RBV: Resource-Based View

RTU: Remote Terminal Unit

SCADA: Supervisory Control and Data Acquisition

SCL: Substation Configuration description Language and representation format of IEC 61850

SEI: Strategic Energy Institute

TCP/IP: Transmission Control Protocol over Internet Protocol

10.2 IEEE 1815 (DNP3) and IEC 61850 in Perspective

OEMs benefited from historical advantages in standards development processes. Dominant firms in manufacturing initially proved advantageous for the achievement of interoperability due to exclusive turnkey contracts with single suppliers. As a result, protocols evolved in line with the specific requirements of their users. As siloed, proprietary protocols proliferated, power utilities were increasingly forced to rely on single-vendor supply to ensure device interoperability. The proliferation of more than 100 different non-interoperable SCADA systems eventually led to an environment where innovation stagnated. During this early period, families of products and services may have benefited from forward-backward compatibility within the same family of products. However, they did not have interoperability across vendors, which led to winner-takes-all monopolies until the early 1990s. After Ethernet became the de facto media standard for the transmission of industrial protocols, utilities have benefited from a diversity of suppliers. OEMs were no longer able to lock-in proprietary technologies in the substation control space. Procurement methods for substation automation today no longer follow a turn-key approach where a single vendor supplies OEM with their own standards preferences. While supplier-specific protocols still exist, for example, those that configure or program a PLC or RTU, purchasing utilities have driven OEMs towards more commonality of protocols. The unifying Ethernet over TCP/IP or MAC/GOOSE are most used as a data exchange medium.

EEE 1815 / DNP3

DNP3 was written in the 1980s by a Canadian OEM, Westronic in Calgary, Canada. After realizing the negative effects that perceived vendor lock-in would have on consumers, the OEM transferred rights to the DNP3 protocol to the DNP3 user group which was created to maintain, promote, and open up the protocol for adoption. Today DNP3 over TCP/IP benefits from high levels of inertia, i.e., a support community, extensive libraries, and the Institute of Electrical and Electronics Engineers (IEEE) endorsement formally standardized in 2010. With up to 80% adoption in the North American region, DNP3 constitutes the de facto communications standard for automation of electrical systems as well as oil, gas, water, and waste.

IEC 61850

IEC 61850 is a standard for full substation automation i.e. substation and control center communication, intra-substation and control-center to substation.[15] IEC 61850 provides interoperability through an object-oriented approach to data configuration management: information exchange for configuration of devices using Substation Configuration Language (SCL) to manipulate logical nodes at any architectural level (Process, Bay, or Master station). This data model allows a very detailed description of semantic information using Extensible Markup Language (XML) to enable standardized way data management across the levels.

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[15] As for control center to control center communication, the Inter Control Center Communications protocol (ICCP), standardized in the IEC 60870-6/TASE.2 series benefits from universal adoption.

10.2 IEEE 1815 (DNP3) and IEC 61850 in Perspective (continued)

Other standards are modularly added-on such as the stack of MMS over TCP/IP or GOOSE messaging. Therefore, it is agnostic to other standards development efforts on different layers of competition such as communication or any other potential competing lower-level IT protocol. While leveraging the traditional networking protocols (TCP/IP, Ethernet, etc.) GOOSE messaging was defined by the same WG that produced IEC 61850. It allows to efficiently exchange status messages between peer devices without relying on a client-server architecture, meaning it is low latency and reliable for urgent control actions as it does not require the traditional 3-way ACK/handshake. This function is valued by many North American substation operators, particularly reliability engineers. IEC 61850 provides better support for high bandwidth applications of field devices compared to DNP3, which was designed to work with narrow bandwidth links, yet IEC 61850 is undoubtedly more complex to deploy than its more mature counterpart (35). That said, the gap in the problem space of field applications that it attempts to address is itself complex.

10.3 TCP/IP Transmission Quality

The variable “reliable connectivity”, as defined by Clark et al. pertains to “the speed of interaction between machines, and between machines and personnel enabled by the installation of information and communication technologies.” It should be noted that while “connectivity” generally affects machine-to-machine communication, many factors beyond the link and physical layers will affect the “speed of interaction” including the type of standard in question, service functionality (e.g. urgent GOOSE requests or MMS) as well as the inclusion of Quality of Service (QoS) features. The “speed of interaction (...) between machines and personnel” is determined by the transmission quality and the SCADA functionality in question.

The notion of “reliable connectivity” could be better addressed if isolated to QoS for networks circulating enterprise data. The notion of bandwidth is contingent on the transmission quality and service availability of a firm’s network. The transmission quality of the network is determined by the following three factors where lower values imply higher quality communications:

- **Loss** is a relative measure of the number of packets that were not received compared to the total number of packets transmitted (measured in %). Loss is also a function of service availability. If the network is “Highly Available”, then loss during periods of non-congestion would mostly be zero. During periods of congestion, however, QoS mechanisms determine which packets are more suitable to be selectively dropped to alleviate the congestion for instance, packets for Voice over IP (VoIP) or Internet telephony take precedence over other less loss-sensitive protocols.

10.3 TCP/IP Transmission Quality (continued)

- **Latency** is the finite amount of time it takes a data packet to reach the receiving endpoint after being transmitted from the sending node (measured in milliseconds, e.g. the Georgia Tech network has 1-5 milliseconds (ms) latency, a desirable quality in a network). Packets are assigned a Time To Live (TTL), which is a limiting mechanism that ensures packets don't keep routing endlessly if they get lost in transmission. A network prone to lost and corrupt packets impedes on large-scale data transfers. Latency is of fundamental concern for protection engineers concerned with worst-case message delivery times given network design.
- **Jitter (or latency variation)** refers to the variance in the end-to-end delay between packets. For example, if one packet requires 100 ms to traverse the network from the source endpoint to the destination endpoint and the following packet requires 125 ms to make the same trip, then the delay variation is 25 ms.
- **Service availability** is a straightforward metric expressed in percentage of time that indicates the interval of time in which a network service (client-server or cloud) can be used for its purposes. Service availability is calculated by dividing Uptime (the time a device is powered on) by Total Time. The target for 'High Availability,' 99.999% or 'five nines', implies only five minutes of downtime permitted per year.

A relationship between economic geography and connectivity does exist around the issue of facilities colocation. Colocation refers to the common practice of adjoining server farms and telecommunications hubs to share their fixed costs, creating scale and agglomeration economies. As pointed out in the whitepaper, energy firms such as Shell are using fiber optic cables, created in a special partnership with Hewlett- Packard, to transfer on-site data to privately leased servers with Amazon Web Services (AWS). If energy companies can access remote resources through partnerships with an ICT company (e.g. to lease a fiber cable), the question remains as to what extent (or cost) data will be routed through hubs where agglomeration economies exist vs. building the actual refining operations near a location with "reliable connectivity".