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DIGITAL INFRASTRUCTURES AS PLATFORMS: THE CASE OF SMART ELECTRICITY GRIDS

Research Paper

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Abstract

Smart grids enable customers and utility providers to gain a better understanding of energy consumption and production, by adding a layer of digital data collection and analysis on existing electricity grids. As digital infrastructures they have distinct characteristics from earlier 'pipeline' infrastructures in that they can generate significant network effects that could lead to new opportunities for value creation across different stakeholders. Exactly because of these unique characteristics of digital infrastructures, we propose that they can be approached as platforms. With this conceptualization, we seek to explore what are the design and value propositions of a digital infrastructure. We provide answers to this question by synthesizing existing research on platforms and digital infrastructures. We explore the case of the emerging smart grid in South Africa and develop a set of design and value propositions. We discuss the relevance of our propositions to extant research on digital infrastructures and platforms, and explore opportunities for further research.

Keywords: digital infrastructures, platforms, design, smart grid.

1 Introduction

Business organizations and government agencies are increasingly required to function in an always-on economy, which depends upon the continuous support of various infrastructures, from water supply and electricity to computer networking, among others (Dupuy, 2001; Hughes, 1983; Summerton, 1994). As such, infrastructures can be defined as "the basic physical and organizational structures needed for the operation of a society or enterprise, or the services and facilities necessary for an economy to function" (Tilson, Lyytinen, & Sørensen, 2010, p.748). These can be described as 'pipeline' infrastructures, usually developed in a linear value chain with emphasis on internal control of resources (both human and technological). Exactly because of this emphasis, pipeline infrastructures are usually challenged by tensions of standardization and governance of services (e.g. see Ciborra et al 2001; Constantinides & Barrett, 2015; Hanseth, Monteiro, & Hatling, 1996; Kee & Browning, 2010; Ribes & Finholt, 2009; Tilson et al., 2010). These tensions have a negative impact on the infrastructure's ability to scale and to generate value for the various stakeholders involved.

The advent of the Internet of Things (IoT), enabling interconnections among uniquely identifiable digital objects via Internet Protocols (IP), as well as enabling larger digital data flows among those objects (Atzori, Iera, and Morabito, 2010; Rong, Hu, Lin, Shi, and Guo, 2015), has given rise to digital infrastructures. Unlike pipeline infrastructures, digital infrastructures are characterized by a pervasive ubiquity of digital devices (e.g. smart grid sensors) that open up new possibilities for scale. In contrast to pipeline infrastructures, digital infrastructures are managed through a networked value chain, with external orchestration of resources and a focus on ecosystem value. Great emphasis is placed on the infrastructure itself and the ways it can maximize the total value of its products and services (e.g. smart meters and ancillary services) through an iterative, feedback-driven process. For instance, smart grids enable distributed power generation, improve the reliability and availability of renewable energy

(Futch, 2013), and generate opportunities for "prosumers," who not only consume, but also produce and store electricity (Grijalva & Tariq 2011).

Exactly because of these unique characteristics of digital infrastructures, we propose that they can be approached as platforms. "A platform is a business based on enabling value-creating interactions between external producers and consumers" (Parker, Van Alstyne, & Choudary, 2016: 5). With this conceptualization, we seek to explore *what are the design and value propositions of digital infrastructures.*

We provide answers to this question by synthesizing existing research on platforms and digital infrastructures (Section **Error! Reference source not found.**). Section **Error! Reference source not found.** sets out the method used to examine the case of smart electricity grid in South Africa. Section **Error! Reference source not found.** presents our findings by using the synthesis of the literature to develop a set of design and value propositions for digital infrastructures. Section **Error! Reference source not found.** concludes with a summary of our findings, by discussing the relevance of our propositions to extant research on digital infrastructures and platforms, and discussing opportunities for further research.

2 Literature review: From Pipeline to Digital Infrastructures & Platforms

Early pipeline infrastructures including transportation, electricity, water, and sewerage were responsible for rolling out basic services across geographical territories as public or quasi-public goods using systems of standardized services (Dupuy, 2001; Hughes 1983; Summerton 1994). These early pipeline infrastructures were widely assumed to be integrators of urban spaces (Graham & Marvin, 2001). Even with the advent of information infrastructures for telephone, radio, TV and the Internet in the 20th century the nature of these pipeline infrastructures was a high "concentration of ownership and control, the need for mass markets, and a strong regulatory hand further reinforcing industry boundaries and stability" (Tilson et al 2010:749).

In recent years, the advent of cheaper, smaller and more powerful digital devices has enabled improved communications, storage and processing of information and data, in the process blurring the traditional boundaries between industries (Yoo 2010). This blurring of industry boundaries has allowed different stakeholders (e.g. content providers, computing companies, software developers, etc) to generate heterogeneous bundles of services on established and new business models. New digital infrastructures have emerged, "enabled by lower costs and global reach encouraging wide participation in service production and distribution … and new market conditions created by multisided markets" (Tilson et al 2010: 750).

In technical terms, what distinguishes digital infrastructures from earlier pipeline infrastructures is the integrating role of IP, including the added artificial intelligence in monitoring devices and analysing data. Through unique addressing schemes and standard communication protocols, these digital infrastructures connect a variety of physical devices that can interact with each other (Atzori et al, 2010; Rong et al, 2015). This also means that digital infrastructures not only connect a specific organizational system or linear value chain, but also connect various other stakeholders who consume and produce services for their own purposes.

In economic terms, the transition from pipeline to digital infrastructures means a move from supply to demand-based economies of scale. Digital infrastructures mediate transactions across different stakeholders, generating various network effects (Van Alstyne, Parker & Choudary 2016). "Network effects arise when the value one user places on a good depends on how many other people are using it" (Shapiro & Varian 1999:45). Network effects can be *direct* or *indirect* (Arthur 1994; David 1985). Direct network effects (also called same side effects - see Parker et al 2016) explain how an increase in usage by one set of participants (e.g. consumers) leads to a direct increase in value for other same-side participants (e.g. other consumers). Indirect network effects (also called cross-side effects – see Parker et al 2016) explain how increases in usage of one product or service by a set of participants lead to increases in the value of a complementary product or service (e.g. consumers generate effects for producers), which can in turn increase the value of the original. Value can be both tangible (e.g. financial gains) and intangible (e.g. better information on available products and services). Although network effects have also been observed in pipeline infrastructures (see Hanseth 2001), the difference now is that digital infrastructures create efficiencies in social networking, demand aggregation, application development etc, all of which help networks expand faster, while offering a higher average value per transaction (Van Alstyne et al 2016).

Because of these unique characteristics we propose that digital infrastructures can be conceptualized as platforms. Research on platforms has focused on market dynamics and competition (e.g. Armstrong, 2006; Rochet & Tirole, 2003), as well as architectural design and innovation (e.g. Baldwin & Woodard, 2009; Krishnan & Gupta, 2001). We establish links between research on platforms and digital infrastructures, to identify design and value creation opportunities for different stakeholders. These links are summarized in Table 1.

Platform functions (Parker et al, 2016)	**Design Principles for Digital Infrastructures** (Hanseth & Lyytinen, 2010)	**Links between the two literatures**
Pull participants in the core interaction	Design initially for direct usefulness Build upon the existing installed base	Both literatures call for a need to attract users and increase adoption and participation. Both recognize the importance of the installed base. *Platform research* places emphasis on consumer/producer expectations on market structure and efficiency. *Infrastructure research* places emphasis on the technical design of the infrastructure and user adoption.
Facilitate further interactions among participants	Expand the installed base by persuasive tactics to gain momentum	Both literatures call for a need to enable network effects across the installed base to gain momentum and achieve scalability. *Platform research* places emphasis on the value generated by both supply and demand sides of the platform *Infrastructure research* places emphasis on the role of standards and gateways in increasing the size of the user base.
Match participants to markets	Make IT capability as simple as possible	Both literatures call for a need to make IT capabilities simple to understand in order to generate new uses. *Platform research* places emphasis on ways by which IT capabilities can be recombined to generate new (added-value) services. *Infrastructure research* places emphasis on the role of architectural principles and user interface protocols.
Modularity	Establish a modular architecture, as well as distributed governance structures that will enable independent interactions between core IT components and participants	Both literatures call for a need to establish stability through modularity and governance.

Table 1: Platform Functions and Design Principles for Digital Infrastructures

2.1 Platform Functions & Design Principles for Digital Infrastructures

Platforms provide the rules for a marketplace that brings together different stakeholders. These stakeholders fill four main roles, namely, owners, providers, producers and consumers, but these roles may shift rapidly from one to another (Van Alstyne et al 2016). The design of digital infrastructures can benefit from this classification of roles and rules of interaction.

Deciding what the "core interaction" of the platform will be is the first and most important job for designers (Parker et al, 2016). For example, when a smart grid is added as a platform onto an electricity grid, it can enable utility companies (as producers) to improve its grid management practices, as well as individual customers (as consumers of electricity) to improve their energy use. This may also allow municipalities (as providers) and the main electricity producer (as the owner) to better regulate and govern interactions between producers and consumers, while achieving transparency for both. In this case, the 'core interaction' would consist of exchanges between producers and consumers, facilitated through better data on supply of, and demand for, electricity (i.e. the value unit of the core interaction), data analysis via sensors, and adjustment of cost and services (i.e. the filtering of the core interaction). The smart grid could offer this core interaction through a set of capabilities for "pulling" participants onto the platform (e.g. by offering incentives to use smart readers), "facilitating" further interactions (e.g. offering energy valuations of different appliances in a building), and "matching" participants to markets (e.g. matching consumers with producers of energy-efficient appliances). In addition to these functions, there is one structural commonality across all observed platforms: that of a modular technological architecture (Baldwin & Woodard, 2009; Gawer, 2014; Parker et al., 2016). Below we establish links between these platform functions and the design principles for digital infrastructures.

One of the key challenges of digital infrastructure design is the integration, control and coordination of increasingly heterogeneous IT capabilities (Constantinides & Barrett, 2015; Hanseth et al., 1996; Kee & Browning, 2010; Ribes & Finholt, 2009). On one hand, infrastructure designers have to come up early on with solutions that persuade users to adopt while the user community is non-existent or small. This requires them to address the needs of the very first users, before achieving completeness of their design. This has been called the "bootstrap problem of infrastructure design" (Hanseth & Lyytinen, 2010). On the other hand, when the infrastructure starts to expand by benefitting from network effects, designers need to design for unforeseen and diverse needs. This demands infrastructural flexibility and has been described as the "adaptability problem of infrastructure design" (Edwards et al 2007). Five design principles that aim to address these two problems have been proposed (Hanseth & Lyytinen, 2010). These design principles can be linked to the functions of platforms as described above and summarized in Table 1.

The first two design principles proposed by Hanseth and Lyytinen (2010) link to the pull function of platforms. The authors suggest that, initially, a small user group needs to be identified and targeted, with the proposed IT capability; offering the group immediate and direct benefits, with low design costs for the producer and low learning costs for the consumer. IT capabilities should be designed on the existing installed base so that the targeted user groups face minimal adoption barriers (e.g. smart readers on electricity grid). The notion of an installed base refers to both the existing technological and user base upon which a new infrastructure is built and comes from economics (Shapiro & Varian 1999; Farrell & Saloner 1986). The notion has been used in both platform (e.g. Iansithi & Zhu 2007) and infrastructure research (e.g. Hanseth & Lyytinen 2010; Hanseth 2001), with the former placing emphasis on meeting customer expectations on market structure and efficiency and the latter on the technical design of the infrastructure towards improving user adoption.

The third design principle is linked to the facilitation function of platforms. As argued previously, after establishing an initial user base, designers need to think of ways to generate network effects (Rochet & Tirole, 2003; Armstrong, 2006; Parker et al 2016). Research on digital infrastructures has also noted the importance of network effects, in relation to standards and gateways in particular (Hanseth 2001). The value of a standard (e.g. a smart meter) defining an IT capability depends on the number of users having adopted it (Hanseth and Lyytinen 2010). The more users adopt a standard the more likely that another user will adopt it, which further increases its value and so on (Arthur, 1994; Shapiro and Varian, 1999). Whereas infrastructure research tends to focus primarily on user communities (e.g. Star & Ruhleder 1996), platform research focuses on both the supply and demand sides of the platform, seeking to understand both same side or direct (producers to producers and consumers to consumers) and cross-side or indirect network effects (producers to consumers and vice versa) (Parker et al 2016). Network effects can also be negative, driving away participants and leading to the collapse of a platform (Parker et al 2016). Like positive network effects, negative network effects can be both direct (e.g. decrease in the number of consumers of one service) or indirect (e.g. increase in the costs for consumers to use diverse producer services).

The fourth design principle is linked to the fourth function of platforms and starts to become relevant after initial adoption. Hanseth and Lyytinen (2010:13) argue that "if designers continue to generate highly interdependent and local IT capabilities, the whole system will become inflexible and reach a stasis." To avoid such a stasis, the designers need to follow simple architectural principles (e.g. decomposing service infrastructures into a set of layers, Yoo, Henfridsson, & Lyytinen, 2010) and user interface protocols to simplify the functional scope. These principles decrease the technical complexity of IT capabilities, but more importantly, reduce their social complexity (Tiwana, Konsynski, & Bush, 2010). Research on platforms acknowledges these design guidelines, but once again, places emphasis on market dynamics (Parker et al 2016). The aim is to recombine existing IT capabilities so as to generate new, added value services, enabling platform participants to match their needs to new markets (e.g. enabling consumers who generate energy through solar panels to sell their energy to consumers of coal-based energy).

Finally, the fifth design principle, suggests that infrastructures should be decomposed recursively into separate modules. In addition to a modular IT architectural design, modularity should also involve governance rules for monitoring interactions between core IT components and participants. Getting right the degree of decentralization between the authority and responsibility for each class of decisions to be shared among platform owners and module developers is key to implementing good governance (Tiwana & Konsynski, 2010). In contrast, when governance weighs too much on either side (too much autonomy vs. too much control), participants will tend to feel disengaged and disempowered leading to their non-participation on the infrastructure (Constantinides & Barrett, 2015). This design principle is also fully supported in platform research (Baldwin & Woodard, 2009; Boudreau & Hagiu 2009).

In summary, we have established links between research on platforms and the design of digital infrastructures. We will apply these ideas, as summarized in Table 1, in the analysis of an empirical case study of smart grid development in South Africa to derive a set of design and value propositions. In the next section we describe our methods, before presenting our findings.

3 Methodology

3.1 Setting

The South African electricity sector remains dominated by the state-owned monopoly of Eskom. Its customer segments are predominantly municipal (about 42% of its load), industrial, commercial (e.g. mining, agriculture), as well as residential. The increased demand for electricity in the country has resulted in extensive 'load shedding' practices (i.e. scheduled electricity cuts) and increased electricity costs. These problems have led to customer non-payment and electricity theft, especially in low income regions. Developing a smart grid aims at addressing these problems by adding a layer of intelligence onto the existing electricity grid. This allows for the monitoring of supply and demand through sensors, making adjustments through appropriate switches, and better educating customers.

3.2 Data collection and analysis

In this research we sought to understand the strategy of designing a smart grid for South Africa, as well as the value that can be created from such a strategy. We should note here that, although there is both a national strategy, as well as independent municipal initiatives to develop smart grids, so far only a few pilots have been successful. Drawing on primary and secondary empirical data we develop propositions that could help South African stakeholders successfully implement a national smart grid. The NRS049 - Advanced Metering Infrastructure (AMI) standard has been drafted to create a specification for a national smart grid in South Africa, as shown in Figure 1.

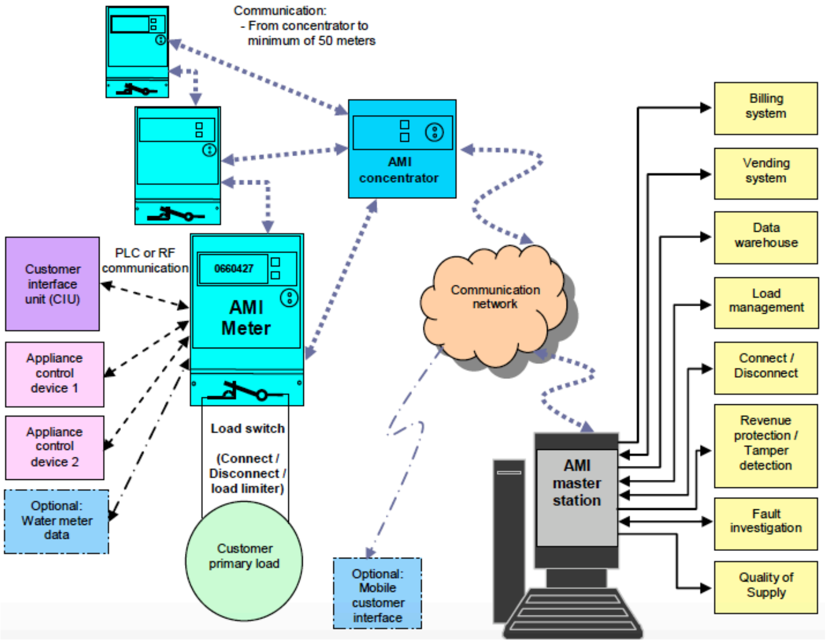

Figure 1. Advanced Metering Infrastructure (AMI) for South Africa's National Smart Grid

Source: Eskom (2014)

We collected primary data through interviews with 21 respondents. This sample includes views from (i) innovators in the electricity sector (e.g. Siemens and Schneider Electric); (ii) companies involved in broad-based digitisation efforts for which the electricity sector presents a special interest (e.g. IBM, SAP); and (iii) connectivity providers (e.g. FastNet, MTN). Table 2 lists all the participants with their positions and the companies they represented at the time of data collection. Interviews followed a semi-structured format, where the questions were adjusted depending on the company profile. In addition to the data collected via interviews, the analysis considered the contents of secondary documents including case studies, presentations, white paper reports, product catalogues, and user manuals provided by our interviewees and their companies. These documents were able to provide context to the interviews and prepared us to extract better insights (Denzin and Lincoln, 2005).

	Company	**Respondent No**	**Interviewees roles/positions**

Electricity sector	Siemens	Respondent 1	CEO Siemens Smart Grids Africa
	Eskom	Respondent 2	Strategy manager
	Eskom	Respondent 3	Corporate Tech Specialist, Smart Grids and Energy Efficiency
	Eskom	Respondent 4	Smart Grid CoE Manager
	Accenture	Respondent 5	Senior Principal - Accenture Smart Grid Services
	Schneider Electric	Respondent 6	Sales Director Field Services
	CSIR	Respondent 7	Research Group Leader
	NRG Renew Africa	Respondent 8	Chairman
Digitisation -- Software	SAP	Respondent 9	Director Mining & Metals Industries
	SAP	Respondent 10	Industry Principal
	IBM	Respondent 11	Program Director, Software Offering Management
	Dimension Data	Respondent 12	Chief Solutions and Marketing Officer – Networking
	HP	Respondent 13	HP Software Country BU Manager
	HP	Respondent 14	Director of Strategic Marketing
	Microsoft	Respondent 15	Partner Channel Development Manager - Cloud
Digitisation- Connectivity	FastNet	Respondent 16	Head: Product Portfolio Management
	Sentech	Respondent 17	Head: Innovation & Solutions
	MTN	Respondent 18	Senior Manager: Service Delivery - ICT Services
	Ericsson	Respondent 19	Head: Government and Industry Relations
	Cisco	Respondent 20	Client executive
	Cisco	Respondent 21	Solution Account Manager Service Sales

Table 2. List of interviewees

We analysed the data seeking to understand how the elements summarized in Table 1 applied in the case, and to what outcomes. We examined the relationship between all the elements in Table 1 to develop a set of propositions. These propositions were expressed as case-specific relationships between the elements identified in the literature, exploring how their combination can produce particular outcomes (Eisenhardt and Graebner 2007).

4 The case of smart grid in South Africa

4.1 The Core interaction

The core interaction between electricity producers and consumers occurring on the South African electricity grid consists of balancing energy generation (i.e. supply) and load (i.e. demand). Implementing a smart grid could facilitate the core interaction by enabling utility companies to balance electricity generation and load by adjusting time-of-use pricing. Meanwhile, customers could be offered improved spent management capabilities through real-time pricing transparency, and opportunities to contribute through distributed green energy generation capacity. Thus, the key incentive for utility companies (as producers) would be to meet electricity demand by using the energy produced most efficiently, and at costs below price. The key incentive for customers (as consumers of electricity) would be to minimize their electricity use at times when the price exceeds their willingness-to-pay. We consider the smart grid as a platform; better data on the supply, demand and cost of electricity as the 'value unit'; and 'filtering' as achieved through the analysis of data on supply, demand and cost.

4.2 Pulling participants in the core interaction

In our research we sought to understand how the core interaction for digital infrastructures such as smart grids could be initially designed for direct usefulness while building on an existing installed base (design principles 1 and 2) and whether these design principles could increase the value generated for consumers and producers. We develop three propositions to understand this relationship (1a, 1b and 1c).

First, initially designing for direct usefulness could be achieved through improved instrumentation of the electricity grid in South Africa. Such instrumentation would be directly useful to producers since it would enable a number of data-driven processes in the sector. Combining measurements and observability into the grid, with external information on weather and other adverse events would bring immediate value to producers in terms of improved awareness of its load and its generation structures.

"We've got tools in place that assist the network operator with looking at your grid holistically, so it's a macro view of your grid called grid situational awareness. It tells you exactly what's happening to your grid with a lot of static and dynamic sources that are now being considered." [Respondent 3, Eskom]

Drawing on the above, we put forward the following proposition:

1a. Designing for direct usefulness (i.e. monitoring, predictive maintenance, balancing supply and demand), can generate direct network effects (i.e. situational awareness) for producers.

Second, smart meter designs providing customers with usable and transparent interfaces, could encourage energy efficient habits among consumers. The earliest residential time-of-use pilot in South Africa, was carried out by Eskom in Table View, Cape Town, in 2001. In a subsequent pilot, Eskom improved the interface of smart meters by adding LED lights. Red, yellow and green lights allowed customers to monitor continuously their energy consumption and its level of affordability. According to the South African Smart Grid Initiative (SASGI), supported by the South African National Energy Development Institute (SANEDI), these pilots were followed by the implementation of approximately 65,000 smart meters in Soweto, Sandon & Randfontein (Johanneburg), in Margate (KwaZulu-Natal), Ethekwini (Durban), Msunduzi and Nelson Mandela Bay Municipality, Nala, Naledi, Govan Mbeki, Thabazimbi and Mogale City (SAMSET 2015). The smart meters led to considerable changes in behaviour. As an Eskom executive put it, introducing "a price signal […] that the market can respond to" [Respondent 2, Eskom], improved the usability of the system and the transparency of the incurred payment charges. Thus, it improved consumers' awareness, thereby leading to changes in behaviour.

"Now the ones that we have worked on the pilot, the thirty thousand we've taken through the whole theme, they are very positive and in fact they're already saying 'well you know Nick's my neighbour, how come he's using half of what I use. I need to look at what I'm doing.' So we've had sort of a peer comparison which has worked extremely well." [Respondent 3, Eskom]

In other words, exactly because all smart meters are connected to the smart meter platform, there are recommendations on energy prices at different times of the day. As discussed in our first proposition above, this could be valuable for the producers in terms of predicting demand, but it could also be valuable for consumers because they could budget and manage their energy consumption better. Drawing on the examples presented above, we put forward the following proposition:

1b. Designing for direct usefulness (i.e. clear price signal) can generate direct network effects (i.e. energy consumption awareness) for consumers.

Smart grid implementations superimpose an additional layer of intelligence to the existing electricity grid. Thereby, they require connectivity to the existing infrastructure for aggregating and processing the data collected at the level of individual customers. Despite this, smart grid implementations have struggled with connectivity in the aggregation of data from end points (e.g. consumers' meters) to central data management and control centres. While alternatives abound, ranging from powerline carriers, to radio frequency and mobile network implementations, experience points to preference for IoT implementations. Designs leveraging the existing grid such as, relying on connectivity via powerline carriers, have proved ineffective in delivering smart grid benefits.

However, IoT systems tend to comprise of edge-metering devices, which capture and transmit data using proprietary standards, which sooner or later hit an IP address. While previously GSMA standards and IT standards (e.g. SSL) were very far apart, over recent years standards have increasingly converged towards IP. Consequently, we see many GSMA operators also contesting the IoT connectivity space. As there is still a lot of bespoke proprietary equipment that does not adhere to IP-based standards, connectivity presents a particular challenge to the technical work of systems integrators.

"My Samsung fridge at home has got internet connectivity. The chips and the monitoring it does, are proprietary to Samsung. [So is] the network they are using to bring back the data to the screen my fridge has got a on it. The Internet connectivity component, which breaks it outside of the fridge, is IP. The sensor connectivity that it is telling me what the cooling is, that my milk is gone […] that is proprietary. The network back into the sensors over there I have no idea what it is. ... if you go outside of the purest ICT environments, that is where you find your standards don't align. It is a big challenge." [Respondent 13, Dimension Data]

In addition to the technical challenge of standardization, building upon the existing grid also requires developing a robust business case to address the needs of both producers and consumers. Convincing business cases hinge on identifying measurable value to be derived from the implementation of IoT. The key factors which impact the development of business cases for investment in smart grids are largely centred round producers' current cashflow problems, stifled by direct and indirect non-technical losses. These problems reduce their capacity to invest in devices of sufficient quality for the instrumentation of the electricity grid, leading to subsequent increased costs for maintenance, replacement and running of the devices.

"The utilities are cashed strapped as I explained, so they are forced now to go for a lower spec devices because that's all they can afford. And these lower spec stuff will just last less, that's the reality of things." [Respondent 6, Schneider Electric]

Summing up, we find competing strategies of reliance on installed powerline connectivity and reliance on innovative IP-based designs. Whereas powerline designs leverage installed connectivity, IoT designs are in better position to deliver the perceived benefits of a smart grid. Nonetheless, they are rife with incompatibilities in terms of standards and integration difficulties. In addition, developing robust business cases to invest in IoT designs is very challenging for producers, while also affecting consumer adoption and use. Drawing on this case material, we make the following proposition:

1c. Building upon the existing installed base requires extensive standardization (technical interoperability) and business case development (pricing), without which adoption and participation cannot be achieved.

4.3 Facilitating further interactions

A second objective of our research was to understand how digital infrastructures could be designed to facilitate further interactions between participants by expanding the installed base and using persuasive tactics to gain momentum (design principles 3 and 4), and whether these design principles could lead to further value creation. We develop three propositions to understand this relationship (2a, 2b and 2c).

As smart meters are able to provide readings on consumption of other utilities besides electricity (e.g. gas), the provision of value-added services is increasingly becoming feasible. Such business cases often pivot on the provision of ancillary services (e.g. VOIP, Internet, IPTV, water and gas). For example, Eskom's strategy manager (Respondent 2) pointed out that in the smart meter project, conducted in 2012, meters were deployed costing approximately R6500 each. With typical bills of less than R1000 per month, for Eskom the rate of return from the capital investment was negative. There was not really a business case for the smart meters as such. Yet, there was a business case when ancillary services were added to the model. Since then, the technology has matured and the devices have reduced in price, costing approximately R2200, thereby strengthening the business rationale for the deployment. Thus, enabling ancillary services on the smart grid could offer opportunities for producers -- other than electricity producers (e.g. internet, water and gas) -- to also generate value for the smart grid itself, and subsequently for producers of electricity. Drawing on the above we put forward the following proposition:

2a. Adding value-added (ancillary) services on the digital infrastructure can generate direct network effects on the supply side (producers to producers).

In addition, by adding new value-added (ancillary services) on the smart grid can have indirect or cross-side network effects, by enabling new interactions between different stakeholders with value added services. One example of how the expanded smart grid can generate indirect network effects are mechanisms for addressing the cross-cutting problems of urban living, encountered by government, utility companies and health services. For example, through a partnership led by the research institute CSIR working alongside Eskom and city municipalities they were able to demonstrate the value of their smart city platform. Considering the underlying complexity of switching and grid management practices, they were able to show added value from smart switching which goes beyond improved grid management.

"So what we are positioning for and what we are doing is, we are allowing for smarter decisions. That is ultimately ... the main value proposition of IoT, [a] smarter decision…: 'Control this, don't control this', or 'Send this alert because this is happening'."[Respondent 7, CSIR]

The senior manager for service delivery from MTN, a telecoms company, also added on the possible added-value services that can be offered by an expanded smart grid:

"Yes, we can charge a utility company for monitoring geysers. That is something we do. It is a defined revenue stream. But what if we could use the data that is coming off [...] and sell it to another partner. [...] Now who would be interested whether the geyser is leaking or not? Insurance companies… So what if we were monitoring a whole lot of geysers across South Africa and accessed the data and we could inform the insurance company before the geyser [bursts]?" [Respondent 19, MTN]

Thus, by enabling new producers to join the smart grid (e.g. insurance companies), new synergistic interactions between producers and consumers can develop. Drawing on the above we put forward the following proposition:

2b. Adding value-added (ancillary) services on the digital infrastructure can generate indirect network effects between the supply and demand side (producers to consumers and vice versa).

While over the years, smart meter designs have improved their usability and their capacity to deliver meaningful information to customers (e.g. light indicators, LED panels), designs are not necessarily geared towards delivering value to both consumers and utility companies. For example, because of the increased infrastructure investments required by utility companies, they are forced to cut down their costs by investing in less smart devices. Such devices have limited technical features compared to smart devices. One example of such a device is 'split meters', which physically separate the meter from its display. The design allows utility companies to counteract non-technical loses such as tampering with the meter and to manage utility pre-payment. Nonetheless, the design does not allow for additional value (e.g. smart home services) to be captured by consumers who are not able to access the meter itself, even though they receive energy consumption information via a display. Some customers have complained that this design is an oppressive technology, used for "controlling our energy" [Respondent 3]. Thus, consumers are dis-incentivized to install these split-unit meters, which can lead to negative network effects and decreased participation.

2c. Barriers to the use of added value-added (ancillary) services on the smart grid, can generate negative network effects and decreased participation

4.4 Matching participants to markets

A third objective of our research was to understand how a digital infrastructure could be designed to enable better matching of participants to relevant markets by making IT capabilities as simple as possible (design principle 3), and whether this design principle could lead to value creation between consumers and producers. We develop two propositions to understand this relationship (3a and 3b).

The key matching properties of a smart grid are improved measurements and increased degree of observability into the grid. By improving these matching properties, smart grid deployments are capable of enabling, hitherto unachievable, fine-tuned grid management practices. For example, utilities are able to engage in load forecasting, load balancing, peak-shaving, outage management, voltage optimisation, optimising network and energy trading, etc.

"You can now become very clever and you can have arrangements with certain [large] customers that they don't use electricity between certain times [...] and you can switch them off. It is called surgical data curtailment. And with strategies like that you can manage supply and demand." [Respondent 1, Siemens]

As electricity customers are increasingly becoming generators of power, for utility companies such as Eskom, smart meters could offer an interface not only for selling but also for buying power supply. This is especially true for customers who produce alternative energy such as, solar panels connected to the electricity grid, enabling them to 'sell' energy supply to utility companies, by offsetting their energy bills. As an extension to this, the introduction of smart meters to more regions in Africa could generate momentum for value creation across a wider range of customers and utility companies. Schneider Electric, 60% owners of the Durban-based pre-paid and smart meter manufacturer Conlog, exports its meters to more than 20 countries. Their smart meters have proved to be adaptable to several standards including, SABS and ISO standards generating more opportunities for value creation.

Alternative energy production and improved standardization could enable the creation of independent power producers (IPPs) such as, multinationals (e.g. France's EDF) and commercial customers (e.g. mine corporations) to not only generate their own energy, but to also sell it back to Eskom (McDonald 2012a). Subsequently, Eskom could sell it back to other customers. Drawing on the above we put forward the following proposition:

3a. Digital infrastructures allowing producers and customers to trade with one another, can generate direct and indirect network effects for both the supply and the demand side.

Despite such positive direct and indirect network effects, the vast potential for renewable energy generation, alongside with relaxed regulation and improved affordability of renewable technologies, has led to the evolution of micro-grid models. These allow customers to go 'off grid' i.e. to use the main electricity grid only as a backup source, adding uneven demand to the challenges of grid management. The CEO of Siemens told us:

"In the old days it was a question of pushing energy on one side of the grid, and just pulling it out on the other side, making sure that there is enough. Now energy is flowing in all directions and you have to be able to manage that. You have to switch it on and off, and that's not a trivial activity. But you also have to modulate it." [Respondent 1, Siemens]

Renewable energy is very difficult to predict and requires accurate weather forecasts. It also has steep rates of change and when extra energy is generated, furthermore it is very expensive to store. Experts estimate roughly that each Megawatt of renewable energy that is added to the grid needs to be offset by another Megawatt of controllable load in order to compensate for its variability. All of these factors raise the complexity of grid management. Based on this evidence we put forward the following proposition:

3b. The complexity of managing a range of services on digital infrastructures can generate direct and indirect negative network effects between the supply and demand side and decrease participation.

4.5 Modularity

A fourth and final objective of our research was to understand how a digital infrastructure could be designed based on a modular architecture with governance structures that can enable independent interactions between core IT components and participants (design principle 5), and whether this design principle could lead to value creation. We develop one proposition to understand this relationship.

Eskom centrally controls the generation and transmission of electricity throughout South Africa, with some exceptions for IPPs. Much of the distribution, however, falls in the responsibility of South African municipalities, which buy bulk electricity from Eskom for resale. This was a state policy to rationalize pricing structures in order to give some autonomy to municipalities to generate income from electricity, but also to distribute governance away from Eskom (McDonald 2012a). The role of municipalities as providers of electricity meant that many of them proceeded to the deployment of their own smart meter programs with the help of third party device manufacturers and software developers. In this way, modularity was achieved by policy design.

Modularity in the design of digital infrastructures is very important for better managing vulnerabilities and enabling a continuous flow of services to the end consumer. With the help of IoT, faults could be identified and measured very precisely. Furthermore the costs of remedying faults could fall considerably as technicians would be able to detect the exact position of the fault. Governance structures around who is responsible for identifying and managing a fault could be decentralized according to the individual modules or assets. Governance, thus, could become embedded in the digital devices, and the smart grid would be able to self-govern itself, informing technicians where there is a fault.

“By having the data concentrator on the mini-sub and it’s PLC [power line carrier], it [is] self-discovered. It will look for everything that’s on its lines and connects to it. So automatically you know where each meter is installed. The reason for that is if there’s fault finding required, you know exactly where the fault lies and where it’s installed.”[Respondent 6, Schneider Electric].

“[…]The more intelligence you bring in, the more closely you can detect that [you have] a fault, the technician can drive to the exact position of the fault, and you can also remediate very very quickly because you can cut that piece of line that has caused the short circuit. You can cut it out of the grid and you can run the power via other lines.” [Respondent 1, Siemens]

Based on the above we put forward the following proposition:

4. By designing digital infrastructures on a modular architecture with decentralized governance structures, interactions between core digital components and participants could be stabilized.

5 Discussion & Conclusion

This paper established connections between research on platforms and the design of digital infrastructures. In developing design and value propositions, the paper contributes to a theoretical distinction between digital infrastructures and earlier pipeline infrastructures, by placing emphasis on the network value generated through demand-side economies of scale by both producers and consumers. This is in contrast to earlier research on pipeline infrastructures which focused on internal control of resources and supply-side economies of scale. Extant research has only examined the value of IT infrastructure investments (e.g. Kumar 2004), but there has been limited (if any) research examining the direct and indirect network effects between producers and consumers and the value generated from their interactions. Only research on value co-creation has examined the value generated through the synergistic interactions between different stakeholders through new IT capabilities (e.g. Han et al 2012; Rai et al 2012). However, even in this research, the emphasis is on producers with little (if any) consideration of the role of consumers. Furthermore, the negative effects of value co-creation have not yet been explicitly explored in the IT value co-creation literature. Finally, we contribute to research that examines the complementarities between architectural modularity and governance decentralization (Tiwana & Konsynski 2010). Our findings support such complementarities and extend the argument beyond the boundaries of a single organization. The combination of ubiquitous connectivity and modularity inherent in a digital infrastructure, enables governance decentralization to be achieved through the distributed digital devices themselves. This can lead to value extension across multiple stakeholders.

The paper also has a number of practical implications for the design and implementation of smart grids. Although South Africa is far from implementing a national smart grid that could capitalize on the value generated from demand-side economies of scale, the few pilots that have been implemented show signs of potential success (SAMSET 2015). The biggest challenges for a national smart grid are institutional stemming from increased demand growth due to urban population growth, increased electricity cost, and subsequently non-payment and electricity theft (McDonald 2012b). These challenges need to be addressed with policy and pricing reforms, which are beyond the scope of this paper. In addition to this, any plans for a national smart grid need to also address the technical challenges of poor interoperability and standardization and the business challenges of providing the appropriate incentives for different stakeholders to participate on the smart grid.

The opportunities and challenges of designing smart grids with an emphasis on demand-side economies of scale are not unique to South Africa. A recent study by Accenture (2014) analyzed the smart grid deployment strategies of 15 countries across Europe, Asia, North and South America, finding that all of them faced the same challenges, albeit at different degrees. In this and other studies (Giordano and Fulli, 2012; Groh et al 2015) great emphasis is placed on the role of consumers in transforming existing models. As Groh et al (2015) argue, “end-users could act as ’prosumers’,” forming the core nodes of the smart grid. Giordano and Fulli (2012) also propose that smart grids could be viewed as multi-sided platforms – a paradigm shift that could reverse the supplier-led paradigm of the electricity sector. Further research could draw on the insights of these studies and our own conceptualization of smart grids as platforms to develop a better understanding of the value creation opportunities offered by these new digital infrastructures.

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