

II Designing IT Solutions for Individual Households

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Abstract

In recent years, research on the role of information systems (IS) in creating sustainable power systems has become a cornerstone of the IS discipline. In this paper we consider a particular aspect of this role—information systems as the facilitator of synergies between green technologies in the Smart Grid. Following a design perspective we propose that information systems can enhance technical objects with new features, thereby increasing their potential value towards a sustainable energy paradigm. We substantiate this proposition using a case study on batteries of electric vehicles. The information system designed in this study enables the battery to serve as an energy storage device in conjunction with a residential photovoltaic system while the vehicle is parked at home. This IS-enabled additional feature provides several financial and environmental benefits to the owner and society at large. Additionally, based on this case study, we outline possible

interferences and obstacles in designing information systems for the Smart Grid and provide recommendations to guide future research.

1 Introduction

The pursuit of environmentally sustainable practices in society and economy has become one of the central objectives for many governments, companies, and citizens around the globe. Its incarnation takes various shapes—from organic farming in California to the phase-out of nuclear power plants in Germany and solar-powered rural electrification in Bangladesh. Through *Green Information Systems* and *Energy Informatics*, it has also developed into a major stream of Information Systems (IS) research. The scale and scope of publications range from theoretical groundwork (Elliot, 2011; Melville, 2010; Watson et al., 2010) through transitions towards sustainable information systems (Hilpert et al., 2013; Seidel et al., 2014) to design and behavior (Corbett, 2013; Looock et al., 2013). However, since “green” technologies are still facing tremendous obstacles with respect to costs and system integration, further research is clearly needed in order to overcome these barriers.

In this paper we investigate the impact of information systems at the intersection with physical power systems from a theoretical as well as an applied design perspective. This intersection is commonly referred to as the *Smart Grid* (Farhangi, 2010) and issues surrounding smart grids have been a cornerstone of recent Energy Informatics research (Goebel et al., 2014). We start out by developing the guiding hypothesis of our research—*information systems give access to new features of technical objects within the power system*. For this purpose, we introduce a theoretical model that relates design features of the information system to features of the power system. We coin them *Enhancing Features* since they enhance a technical object by providing a new use that was previously inaccessible. We proceed by presenting a case study on electric vehicles and residential renewable energy

sources to substantiate the theoretical model. Based on this case study, the theoretical model, and on our experience in designing the information system, we outline possible obstacles and opportunities when designing information systems for the Smart Grid. We condense these insights into a set of guidelines to advise future IS design research with a smart grid background.

The remainder of this paper is structured as follows. In Section 2, we discuss research related to our work. We introduce our research model and develop the guiding hypothesis in Section 3. Section 4 contains the case study. We discuss implications from the case study relating to the achievement of anticipated outcomes through IS design in Section 5. Section 6 concludes with a summary of our analysis and the derived guidelines.

2 Related Work

In this section we provide an overview of publications related to our research. We divide this review into work related to the research domain (Energy Informatics) and to the research approach (Design Science). Since there exists a vast body of literature for each area, we focus on work closely relevant to our research. We conclude this section by identifying the research gap subsequently addressed in this paper.

2.1 Research Domain: Energy Informatics

Watson et al. (2010) define Energy Informatics (EI) as an interdisciplinary subfield of IS research “concerned with analyzing, designing, and implementing systems to increase the efficiency of energy demand and supply systems” (p. 24). The need for research on a cleaner, more sustainable energy paradigm has been made evident by the threat of man-made climate change (Anderegg et al., 2010; Cook et al., 2013),

an uncertain stock and accessibility of fossil fuels (Heinberg & Fridley, 2010; Howarth et al., 2011; Owen et al., 2010), as well as a dependence of the energy markets on politically unstable regions of the world (Doukas et al., 2011; Hamilton, 1983). The potential contributions of IS research in reshaping energy systems have since been further outlined by, for instance, vom Brocke et al. (2013) and Goebel et al. (2014). The latter in particular point out that applied EI research has focused on energy-saving solutions and the Smart Grid. Recent publications cover a wide range of topics in this context. For instance, Loock et al. (2013) investigate behavioral aspects of the design of energy management systems. Feuerriegel et al. (2012) and Feuerriegel & Neumann (2014) analyze the costs and benefits of integrating demand response mechanisms into electricity markets. Gottwalt et al. (2011) study the demand reaction of households under flexible energy prices. The adoption of smart meters, which are generally considered an essential building block of a smart grid, is discussed in Jagstaidt et al. (2011) and Wunderlich et al. (2012). Strüker & Kerschbaum (2012) consider privacy issues associated with an increasing prevalence of smart meters. Furthermore, several research groups have proposed ways to integrate electric vehicles into a smart grid (e.g. Brandt et al., 2012; Flath et al., 2013; Kahlen et al., 2014).

Nevertheless, sustainable energy technologies still face tremendous obstacles. The adoption of electric mobility is substantially hampered by the price difference between electric and conventional vehicles (Carley et al., 2013). Similarly, the rise of renewable energy sources could only be realized with immense subsidy schemes, whose long-term consequences are difficult to predict (Kalkuhl et al., 2013). Hence, further research on building an ecologically and economically sustainable energy supply is clearly needed.

2.2 Research Approach: Design Science

Questions relating to the design, creation, and development of information systems have been central to the IS discipline since its inception (Goes, 2014). However, following Hevner et al.'s (2004) landmark article in *MIS Quarterly*, Design Science has truly established itself as a major research paradigm within the community (Land et al., 2009). Since then, the theoretical foundation of Design Science research has been further strengthened by a variety of articles, such as Hevner (2007), Gregor & Jones (2007), as well as Kuechler & Vaishnavi (2012). Nevertheless, Design Science research is still lacking presence in top-tier IS journals (Goes, 2014; Gregor & Hevner, 2013) and conferences (Bichler, 2014). This coincides with a resurgent discussion within the community concerning the general value of IS research (Hassan, 2014; Niederman, 2014).

There is a widespread sentiment that tackling questions of environmental sustainability provides a solution to both issues. On the one hand, contributing to a more sustainable way of life is perhaps the most valuable outcome any field of research can give to society (Watson et al., 2010). On the other, the relevance of Design Science in tackling environmental issues has been emphasized by, for instance, Pernici et al. (2012), Malhotra et al. (2013), and vom Brocke & Seidel (2012). In fact, many of the papers cited in the previous subsection employ a design-orientation in their approach. Hence, in this paper we seek to contribute to the Design Science knowledge base as it intersects with Energy Informatics issues. In the following subsection, we identify the specific gap in the current state of research that we address in our work.

2.3 Research Gap: IS Design in Smart Grids

The contribution of this paper is twofold. First, we closely investigate the link between IS design and the Smart Grid. Recall that a wide

range of studies design artifacts for the Smart Grid with the overarching objective of improving environmental sustainability. Furthermore, it has been emphasized that Design Science is in an exceptional position to tackle sustainability challenges. Yet, little research has been done on the specific mechanisms that make IS design successful in tackling environmental issues. To address this lack of understanding, we develop a theoretical model that traces the causal chain between IS design and the realization of sustainability objectives for a broad range of applications in the Smart Grid.

The second contribution of our work lies in the case study used to underpin the theoretical reasoning. Besides its demonstrative purpose, the artifact designed in the study also serves as a practicable solution to a very real sustainability challenge. As we have outlined, the lingering adoption of green technologies stems from their high investment costs. Particularly electric vehicles, as a way to decrease the environmental footprint of the transportation sector, suffer from a substantial price difference to conventional cars. While measures to offer additional financial incentives by using electric vehicles as energy storage for the power grid have been developed, they require fleets of thousands of vehicles to function. Consequentially, they provide no solution to the immediate problem of high costs restraining customers from acquiring electric vehicles. In our case study, we present an artifact that exploits synergies between an electric vehicle and a residential photovoltaic panel. It implements smart charging strategies that increase the amount of solar energy the household itself can use. Thereby, it reduces annual energy expenses and increases the appeal of these green technologies. Furthermore, it does not require a high adoption rate of electric mobility to work—even a single household can reap its full financial benefit.

In summary, this paper outlines a specific application of IS research in the Smart Grid with the objective of improving environmental sustainability. On a broader scale, we hope that the theoretical reasoning we present results in a better understanding of how to conduct IS design research in a smart grid context to achieve specific

outcomes. As we introduce the theoretical model in the next section, we will elaborate on this link between design objectives and design outcome.

3 Research Model

IS Design for Environmental Sustainability—in recent years, this catchphrase and its derivatives have been reliable guests at various IS conferences. Undoubtedly, this is a promising development, having in mind the importance of leveraging IS research to address environmental issues. We use this catchphrase as the starting point for the development of our model, since it is very unambiguous about the outcome that is to be achieved. The goal environmental sustainability implies that the impact of the conducted research should provide a tangible contribution towards a more environmentally friendly society. Such outcomes include, for instance, supporting companies in the implementation of sustainable business practices (Seidel et al., 2013), informing policymakers to improve environmental decision-making (Eickenjäger & Breitner, 2013), and using information technology to improve power supply, distribution, and consumption (Appelrath, 2012).

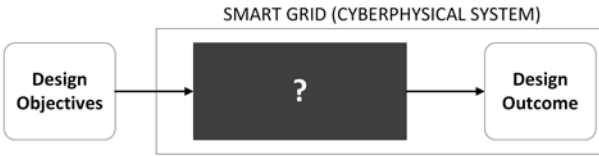


Figure II–1: Starting point: IS design for the Smart Grid

In this paper, we focus on the latter aspect—IS Design for the Smart Grid. The theoretical issue we seek to address here is that any IS design is necessarily associated with a certain anticipated outcome (cf. Figure II–1). It is the work of the researcher to translate this goal into a set of design objectives. However, the actual mechanisms in the

design product that link objectives and outcome vary according to application domain. We investigate these mechanisms for IS design in a smart grid context. Considering the work of Eickenjäger & Breitner (2013) as an example, the anticipated outcome may be to empower policymakers to make informed decision concerning fossil fuels and their alternatives. The authors translate this into design objectives of, first, modeling the future development of fuel markets and, second, visualizing the results of various scenario analyses to the intended recipients. There is already a body of work on design principles that guide this type of research, most famously the guidelines by Hevner et al. (2004). However, designing for the Smart Grid poses additional challenges. Smart grids are complex cyberphysical systems—hybrids of information technology and a mix of modern as well as decades-old (legacy) power infrastructure. Successful design for the Smart Grid, thus, requires a profound understanding of the interactions between the various components in this cyberphysical system and their relationship with the people who are eventually dependent on a reliable energy supply.

Hence, our objective is to investigate the black box outlined in Figure II–1. We contemplate that one mechanism through which IS design contributes to the Smart Grid is by enhancing components of the power system with new features that were previously inaccessible. We will elaborate on this concept in the remainder of this section while we further develop the theoretical model.

3.1 Definitions

As part of our study, we discuss outcomes that are generated by information systems. Naturally, this has been extensively researched within the IS community (e.g. Markus & Silver, 2008; Robey et al., 2013; Volkoff & Strong, 2013). Since labels are not always unambiguous in the literature and we are adapting some of them slightly to

fit the specifics of our context, we provide short definitions of the constructs used in our model.

Technical Object. According to Markus & Silver (2008), technical objects include IT artifacts, their components, and their output. In a Smart Grid context, this definition is somewhat problematic, since the cyberphysical system contains components of the power system that are certainly technical objects, relevant, but not necessarily IT-related. Since these two types of technical objects are distinctly different, we label them differently. During the remainder of this paper, “technical objects” exclusively refers to components of the energy infrastructure, such as power lines, generators, or batteries.

IT Artifact. This construct covers the IT-related technical objects from Markus & Silver’s (2008) definition. It is the core product of the design process and can take various forms, ranging from “software, formal logic, and rigorous mathematics to informal natural language descriptions” (Hevner et al., 2004, p. 77).

Feature. Essentially, a feature is what a technical object or IT artifact does, as opposed to what it is used for. Zammuto et al. (2007) provide the example of real-time tracking sensors that indicate when a product has passed a specific stage in the process. Similarly, a feature of a battery would be that it stores energy.

Affordance. Contrary to features, affordances identify “what the user may be able to do with the object, given the user’s capabilities and goals” (Markus & Silver, 2008, p. 622). This reflects the argument by Zammuto et al. (2007) that affordances arise from a combination of technological and organizational features. However, Robey et al. (2013) note that they are not limited to those the artifact’s designer intended, but are shaped by human agents that use the system “with their own purposes in mind” (p. 387).

Hence, we assume that the designer conceives the IT artifact with certain features. Which affordances arise from this design and whether they achieve the intended outcome depends upon the interaction with

the technical objects from the power system and the features of the socio-organizational environment.

3.2 Modeling IS Design in the Smart Grid

The Smart Grid concept comprises the reinforcement of the conventional power infrastructure with information and communication technology, as well as novel products and services arising from this hybridization. The crucial notion is that smart grids are not built from scratch, but are developed on top of an existing infrastructure. Consider, for instance, smart meters and the service environment emerging around them (Jagstaidt et al., 2011; Looock et al., 2013). They allow customers and utilities to observe the energy consumption of a particular building or device in real time. While they do grant “smartness” to the Smart Grid, they are only a tiny part of the overall cyberphysical system—the multitudes of generators, transformers, power lines, and wirings remain essentially unchanged. However, they constitute a complex system that adheres to strict laws of physics and whose stability is vital to all stakeholders.

When designing information systems for the Smart Grid, this complexity and the hybrid nature of the cyberphysical system must be kept in mind. Furthermore, the example of smart meters shows that such information systems often enhance existing infrastructure in some way. As we will show in detail in our case study, components in the power grid remain unchanged as such, but acquire new potential uses. This brings us back to Figure II–1 and the black box that contains the links between the initial design objectives and the intended outcome. As “potential uses” follow the definition of affordances by Markus & Silver (2008), we already are in the process of uncovering these links. The designer of the information system may conceive it with certain affordances in mind that would result in the intended outcome. However, these affordances arise from features of technical objects in the power system, which they acquired as a result of a certain

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Brandt, T.

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