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SPECIAL THEME

What are the main barriers to smart energy information systems diffusion?

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Abstract The aim of this study is to identify the main barriers to smart energy information systems (SEIS) diffusion. We used the grounded theory method (GTM), with its repetitive cycles, to develop a theoretical model that illustrates these barriers. As a starting point, we discussed the discrepancy between the potential and the actual status of smart energy information systems diffusion. Having conducted a literature review and 23 interviews, we discovered that the main barriers to SEIS diffusion are adoption costs, switching costs, a collective action dilemma, and a lack of business cases for all stakeholders. Our study contributes to the literature on IS-enabled smart energy solutions in the industrial sector by deriving propositions for SEIS diffusion and by developing a theoretical model of the main barriers to SEIS diffusion that explains the discrepancy between the advantages and the actual diffusion of such systems.

Keywords Barriers to smart energy information systems · Adoption costs · Switching costs · Collective action dilemma · Grounded theory method

JEL classification Q40 · Q41 · Q47 · Q48

Introduction

Smart energy information systems (SEIS), which are based on information and communication technology (ICT), allow stakeholders in the energy sector to share information across organizational boundaries. SEIS are bidirectional electricity and information networks that connect generators, consumers, as well as transmission and distribution operators. These systems have numerous theoretical advantages. Among others, they promote environmental sustainability, cost efficiency, and cost reductions for all users along the energy value chain. SEIS are sustainable power systems that supply high quality and secure energy (ERGEG 2010; Depuru et al. 2011). It is not surprising that most studies on SEIS focus on how information systems (IS) and ICT influence and are used to increase the efficiency and sustainability of energy production and consumption. However, there appears to be a discrepancy between the advantages, and the de facto diffusion of SEIS. The goal of this paper is to identify the apparent barriers to SEIS by answering the research question: What are the main barriers to smart energy information systems diffusion? To answer it, we derived a theoretical model of the main barriers to SEIS diffusion.

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Barriers to SEIS diffusion

Literature focusing on barriers to the diffusion of SEIS can be divided into two thematic categories: IS barriers in general and their impact on SEIS and SEIS barriers in particular.

The European energy markets have undergone substantial changes over the last decade. The liberalization and unbundling of former vertically integrated utilities have significantly changed the European energy landscape. The consequence of these developments is a multiplication of processes and operations. Therefore, the flow of information across companies and the communication between energy parties have become more difficult to handle (Wissner 2011).

From an IS perspective, typical obstacles are adoption costs (Zhu et al. 2006a; Tornatzky and Klein 1982), switching costs

(Klemperer 1987, 2005), and the collective action dilemma (Markus et al. 2006).

Adoption costs

According to Zhu et al. (2006a) adoption costs comprise four variables: financial costs, managerial complexity due to lack of interoperability, transactional risks, and legal barriers. Financial costs lead to several IS barriers, which may in turn influence the electronic data interchange (EDI) of IS (Iacovou et al. 1995) or demand systems (Gallant and Koenker 1984). Furthermore, financial costs include financial investments in the implementation or use of IS (Allcott and Greenstone 2012). According to Allcott and Greenstone (2012), misinformation prevents consumers and firms from making profitable private investments in energy efficiency. These investment inefficiencies create an energy efficiency gap — a wedge between the possible minimum cost of energy efficiency and the cost actually realized (Allcott and Greenstone 2012). Since the costs of new embedded services in SEIS are uncertain, they are also potential barriers to SEIS diffusion (Clastres 2011). Another cost aspect is the inelasticity of demand, which inhibits investments in demand systems (Torriti et al. 2010).

In IS literature, a lack of interoperability is considered one of the most prominent issues related to managerial complexity in an energy value chain (Wissner 2011). In general, interoperability can be further categorized into syntactic and semantic interoperability (Park and Ram 2004). Multiple interpretations of the same data set make an integration effort extremely difficult, since each source of information and potential receiver of this information operate in a different context, which may in turn lead to large-scale semantic heterogeneity (Madnick 1999; Park and Ram 2004). The majority of interoperability issues are rooted in the absence of universally accepted interfaces, messaging and control protocols, and standards, which are necessary to ensure a common communication vocabulary among system components (Farhangi 2010). March et al. (2000) consider semantic interoperability one of the most important research issues and technical challenges in heterogeneous and diverse environments. Meeus et al. (2010) look into managerial complexity, particularly the cost of information asymmetry between regulators and network operators. March et al. (2000) consider today's database system technologies challenged in virtually all areas of data management involving new applications that demand ways of dealing more explicitly with the meaning and use of the data being managed. These technologies do not handle expressive semantic representations and processing capabilities well (March et al. 2000).

The third adoption cost variable, transactional risk, occurs when transactions are conducted over several different IS platforms (Zhu et al. 2006a). The main concerns are the protection of data privacy and encryption (Wissner 2011). The requirements for owning and selling SEIS data are complex. SEIS contain petabytes of operational data, which are either in real-time and thus updated every second or microsecond, or are archival. The latter data can be static, for instance in the form of nodal diagrams within distribution management systems, or dynamic, for instance in the form of switching orders (IEEE 2011). As Fang et al. (2012) state, security and privacy issues are also transactional risks typically associated with SEIS.

Finally, there are legal barriers to IS diffusion. These barriers include incomplete and inconsistent regulatory and legal frameworks. In addition, stakeholders' level of participation in SEIS might depend on market design and regulatory intervention (Zarnikau 2010). In addition, power sector reforms might not remove barriers to SEIS diffusion (Wang et al. 2010).

Switching costs

Williamson (1985) looks into asset relationships, such as adoption costs, which create switching costs (Farrell and Shapiro 1988). Switching costs differ from adoption costs insofar as both IS users and nonusers pay adoption costs, but only IS users incur additional switching costs (Beggs and Klemperer 1992). IS switching costs include the transaction, learning, and/or monetary costs incurred when a user changes suppliers (Klemperer 2005). Switching costs are a barrier to SEIS diffusion (Caves and Porter 1977) because they make it harder for entering firms to attract established buyers (Farrell and Shapiro 1988).

Collective action dilemma

The barriers to IS diffusion can be viewed from several theoretical perspectives. The collective action theory seems to be an important aspect in this regard, as it focuses on the conditions under which organizations collaborate to achieve common goals. IS standardization involves two linked collective action dilemmas with different characteristics: the standard development and standard diffusion dilemmas. A solution to the first dilemma might complicate solving the second dilemma (Markus et al. 2006). To realize promising standards' maximum economic value, their industrial diffusion is a critical step beyond the mere development of a standard (Rogers 1995). According to Römer et al. (2012), the low diffusion of the smart meter is one of the main barriers to SEIS diffusion. Uslar et al. (2010) provide a detailed overview of smart grid roadmaps and indirectly identify the standards issues preventing SEIS adoption. The obstacles to standard development and standard diffusion are part of the collective action dilemma.

A thorough analysis of the literature on IS and SEIS barriers revealed that there is a need for developing a theoretical model that explains barriers to the diffusion of SEIS. This is one of the reasons why we decided to use a qualitative approach in our study. Using qualitative data has several additional advantages when building new theories and when prior theory is absent, underdeveloped, or flawed. It helps capture individuals' lived experiences and interpretations, provides insights into complex process issues, and clarifies abstract ideas (Graebner et al. 2012). Another advantage of using qualitative data is that it enables informants to express themselves in their own words. Besides the mentioned advantages of a qualitative approach in general, we determined that the GTM is the most appropriate method for our study. We aimed to build theories based on specific situations. Consequently, theories were based on evidence, not on theoretical frameworks. We chose Strauss's GTM to identify the barriers to SEIS diffusion (Strauss and Corbin 1998). This approach combines a high degree of openness in the data collection process with a structured and traceable approach to data analysis. Consequently, it is appropriate in situations like ours, in which little prior research has explored the causalities of a phenomenon (Glaser and Strauss 1967). Miles and Huberman (1994) back our research approach by demonstrating that researchers should use a qualitative research design when there is a clear need for an in-depth understanding of the potential of causal inferences.

Research method

Owing to its general epistemic orientation, the GTM is widely applicable in both the natural and social sciences. In this method, data is directly used to generate knowledge rather than verify hypotheses (Wasserman et al. 2009). While there are ongoing debates in the GTM community regarding the advantages of a pre-defined research question, we adopted the Straussian version as it facilitated our research approach, which involved deriving a research question from open issues in the literature (Strauss and Corbin 1998; McCann and Clark 2004; Niekerk and Roode 2009).

Principles and coding procedures of the GTM

Our four key principles of the GTM are the constant comparative, theoretical sorting, diagramming and integrating memos, theoretical sampling, and theoretical saturation (Glaser and Strauss 1967).

Constant comparative analysis

Data is broken down into incidents and then compared for similarities and differences during the constant comparative analysis phase (Glaser 1992). The principle could be described as the persistent iteration of the climax process of naming and comparing data incident with data incident, data incident with concept, and concept with concept (Glaser and Holton 2004; Locke 2001).

Theoretical sorting, diagramming, and integrating memos

Sorting, diagramming, and integrating memos is a continuous, inter-related process (Charmaz 2006). It facilitates linking and comparing different results and ideas throughout the research process.

Writing memos helped us explore our ideas in an unrestricted fashion. These memos were treated as partial, preliminary and provisional, and imminently correctable ideas (Charmaz 2006). We recorded where we were certain and where we were making conjectures. We discussed our knowledge of the energy market in general and SEIS in particular, open issues and research questions in the field of SEIS, as well as the data collection process.

Following the evolutionary approach of Strauss and Corbin (1998), the two criteria for the research process and the empirical grounding of the study formed the basis of both our theoretical and process memos. Theoretical memos display major changes to the extensions of our theory based on the analytical process. Process memos illustrate major changes in or extensions of our analytical process (see Appendix 1) (Gasson and Waters 2013).

We subsequently triangulated our findings with secondary data (Jick 1979; Eisenhardt 1989). The effectiveness of primary and secondary data triangulation depends on the counter-balancing strength of the different data origins (Jick 1979). We used press releases, newspaper articles, and other publications as secondary data. The Federal Ministry of Economics and Technology as well as the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety in Germany were major sources of secondary data for this study.

Theoretical sampling

Theoretical sampling differs from traditional qualitative methods, in that it uses generated data to create and define classifications. The main objective of theoretical sampling is not to characterize the target group or generalize results, but to affect the theoretical process (Charmaz 2006).

The theoretical sampling process is derived directly from the written memos. In accordance with the GTM, our theoretical sampling strategy started with the decision of when and where to sample. We started sampling by conducting interviews with experts in the energy sector from February 2013 to August 2013. An intensive interview permits an in-depth exploration of a particular topic with a person who has the necessary experience (Charmaz 2006). The majority (65 %) of the interviews were conducted via telephone, while both interviewer and interviewee were in their respective offices. The remaining 35 % were conducted at the interview partners' companies, mostly in conference rooms. We scheduled 60-min for each interview. The interviews lasted 30 min on average. In each instance, the interview was conducted in a relaxed atmosphere.

All interviews were personally conducted and recorded by one of the authors. A key informant working at a strategy and IT consulting company, who specializes in energy IS, helped us identify potential interviewees in a suitable position to comment on and confirm SEIS limitations. We interviewed chief executive officers, chief operating officers, senior managers, consultants, and sales people from 13 companies. The company range included strategy and IT consulting companies, big energy companies, municipal energy companies, technology companies, and telecommunication companies in two German industries (energy and telecommunications). A politician and journalist with extensive knowledge of SEIS were also included. All informants provided us with rich descriptions of their experiences (Wilson and Hutchinson 1991). A detailed list of the experts, their positions, and company profiles is included in the appendix (see Appendix 2).

The authors asked a specific set of questions. Each interview started with a few open questions about SEIS, before focusing on the barriers to SEIS diffusion. The combination of open-ended and non-judgmental questions promoted detailed answers. To give a first impression of the quantity and quality of the data, we list the nine main questions (see Appendix 3). These questions defined our approach and helped generate our theories on the main barriers to SEIS diffusion.

We asked interviewees to describe their understanding of SEIS and asked them about their views on different issues related to SEIS diffusion. Special attention was paid to the expected benefits of overcoming the barriers to SEIS diffusion, such as cost reductions, market expansion, and value chain coordination. We also inquired about the different stakeholders' dependencies and the risks they face along the entire energy value chain. All interviews were conducted in German and translated into English. All interviews were transcribed verbatim, resulting in an empirical database of 219 pages.

The essential theory development process needed two main iterations of analysis. The theoretical sampling strategy became increasingly complex and the boundaries between separate barriers started to blur. On top of that, we generated new insights into SEIS and their barriers. Appendix 4 reflects the continuous iterations of our data selection process, the progress of our key categories, and the development of our model. We first interviewed consultants from two strategic and IT consulting companies focusing on the energy sector. After the first round of seven interviews, we expanded the circle of interview partners to a total of 23. We chose to include both iterations in our study, as our questions revolved around the same main barriers to SEIS diffusion and we did not detect any inconsistencies in our data as the data analysis process evolved.

Based on the Straussian version of the GTM, we prepared a pre-defined research question: What are the main barriers to smart energy information systems diffusion? During the theoretical sampling stage, we were confronted with the problem of having to decide what type of data was required during each stage to further develop, improve, change or reject emerging categories. From an industry perspective, most barriers to SEIS diffusion correspond to typical IS issues.

Theoretical saturation

Theoretical saturation is defined as the point at which additional data analysis leads to no new concepts related to the main concept (Glaser and Strauss 1967). A sample size of 20 to 30 informants is common for GTM research (Wilson and Hutchinson 1991). We reached saturation after 17 interviews. However, we conducted an additional six interviews to make sure we had reached the saturation point.

Coding procedures

The coding procedure is an investigative process of fracturing, conceptualizing, and integrating data in order to formulate a theory (Strauss and Corbin 1998). We followed the three types of coding advised by Strauss and Corbin (1998): open, axial, and selective coding. In our practice, the coding phases are often repeated several times as we moved back and forth between research stages as required.

Open coding: Open coding describes the analytical process in which concepts and categories are identified as their attributes and dimensions are found in the data (Strauss and Corbin 1998). In order to generate concepts and categories, statements are named, compared, and written during the open coding phase (Locke 2001).

The first open coding phase started when we generated open codes for seven of the interviews we conducted. In the next step, the authors compared the open codes they had generated by exchanging and checking them for similarities and differences. The authors debated the differences between their open codes and subsequently refined them.

The second open coding phase included a second iteration of analysis to produce a substantive theory. We generated codes for an additional 15 interviews, using the same process followed in the first coding phase.

Throughout the whole coding process, we generated theoretical and process memos focusing on general IS issues and possible special SEIS issues. The produced memos were exchanged subsequent to the memo process. One major issue we encountered was the inconsistent definitions of specific terms.

The first phase of our data analysis involved three open coding steps. First, the transcribed empirical data was analyzed line by line. Second, we conceptualized the empirical data. In the third and final phase, the empirical data was categorized. Line-by-line coding involves naming each line of written data (Glaser 1978). Concepts are the basic unit of analysis, representing an observation, a sentence, a paragraph, an idea or an event, and are labeled with a conceptual name (code). We defined 20 concepts (20 codes) in the open coding phase.

Appendix 5 and 6 contain data extracts from two interviews focusing on managerial complexity to illustrate their analysis in the open coding phase. The data extracts illustrate the open coding strategies of in vivo and theoretical coding. While in vivo codes are derived from the informants' direct words and are interpreted by the researcher, theoretical codes are derived from the literature with which the researcher is familiar. For confidentiality reasons, all interviewees were anonymized.

Axial coding: Axial coding is the process of describing categories. It is referred to as axial, because code categories are connected, in terms of their properties and dimensions, along the axis of the categories (Strauss and Corbin 1998).

The next step is the axial coding phase, in which the coding paradigm is applied to a substantive area. The purpose of this step is to specify a certain category or phenomenon in terms of its causal conditions, the context in which it is embedded, the intervening conditions that affect the phenomenon and its management, the action/interactional strategies according to which it is handled, and the consequences of managing this phenomenon (Strauss and Corbin 1998). We provide an example of axial coding, presented as an original result of the data analyses (see Appendix 7). This example illustrates the managerial complexity phenomenon based on the open coding presented in Appendix 5 and 6 (Wolff 2005; Fiedler et al. 2010).

Complexity may pose a significant implementation risk that can increase the overall expected adoption costs (Chau and Tam 1997). Thus, in addition to monetary costs, managerial complexity and the resulting risk it poses to the change management process can be considered significant components of the adoption costs barrier (Zhu et al. 2006b).

Appendix 7 gives an example of the derivation of SEIS, which — as a theoretical construct (phenomenon) — is embedded in the framework of the legal barriers (context) and is derived from the adoption cost theory (condition) (Zhu et al. 2006a). Interviewee 1 only mentioned the lack of regulations as an important limitation of SEIS as a theoretical construct (intervening conditions). Interviewees 1 and 7 mentioned several options to understand the barriers to SEIS as a theoretical construct: Regulation could promote SEIS, while restricting the current market rules could possibly vanquish barriers to such systems' diffusion (strategies). As a result, legislation might promote SEIS (consequence).

The aim of this research is to generate propositions for the main barriers to SEIS diffusion. As our research question is clearly defined, it was not necessary to include the third phase of the GTM (selective coding), which involves the definition of an essential, abstract proposition to aggregate different categories of axial coding to integrate and refine the theory (Strauss and Corbin 1998). Open and axial coding are indispensable to identify the core obstacles to SEIS diffusion (Fiedler et al. 2010). Memos are essential during the entire axial coding phase and identify, abstract, and generalize the gathered data. The framework of this study is based on the propositions derived from the coding phase and memos.

Findings

After conducting two theory iterations, we developed two propositions to answer the research question.

Proposition I: Adoption costs, switching costs, and the collective action dilemma are among the main barriers to smart energy information systems diffusion

Proposition II: Missing business cases for all energy stakeholders is one of the main barriers to smart energy information systems diffusion

Discussion

Proposition I: Adoption costs, switching costs, and the collective action dilemma are among the main barriers to smart energy information systems diffusion

The goal of our findings, which are based on empirical data, is to build a vibrant theoretical model. This model should capture the interviewees' experience in theoretical terms, defined as propositions (Gioia et al. 2013). Our model shows the dynamic relationship between the different IS and SEIS barriers to explain the phenomenon of barriers to SEIS diffusion. We achieved this by comparing all the relevant data to theory.

Which factors should be considered when explaining the economic phenomena of interest (Whetten 1989)? We base our theoretical model on the barriers to IS mentioned earlier: adoption costs (Zhu et al. 2006a; Tornatzky and Klein 1982), switching costs (Klemperer 1987, 2005), and the collective action dilemma (Markus et al. 2006), which are all comprehensive barriers. None of them could be excluded, as every barrier contributed to our understanding. Figure 1 provides a

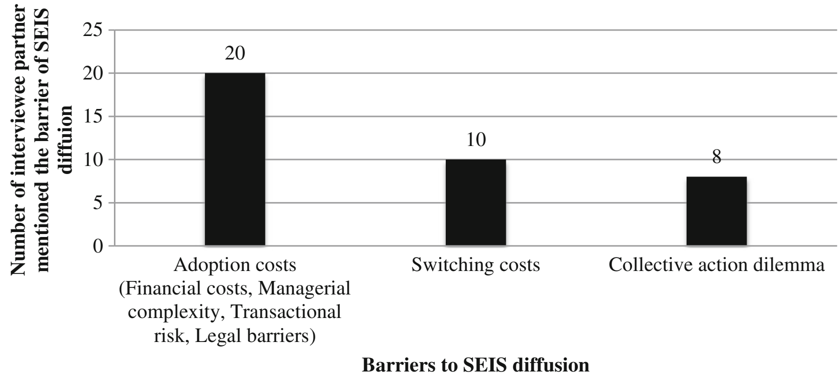

Fig. 1 Distribution of barriers to SEIS

first impression of the distribution of the main barriers to SEIS diffusion from an industry perspective. The figure displays the amount of answers regarding the main barriers to SEIS diffusion. Each barrier type was mentioned by at least one of the interview partners.

Once the set of factors was identified, we needed to determine how they are related (Whetten 1989). Appendix 8 describes the intensity of the barriers to SEIS diffusion and their individual effects on SEIS diffusion based on the interviewees' answers. We used the categories "Small relation," "Medium relation," and "High relation" to describe the weighting of the effects. If none of the interview partners or the literature mentioned a connection between two barriers, we added "Unknown relation." The items should be read in the direction in which they occur, from left to right, for example "Financial costs" have a strong relation to "Managerial complexity."

How do financial costs prevent the diffusion of SEIS?

The costs involved in smart homes exceed the potential customer benefits (see Appendix 9). SEIS require a smart meter or another enabling device for customers. However, there are no formal guidelines on who should be responsible for financing the installation and maintenance of SEIS (Kim and Shcherbakova 2011). If consumers are expected to pay for a smart meter, the method and cost of finance are serious issues (Kim and Shcherbakova 2011).

SEIS are designed to lower the energy demand during peak usage periods, when energy is most expensive. However lowering peak usage could lead to revenue losses for the generators (Kim and Shcherbakova 2011). If profit margins for peak generation are lower than for off-peak generation, which is typically the case given the extremely high costs of running plants at peak times, generators will incur revenue loss unless the ratio of changes in off-peak to peak consumption exceeds the inverse ratio of their respective marginal revenues (Kim and Shcherbakova 2011).

Furthermore, there are no formal measures aimed at facilitating the recovery of initial investments for electricity providers (Wang et al. 2010). Generators will not invest in SEIS if they are unable to recoup their initial costs (Kim and Shcherbakova 2011). Moreover, the technological infrastructure is an expensive component and an operational necessity, especially for demand response programs (Kim and Shcherbakova 2011).

Thus, according to our interviews and the literature, financial costs are strong barriers to SEIS diffusion.

How does managerial complexity prevent the diffusion of SEIS?

March et al. (2000) analyze semantic interoperability as one of the most important SEIS research issues. The third interviewee also mentioned this issue (see Appendix 10). Semantic interoperability is the knowledge-level interoperability that causes information asymmetry between different stakeholders. Imperfect information may prevent consumers and firms from undertaking profitable private investments in energy efficiency (Allcott and Greenstone 2012). These investment inefficiencies create a barrier to SEIS diffusion.

SEIS diffusion also brings with it challenges associated with processing an enormous amount of data. SEIS contain petabytes of operational data. Operational data includes real-time data, which is constantly updated in microseconds or seconds, archival data, static data, such as nodal diagrams within distribution management systems, and dynamic data, such as switching orders (see Appendix 11) (IEEE 2011).

The literature and interviewees remark that the vast amount of data is one of the main obstacles to SEIS. March et al. (2000) mention that today's database system technologies are challenged in virtually all areas of data management with new applications that demand ways of dealing more explicitly with the meaning and use of the data being managed. These technologies do not handle expressive semantic representations and processing capabilities well (March et al. 2000). The principles governing the ownership and the sale of SEIS data are complex (see Appendix 12).

How do legal barriers prevent the diffusion of SEIS?

An inconsistent regulatory and legal framework is another often-mentioned barrier to SEIS (see Appendix 13). Government regulation still plays an important role, even in a liberalized power market (Kim and Shcherbakova 2011). We believe that clear regulations will promote the diffusion of SEIS. Besides financial costs, legal barriers are considered to have the highest impact on diffusion. However, none of the interview partners provided deep insights into the legal barriers.

How do transactional risks prevent the diffusion of SEIS?

The protection of data privacy is a main barrier to SEIS diffusion (Cavoukian et al. 2010). Interviewee 22 confirmed Wissner's (2011) thesis that the solutions implemented by German telecommunications companies are the most appropriate means to protect data. These solutions allow them to generate, process, and save personal data as long as this is necessary to complete or change stakeholders' information. Explicit confirmation is needed for purposes other than generating, processing or saving personal data (see Appendix 14) (Wissner 2011).

Data encryption is another very sensitive barrier to SEIS diffusion. Some of the data generated, such as the time of energy use, needs to be protected from being disclosed, manipulated, or lost (Akella et al. 2010). However, the required hard and software components are extremely costly (see Appendix 15). Further, the protection of data privacy and encryption are often connected with missing or inconsistent regulatory and legal frameworks (see Appendix 16). Adoption costs are typical barriers to SEIS diffusion, as both the interview partners and the literature mention them. Adoption costs have a weakening effect to the diffusion of SEIS.

How do switching costs prevent the diffusion of SEIS?

A possible reason for the identified dissimilarities in the diffusion of SEIS may stem from the varying switching costs. In a market with switching costs, IS tend to adapt in the long run (Klemperer 1995). Furthermore, a reduction of switching costs may lead to a winner-takes-all situation (Shi et al. 2006). According to economic literature, switching costs are high when companies set low prices for their goods to attract a high number of users. These customers will later be locked in. In the presence of switching costs, users often agree to higher prices, as previous investments would be lost when the user switches to another company. However, the diffusion of SEIS conforms to none of the theories mentioned. So far, we have only determined that missing switching costs do not prevent the diffusion of SEIS. Switching costs have an intensifying effect to the diffusion of SEIS

It appears that future transaction, learning, and monetary costs are the crucial components of switching costs preventing the diffusion of SEIS. Companies are afraid to invest in a product and become stuck with it, not because of the price, but because of future interoperability issues. Switching costs have an intensifying effect to adoption costs and subsequently a weakening effect to the diffusion of SEIS.

How does the collective action dilemma prevent the diffusion of SEIS?

The lack of standardization in SEIS is another barrier to SEIS diffusion. The different standards make it more difficult to disseminate secure and reliable information to any point in the grid where the information is needed to make decisions or perform critical monitoring (IEEE 2011). However, Uslar et al. (2010) show that no standards have yet been established across different fields, countries, and organizations. The interviewees share Fang et al.'s (2012) opinion that the standards need to be developed to overcome technical, political, and regulatory barriers. SEIS standardization involves two linked collective action dilemmas: standard development and standard diffusion. Interviewees 1, 2, and 10 focused on the missing standard development in SEIS (see Appendix 17). Other interviewees concentrated on the missing standard diffusion of SEIS (see Appendix 18). The lack of standardization in SEIS is mentioned as a common barrier to SEIS diffusion. Collective action dilemma has a weakening effect to the diffusion of SEIS.

Proposition II: Missing business cases for all energy stakeholders are among the main barriers to smart energy information systems diffusion

Ten of the 23 interviewees mentioned the lack of a holistic business case as one of the main barriers to SEIS diffusion. However, their answers differed significantly. An overview of the range of answers is given in Appendix 19.

Any major system is influenced by a variety of stakeholders, who determine its future (Freeman 1984). For example, grid operators are often reluctant to invest in SEIS (Wissner 2011). In many cases, it is unclear which stakeholder group will be responsible for paying for SEIS and for their diffusion. One of the reasons for the extremely slow expansion of SEIS, is that it is unclear which segment of the electricity market should be responsible for connecting it to the grid (Greening 2010).

Often, stakeholders are simply unaware of the possibilities of and potential profits from SEIS (Heiskanen et al. 2010). For example, by monitoring interrupted production in real time and resolving load issues, SEIS will impact the management of grid congestion. However, at the same time, congestion is a source of revenue for some players in the energy value chain (Glachant and Pignon 2005). The loss or reduction of congestion revenue will act as an incentive or disincentive for investment, as it implies gains for some stakeholders, for example consumers and owners of merchant lines, and losses for others, for example generators and owners of existing networks (Clastres 2011). Another interviewee agreed that demand side management would be more effective if it was fully and dynamically integrated into the customer domain (Huibin et al. 2011).

Interviewees agreed that there is no holistic business case for SEIS diffusion. The uncertainties regarding potential gains as well as freeriding strategies and waiting games delay investments by market players who wait for lower risk revenues before deploying the technology. A business case could reduce the costs of providing the proper infrastructure to facilitate efficient use. However, the costs typically fall on a few firms. No stakeholder wants to pay to benefit others. All stakeholders will be inclined to freeride on the investment of the other. In an extreme case, no investment will take place (Kim and Shcherbakova 2011). However, many parties can benefit from these investments, which complicates the task of classifying each party's gains and thus the mechanisms for redistributing the resulting rent and for motivating the investments in the first place (Clastres 2011). The asymmetry of information between different stakeholders is a part of semantic interoperability and leads to a lack of added value (Park and Ram 2004).

The theoretical model for SEIS diffusion

Sparked by a discussion of the traditional IS barriers, we were interested in exploring the unique character of the energy market and subsequently developed the propositions regarding barriers to SEIS diffusion. Although the analysis did not add new barriers to the known barriers, it deepened our understanding of the specific phenomenon under study.

Thus, we focused on the barriers to SEIS diffusion that the interview partners did not mention. Those barriers are based on their knowledge of SEIS and missing institutional conditions. We realized that none of our interviewees were able to give a detailed outlook on the future development of SEIS over the next two years. Further, the need for a holistic business case stems from the lack of appropriate knowledge of SEIS.

A complex combination of economic and political barriers hinders SEIS diffusion. We validated the intensity of the interrelations between the different barriers to SEIS diffusion. Compared to the current state of the art of the IS and SEIS literature, we find that significant and persistent barriers to SEIS diffusion need to be challenged at multiple level of the energy value chain.

Figure 2 represents the theoretical model of SEIS diffusion. The theoretical model of SEIS diffusion contributes to the literature by defining the influencing factors that allow for the acceptance, adoption, and subsequent diffusion of SEIS. This theoretical model exhibits the direction as well as the weighting effect of the barriers to SEIS diffusion. Moreover, the model defines the critical barriers that might be incorporated into a holistic business case that will eliminate all the barriers to SEIS diffusion from a practical and theoretical perspective. Our model could help managers and technical engineers focus on the complexity of barriers to SEIS diffusion.

We thus contribute to the literature on IS-based solutions in two ways. First, we identified the unheeded interrelations between the main barriers to SEIS diffusion. Second, we conducted a holistic theoretical model of SEIS diffusion to enhance the theoretical and practical understanding of such systems and provide deeper insights into the discrepancy between the advantages and the de facto diffusion of SEIS.

Conclusions

Our primary objective was to identify the main barriers to SEIS diffusion. Analyzing the 23 interviews with stakeholders from the energy sector, we found that some of the main barriers are adoption costs, switching costs, and the collective action dilemma. More specifically, these barriers are interoperability, the protection of data privacy and encryption issues, the incomplete and inconsistent regulatory and legal framework, enormous data volumes, and the lack of standards. Moreover, syntactic and semantic interoperability issues were found to be significant barriers to SEIS. The majority of these issues are rooted in the absence of universally accepted interfaces, messaging and control protocols, and standards that would be required to ensure a common communication vocabulary among system components. Varying syntactic interpretations of the same data make an integration effort extremely difficult, since each source of information and potential receiver of that information may operate within a different context. Semantic interoperability issues prevent cooperating businesses from resolving conflicts arising from differences in implicit meanings, perspectives, and assumptions.

Another barrier to SEIS diffusion is an incomplete and inconsistent regulatory and legal framework. Researchers and governments need to create a well-designed and consistent legal and regulatory framework to support further SEIS development. We believe that, with the implementation of such a framework, SEIS could foster data management and communication between its different stakeholders and thus resolve the issue of semantic interoperability. Smart meter information systems could lead to added value for different stakeholders, either by implementing SEIS in a conglomerate of firms to maximize profits or by maximizing SEIS's utility to increase the added value to the customer. Especially a plant control, demand-side management, or an advanced metering infrastructure could help close the energy efficiency gap.

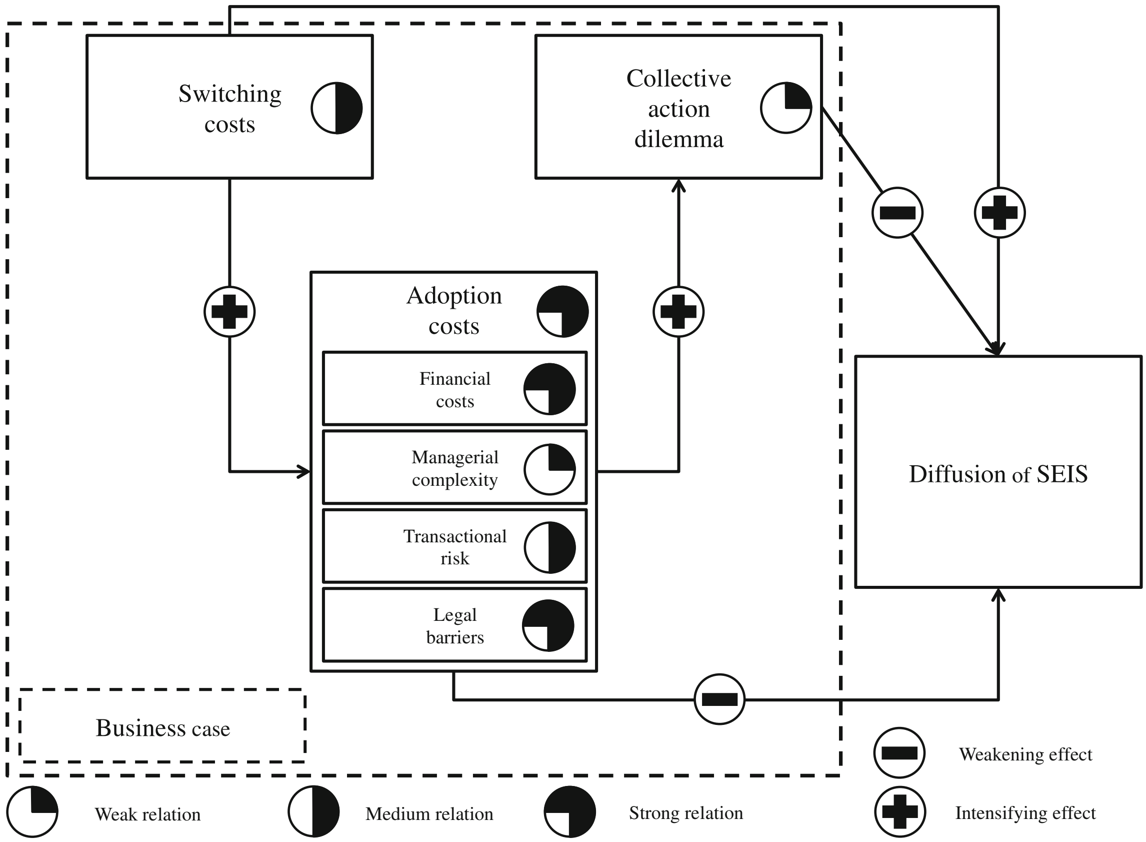

Fig. 2 The theoretical model of SEIS diffusion

Moreover, we found that a lack of business cases leads to insufficient additional value for each stakeholder. The lack of cases is due to miscommunication and diametric profit functions. Therefore, SEIS diffusion could be overcome by creating real business cases. Energy generation, transmission, and distribution firms need to form a conglomerate to profit-maximize their energy output and transmissions while customers need to utility-maximize their energy consumption. Additionally, the high costs of implementing smart meters should not outweigh their benefits to individual stakeholders (Römer et al. 2012). We agree with Farrell and Shapiro (1988) that switching costs, adoption costs, and the collective action dilemma alone do not form a barrier to SEIS diffusion. However, the lack of business cases for all stakeholders exacerbates these barriers. Our findings suggest that SEIS diffusion will be impeded as long as no business cases are developed.

Limitations and further research

Our research has several limitations, some of which are unique to this study. First, we cannot yet quantitatively evaluate to what extent overcoming the barriers to SEIS diffusion will generate added value for individual stakeholders, because very little objective data is available. In the future, data from business cases might alter our analysis of SEIS limitations. An obvious direction for future research is to build a conceptual model of SEIS.

The second limitation is that we conducted interviews with only German experts who focus on the German electricity market. However, Römer et al. (2012) suggest that the results could be applied to other countries faced with similar energy value chain issues. Our results should thus be validated against other articles or case studies. We tried to minimize the limitations of using data from only one country by basing our analysis on prior theoretical literature and by triangulating our results against those of other case studies, including those by Markus et al. (2006) and Zhu et al. (2006a). Nevertheless, a second clear direction for future research is to compare our study with results from other countries as well as from other local and foreign industries.

The third limitation is that this study focuses on the actual status of the barriers to SEIS diffusion and not on the development of the SEIS limitations. Future studies should look into how these limitations came to be, which might provide additional insights into overcoming these barriers.

Other limitations are common to GTM research designs. Our results are based on the analysis of 23 qualitative interviews. The results could be validated by choosing another research approach or future research could combine qualitative and quantitative data to validate these results.

Appendix 1

Process memo 1: *Based on the research question, we focus on the barriers to SEIS.*

Theoretical memo 1: *First, we need to define SEIS→ SEIS is a bidirectional electricity and information network.*

Process memo 2: *We need to agree on special terms. The general terms are often too vague and require further adjustment. We need to create a catalog of used terms and how we define them.*

Theoretical memo 2: *Legal barriers and uncertainty seem to be the main barriers to SEIS. These barriers are well investigated in IS literature. Furthermore, the interviewees provide no new insights from an energy perspective.*

Appendix 2

Table 1 Overview of interviews

Interview#	Position	Company
Interview 1	Consultant	Strategy and IT consulting company focusing on energy (I)
Interview 2	Vice chief executive officer	Strategy and IT consulting company focusing on energy (I)
Interview 3	Chief executive officer	Strategy and IT consulting company focusing on energy (I)
Interview 4	Senior manager	Strategy and IT consulting company focusing on energy (I)
Interview 5	Project leader	Strategy and IT consulting company focusing on energy (II)
Interview 6	Project leader	Strategy and IT consulting company focusing on energy (II)
Interview 7	Senior manager	Strategy and IT consulting company focusing on energy (II)
Interview 8	Project leader	One of the big three energy companies (I)
Interview 9	Project leader	One of the big three energy companies (I)
Interview 10	2nd level manager	Municipal energy supplier (I)
Interview 11	Journalist energy sector	TV station
Interview 12	Senior manager	Energy IT consulting company (I)
Interview 13	Manager	Municipal energy supplier (II)
Interview 14	Manager	Telecommunication (Smart Meter)
Interview 15	Chief operating officer	Municipal energy supplier (II)
Interview 16	Salesman	Meter company
Interview 17	Politician	Major party in Germany
Interview 18	Senior consultant	Strategy and IT consulting company focusing on energy (II)
Interview 19	Chief executive officer	Municipal energy supplier (III)
Interview 20	Manager	Demand response and virtual power plant solutions
Interview 21	2nd level manager	Strategy and IT consulting company focusing on energy (III)
Interview 22	Manager	Strategy and IT consulting company focusing on energy (IV)
Interview 23	Chief executive officer	Technology company

Appendix 3

Table 2 Initial interview questions

Nine main questions
What are the main elements of SEIS?
How would you define SEIS?
What are the interfaces of SEIS?
What are the main barriers to SEIS?
Which barriers to SEIS counteract which advantages?
How can these SEIS barriers be overcome?
Do you think that the barriers to SEIS could be compared to the barriers faced by the telephone industry 10 years ago?
How will SEIS change the industry in 2, 5, and 10 years?
Once again, what do you consider the main barriers to SEIS?

Appendix 4

Table 3 Theory development across studies

Theoretical sampling	Key categories	Emerging substantive theory
A qualitative analysis of 7 interviews on SEIS. The interviewees were from two strategy and IT companies focusing on energy. Duration of the interviews: 30 min	Two categories of barriers to SEIS diffusion: 1. Financial costs 2. IT issues	Theory iteration 1: 1. Legal barriers 2. IT follows strategy → No technical barriers 3. Freerider issue 4. No existing business cases that show the full potential of SEIS
A qualitative analysis of 16 interviews about SEIS. The interviewees were from four strategy and IT consulting companies focusing on energy, two municipal suppliers, the telecommunications industry, and several energy-related companies. Duration of the interviews: 30 min	Three categories of barriers to SEIS: 1. Adoption costs 2. Switching costs 3. Collective action dilemma	Theory iteration 2: Main barriers to SEIS diffusion are 1. Financial costs 2. Managerial complexity 3. Transactional risks 4. Legal barriers 5. Switching costs 6. Collective action theory 7. Missing business case

Appendix 5

Table 4 Extract with coding (I)

Data extract from interview no. 1	Line-by-line coding	Conceptualization	Categorization
There is no demand for smart energy information systems from the client side.	No demand for SEIS	Demand of SEIS	Business case
Alternatively, it has to come from legislator.	Legislation push demand	Regulation	Legal barrier
In Germany, there is too little motivation for the consumer to use smart meter/smart grid/smart energy information technologies.	Missing motivation	Demand of SEIS	Business case
Moreover, until there is demand for it, no one is going to write some super software.	Missing SEIS	Demand of SEIS	Business case
When this happens, the systems will be implemented and quickly become market-ready. It is currently not worthwhile for software companies, since:	–	–	–
Network operators only do things when regulations force them to.	Missing regulation of network operators	Regulation	Legal barriers
Operators are not functioning in a competitive market.	Missing regulation leads to losses for operators	Regulation	Legal barriers
There are two ways in which this could occur:	–	–	–
(1) The client may want to benefit from the spot-market price and actively demand this or	Consumer benefits from spot market	Spot market	Spot market
(2) — the more probable scenario — it will come from the legislator and there will be deadlines by when the individual smart components have to be in place.	Legislation promotes SEIS	Regulation	Legal barriers

Appendix 6

Table 5 Extract with coding (II)

Data extract from interview no. 7	Line-by-line coding	Conceptualization	Categorization
There are constructs, like the smart grid, which are very interesting, but still completely theoretical.	Theoretical construct of SEIS	Prototype	Business case
Such constructs require a number of prerequisites. I basically have to throw everything out the window due to the interaction between liberal network operators.	New liberal network system	New network	Managerial complexity
Network operators would have to create completely new structures in order to logically achieve something with smart energy information systems.	New market and IS structures	New network	Managerial complexity
I am unaware of a business case.	No business case	Business case	Business case
This does not mean that something like that (smart energy information systems) cannot be established, but it requires a restriction of the current market rules.	Restriction of current market rules	Legal	Legal barriers

Appendix 7

Table 6 Open representation of axial coding of the phenomenon under study based on Fiedler et al. (2010) and Wolff (2005)

Axial coding	Coding the open codes	Opposite values of coding the open codes
Condition	Adoption costs	Special costs of IS
Phenomenon	Missing regulation of network operators	Overregulated network operators
Context	Legal barriers	Legal assistance
Intervening conditions	Missing regulation leads to losses for operators	Regulation leads to losses for operators
Strategies	Regulation; Restriction of current market rules	Reduction of regulation; No current market rules are required to change
Consequences	Legislation promotes SEIS	Legislation prevents SEIS

Appendix 8

Relation between adoption costs, switching costs, and the collective action dilemma as well as their individual effects on SEIS diffusion.

		Adoption costs				**Switching cost**	**Collective action dilemma**
		Financial costs	**Managerial complexity**	**Transactional risk**	**Legal barriers**		
Adoption costs	**Financial costs**		Strong relation	Strong relation	Strong relation	Medium relation	Weak relation
	Managerial complexity	Medium relation		Unknown relation	Strong relation	Strong relation	Weak relation
	Transactional risk	Medium relation	Unknown relation		Unknown relation	Unknown relation	Weak relation
	Legal barriers	Strong relation	Strong relation	High relation		Strong relation	Weak relation
Switching costs		Strong relation	Strong relation	Unknown relation	Unknown relation		Unknown relation
Collective action dilemma		Unknown relation	Unknown relation	Unknown relation	Unknown relation	Unknown relation	

Appendix 9

"For smart homes, the utilization is still difficult, because it costs 200 euros to install. The question is how to get that money back, because the advantages are not that great. So I don't think anything is going to happen there." (Interview 3)

Appendix 10

"We have a producer, a network provider/transmission, a measuring point operator, and a supplier, and it is necessary to develop processes between the individual market participants, not only in terms of data, but also in terms of administration, purchasing management, mistake clarification, etc., to create standards for data exchanges." (Interview 3)

Appendix 11

"Data formats, aggregations of real-time readings — these have enormous data volumes." (Interview 3)

"At the moment, we have a problem involving the large amount of data — there are no mechanisms to analyze and generate added value from this data. However, this will change in the future and it is an interesting application to increase forecast quality." (Interview 4)

Appendix 12

"The data streams will increase exorbitantly. The speed of data exchanges will increase. The need for information will increase. Consequently, the reaction rate must be increased." (Interview 14)

"I must say, I do not consider it appropriate. If the customer wishes to have SEIS installed, that is fine. However, it should not be forced, because the flood of data will be so immense that, in the end, it will be impossible to process all of it." (Interview 16)

Appendix 13

"That is why I say we need legal clarity. We need to know where the journey is going." (Interview 14)

Appendix 14

"We have survived the nationwide telecommunications history from which various horror stories arose. Today, nearly everyone is willing to share private data or banking details via the internet. No one really worries about his or her data. In the near future, the same development will occur in the energy industry." (Interview 22)

Appendix 15

"[The components that are] going to cost money are the computing systems, data processing systems, and data security." (Interview 19)

Appendix 16

"I think everything must take place within a certain legal framework for two main reasons. On the one hand, everything that concerns data protection and data security must be placed in a meaningful framework for the customer. On the other hand, I think investment security is provided by appropriate regulations." (Interview 23)

Appendix 17

"No, the processing (of data) has not yet been standardized in Germany." (Interview 1)

"As far as I can see, each corporation or supplier is still using its original systems, be it power plant control or grid control or others. I'm not aware of any discussions about a comprehensive standard." (Interview 2)

"I'm not aware of any standard. At the moment, there is a wide range of solutions on the market. However, I assume that sooner or later a system will prevail. Although I cannot judge which systems, as the protocols that are currently traded on the market are still completely different." (Interview 10)

Appendix 18

"There is currently no standard. However, I would like to see a standard applied." (Interview 19)

Appendix 19

"I do not see a business case." (Interview 7)

Other interviewees mentioned the added value for each stakeholder.

"I think a business case, which consists of a profitability analysis and potential efficiency, should be seen as a whole. However, one also needs to calculate the effects for individual actors." (Interview 18)

"I consider these the biggest barriers: First of all the acceptance of SEIS on the client side. Often the clients choose the analog technology, as they cannot see any added benefit of the higher priced technology. Furthermore, the energy sector needs to determine whether there is any benefit at all, or whether it is just a prestige object that they desire." (Interview 13)

Another interviewee mentioned the need for smart grids in business cases.

"Following this line of thought, I think there will be areas in which business cases will develop. When it comes to network management and intelligent networks, there will be a business case." (Interview 19)

Interviewee 16 considered a business case necessary for energy providers.

"Energy providers are only interested in a business case if they reach at least a two-digit percentage return. Smaller energy utilities are satisfied earlier and therefore I would imagine that they will create a successful business case at an earlier stage." (Interview 16)

Others mentioned that SEIS have not yet been applied.

"The application is missing. It is a technology-triggered innovation that requires commercial legitimization." (Interview 4)

"Basically, it's a conceptual approach or a new direction, which, at this point, is driven thematically and strategically and not yet by IT. I think IT follows strategy. … But one of the reasons may be that it is still not clear how the market for which comprehensive software might be developed can be defined." (Interview 2)

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