COSTS OF INTEGRATING DEMAND RESPONSE SYSTEMS IN ELECTRICITY MARKETS

Complete Research

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Abstract

As a consequence of an increasing share of renewable energies, balancing electricity production and delivery requires efficient electricity markets. At the heart of electricity markets are Information Systems (IS) that coordinate demand and supply in real-time. IS has recently opened up an alternative towards increasing the efficiency of electricity markets by managing demand side resources; i.e. shifting electricity demand according to fluctuating supply by so-called Demand Response. This paper analyzes Information Systems that integrate Demand Response into electricity markets, with a focus on both the associated costs and benefits. Using historic data from 2011, we compare profits of electricity retailers across three different usage scenarios to determine that load shifting provides the highest revenue: annual IS-related costs account for €2.58 M exceeded by savings of €3.36 M.

Keywords: Green IT/IS, electronic markets, business value of IS/value of IS, information systems, decision making/makers

1 Introduction

Designing and implementing efficient electricity markets is the key to producing and delivering electricity reliably and, hence, satisfy the (ever-growing) electricity demand. Due to its physical characteristics, in particular transience, electrical power dictates tough requirements on the related market design. The market environment is further complicated by regulatory issues and the arising variety of stakeholders that are involved in the value chain of electricity provision. Challenges range from the structure and timing of bidding in wholesale markets to trading in ancillary services while, concurrently, assuring grid stability. Addressing these issues by designing appropriate electronic markets for the trading of electrical power is a native mission of Information Systems (IS) research (cf. Bakos, 1997; Malone et al., 1987; Watson et al., 2010). With this paper, we contribute to this mission by evaluating the potential of IS and electronic markets in managing the demand side of electricity and introducing demand side resources into various market settings.

One of the major challenges is to operate electricity markets successfully: one focal concern refers to the grid stability. Due to highly volatile supply and demand, electricity grids may become unstable when large deviations from the desired power frequency occur. The maintenance of grid stability requires power frequency to be controlled continuously. Hence, grid operators (see Figure 1) have to immediately counteract any imbalances by means of short-term control reserve. While grid operators execute balancing
activities in response to individual deviations in power frequency, the emerging costs are distributed across the associated electricity retailers. Whenever electricity retailers face unexpected deviations in demand or supply that might affect grid stability within their control area, they request the so-called balancing energy, which comes at varying penalty costs.

As a remedy to these costs, both balancing energy and the control reserve can be (partially) replaced by so-called Demand Response mechanisms. Essentially, Demand Response (DR) systems manage the demand side of electricity markets by flexibly shifting power demand according to the fluctuating supply side. It is defined by the U.S. Department of Energy (2006) and the Federal Energy Regulatory Commission (FERC) (2006) as: “Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.” Consequently, Madrigal and Porter (2012) recommend shifting electricity load as a measure for grid stability instead of activating the control reserve. Load shifting is controlled and executed by electricity retailers (see Figure 1) that have access to a certain DR potential at the customer end.

The effective usage of Demand Response requires real-time data and large scale information networks, in conjunction with sophisticated communication network structures. Bearing in mind the intricate information flows and huge amounts of data, Demand Response reveals itself to be inherently daunting for IS research. The inevitable need for Information Systems to match supply and demand in the power grid was stressed by Dedrick (2010). This pushes the boundaries of IS research with its challenging requirements for information processing (Corbett, 2011; Watson et al., 2010). All in all, IS research contributes to managing DR mechanisms efficiently.

As a main contribution to IS research, this paper discusses strategies to integrate Demand Response into existing electricity markets from a market design perspective. In particular, individual contributions are as follows:

1. We present an overview of application scenarios for Demand Response in various market settings, namely control reserve, balancing energy and electricity procurement at the product market. For each scenario, we provide a rigorous derivation of a financial model to gauge both IS-related costs.
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and the corresponding saving potential. Moreover, we define and quantify the value of information in DR systems by setting up a simulation environment using historic data.

2. The results provide decision support in selecting DR implementation strategies for electricity retailers. Based on this decision support, we discuss opportunities for DR aggregators and outline corresponding business cases.

The remainder of this paper is structured as follows. In Section 2, we review related work on the IS perspective of Demand Response systems. Subsequently, we discuss strategies to integrate Demand Response activities into existing electricity markets (Section 3). For each scenario, Section 4 models optimal decisions and derives costs, as well as savings, to gauge the financial return. Finally, in Section 5, we present the results by comparing Demand Response activities across different application scenarios.

2 Related Work

A recent literature review (Strüker & van Dinther, 2012) shows that there is a small, but growing number of IS-related research papers on smart grids. Examining these publications reveals that there are many studies demonstrating the responsiveness of residential, commercial and industrial customers to incentives and prices. However, we came across only a few IS publications dealing with Demand Response itself. The following studies have contributed to IS research:

• Corbett (2011) argues that a Demand Response system will increase the information processing requirements. As a consequence, the author demonstrates that Demand Response systems will incur massive amounts of data and, thus, a Demand Response system poses an inherent IS problem.

• Watson et al. (2010) develops the abstract idea of an Energy Informatics Framework. This framework represents an integrated approach that incorporates all the elements of an energy supply and demand system. However, its foundation remains at a high-level view where the design of individual components is neglected. Several authors advance towards an IS architecture. Tan et al. (2012) design an actual Demand Side Management decision supporting system, but the authors propose a high-level structure only. Palensky and Dietrich (2011) construct a web-based energy information system and name its typical components, while Law et al. (2012) focus on tethering the end-consumer. Similarly, Eto et al. (2007) surveys the necessary communication infrastructure. Watson et al. (2013) links Demand Response with a market for consumption rights. However, none of these IS publications compare different scenarios for market integration.

• Feuerriegel et al. (2013, 2012) and Bodenbenner et al. (2013) integrate Demand Response into the Energy Informatics Framework, study IS-related costs for load shifting, and list required components using a design science approach. However, the authors ignore integration scenarios across both control reserve and balancing energy.

While the above IS publications focus on the general design of a Demand Response system, all listed publications lack (1) a thorough analysis of how Demand Response is integrated into electricity markets, and (2) an in-depth analysis of IS-related costs. Therefore, we pursue a rigorous IS approach: first, we derive mathematical models for optimal DR decision across different use cases. Based on the use cases, we provide decision support for DR activations.
3 Integrating Demand Response into Electricity Markets

Generally, electricity markets can be divided into three categories, namely a product market, a control reserve exchange and balancing energy. This classification (Kirby, 2004) is valid in almost all developed countries. In the following sections, we revisit the landscape of existing electricity markets in detail and elaborate on how to integrate Demand Response resources.

3.1 Market Design of Control Reserve Exchanges

The operator of an electricity grid requires reserve energy to ensure reliable grid operations (Riedel & Weigt, 2007). In case of major load fluctuations, such as power station outages, reserve energy is activated. Reserve energy appears as both positive and negative reserves: positive reserves are used to offset a lack of energy, whereas negative reserves withdraw power from the network and address energy excesses. While different types of control reserve exists, the only option suited for Demand Response is the so-called tertiary reserve, which has to be fully available within 15 minutes after activation (Ma et al., 2013; Paulus & Borggrefe, 2011). By shifting load, the retailer could generate both positive and negative reserve potentials that could be offered as resources in the marketplace. With the liberalization of the energy markets, markets for trading control reserve have been established in many European countries and U. S. regions (Kirby, 2004). In Germany, the system operators procure reserve energy in a control power market where bidding is done through an Internet-based marketplace (Regelleistung, 2012).

3.2 Balancing Energy and Imbalance Penalties

The retailer has to forecast energy demand for the next day. In case of deviations from the forecast, control reserves are activated to offset the imbalances. The grid operator acquires the control reserves at the corresponding exchange. Here, balancing energy comes into play. It serves as a metric for retrospectively allocating the costs of actually activated control reserves to the respective originator of the imbalance. In an ex-post view, the deviations in a given time and control area are accumulated and analyzed. It can happen that certain variations compensate each other. Based on the ex-post analysis of expenditures for grid stabilization, a price for balancing energy is determined. This price, i.e. the imbalance penalty, has to be paid by the originators of the imbalance. Under certain circumstances, balancing energy can even lead to earnings for the retailer. This is the case when the retailer’s deviation from the forecast coincidentally prevents activation of reserve energy.

3.3 Electricity Procurement at the Product Market

At the product market, electricity can be procured on the basis of standardized contracts, as well as over-the-counter deals. However, both derivatives, in the form of futures and options, and spot transactions (day-ahead and intraday), can be traded on the contract market. In Germany, derivatives are sold at the European Energy Exchange, in short EEX, whereas EPEX Spot represents the spot market. Here, the electricity retailer can use Demand Response mechanisms to optimize the balance between production and demand, as well as to prevent electricity procurement during peak times. As a result, Demand Response does not serve as a market product itself, but as an internal tool for the electricity retailer to reduce procurement costs.
4 Research Model: Measuring the Financial Impact of DR

This section presents our research scenarios and their mathematical models for IS-related costs, in order to gauge financial impacts of Demand Response activities. Costs are determined by the Demand Response system and its components. As DR usage can only be realized with the help of a comprehensive IT and communications system, we inspect the costs of individual system components, as well as communication itself. We follow the frequently-used approach (Doostizadeh & Ghasemi, 2012; Feuerriegel et al., 2012; Meng & Zeng, 2012) that considers a single electricity retailer to measure the financial impact.

4.1 Research Questions

Recently, Strüker and van Dinther (2012) asked “how large is the economic value of Demand Response”? Likewise, Strbac (2008) claims that there is a “lack of understanding of the benefits of Demand Side Management solutions”. To quantify the benefits, our research model addresses three scenarios, in which electricity retailers can deploy Demand Response to optimize their revenue streams. Each scenario is derived from the retailer’s tasks, concerning both the maintenance of the flow network and the current electricity market design. The scenarios are defined as follows.

- **Scenario A: Trading DR potential at the exchange for reserve energy.** In our first scenario, the retailer uses DR potential as a trading good on the exchange for reserve energy. Here, the retailer can leverage the available DR potential in the distribution network to offer it both as positive and negative reserve energy on the market.

- **Scenario B: Using DR to avoid balancing energy.** Electricity retailers have to forecast their energy demand one day in advance. In case this forecast deviates from their actual demand, retailers have to pay a penalty. In this scenario, the electricity retailer employs Demand Response to avoid penalties originating from using balancing energy by shifting load whenever the actual demand deviates from the forecasted value.

- **Scenario C: Using load shifting to optimize electricity procurement.** In our third scenario, the retailer employs Demand Response to improve the procurement strategies at the regular energy exchanges (i.e. day-ahead auctions, futures, derivatives). Here, the retailer shifts load to non-peak times in order to purchase energy at lower prices.

Based on the financial evaluation and comparison of the three usage scenarios for Demand Response, we want to derive managerial recommendations concerning the implementation strategies for electricity retailers. This leads to our first research question.

**Research Question 1:** Which usage scenario of Demand Response provides the highest benefit to electricity retailers?

The implementation of DR systems is closely connected to substantial capital expenditures. Hence, it appears necessary to either extend the scope of usage beyond Demand Response or leverage synergy effects from operating infrastructures for multiple retailers. Demand Response requires collecting and processing massive bulks of information. This may provide ways for specialized players, such as telecommunications providers or big data specialists, to establish novel, profitable business cases.

**Research Question 2:** What are the business opportunities for information aggregators in the field of Demand Response?
4.2 Cost Structure of Demand Response Systems

The DR system’s architecture, which is identical for all the considered scenarios, is illustrated in Figure 2. The core component of the DR infrastructure is the central Distribution Management System, which provides the retailer with functionality for monitoring and controlling the distribution flow network. The load forecasting engine and the Demand Response engine are important when considering DR programs. They are responsible for detecting mismatches between demand and supply of electricity in a future time slot, and for triggering counteractions accordingly. Moreover, the sensor network represents the current ongoing technology trend towards an Internet of Things. It provides the retailer with a two-way communication channel towards customers and the connected devices respectively. Only this type of broadband communication enables the full usage of Demand Response. There is a great variety of communication channels. We restrict our considerations to the most popular ones (cp. Gungor et al., 2011), namely powerline communications (PLC) and mobile communications (GSM and successors). The smart meters form the interface between the retailer’s infrastructure and the customer’s home area network (HAN). All energy-consuming devices in a household, as well as at a commercial customer’s residence, should be connected to the HAN to allow for remote control.

The basis for the derivation of the following cost components are information flows and the system architecture. As the infrastructure in the three scenarios remains the same, the capital expenditures and operating costs are also the same in all scenarios. The capital expenditures comprise the initial costs of procuring and installing the DR system. In addition, annual costs $c_{OP}$ are required to operate the system infrastructure. The costs cover e. g. the maintenance, personnel, energy, etc. for all components of the DR system. A more detailed line-up of these cost components is presented in (Feuerriegel et al., 2013).

In addition to the operating costs, the execution of a DR program induces volume-based communication costs. The volume-based costs are limited to traffic that passes through GSM-based channels, whereas PLC-based communication does not generate any volume-based charges.

As shown in Figure 3, the information flow in DR programs basically consists of two parts: first, reading out the usage data from the smart meter and, second, broadcasting the DR control signals. Looking at the first phase, the usage data needs to be collected from the smart meter and transferred to the central

Figure 2. System view on a Demand Response system with an Advanced Metering Infrastructure based on Feuerriegel et al. (2013).
The annual volume $v_{UD}$ for a single smart meter for this *upstream* communication is defined as

\[
v_{UD} = \left( \frac{g_{UD}}{g_T} \cdot \alpha_{UD} \cdot 365 \right) + \left( \frac{\alpha_{OH}}{g_T} \cdot g_A \right).
\]  

(1)

The second phase, namely broadcasting the DR signal to the connected smart meters, exhibits a similar cost structure as the first phase. Here, $\alpha_{DR}$ denotes the accumulated message size for the entire protocol stack, which consists of three steps: initializing the DR session, retrieving the available DR potentials from the customer, and, finally, sending the DR control signals towards the customer. The variable $g_{DR}$ denotes the number of communication activities that are induced by Demand Response per day. The annual volume $v_{DR}$ for the *downstream* communication per smart meter is defined as

\[
v_{DR} = \left( \frac{g_{DR}}{g_T} \cdot \alpha_{DR} \cdot 365 \right) + \left( \frac{\alpha_{OH}}{g_T} \cdot g_A \right).
\]  

(2)

The requirements concerning the frequency of reading out the smart meters and sending DR signals differ for the various scenarios. Consequently, the parameters $g_{UD}$ (i.e. number of read-out events per day) and $g_T$ have to be individually assigned for each scenario (cp. Table 1). In scenario A, DR potentials are offered at the reserve exchange; the notification of available resources has to take place on the previous day. Corresponding to the required activation time, the read-out interval is set to 15 minutes. The data has to be transferred from the smart meter to the retailer once a day. For balancing energy (i.e. scenario B), the read-out and transfer intervals are set to 15 minutes. This allows the retailer to continuously check the actual demand against the projected forecast. If it becomes apparent that imbalances may occur, the retailer can take appropriate action and shift load to prevent penalties. For scenario C, we look at the current product market. Here, electricity is traded in blocks of 60 minutes. Hence, we adopt the interval to 60 minutes accordingly. As the day-ahead market is cleared one day prior to delivery, a daily transfer of the usage data appears to be sufficient.
Table 1. Cost model configurations across scenarios.

In summary, the communication costs $c_{\text{COM}}$ add up to

\[
c_{\text{COM}} = \left( \text{No. of GSM meters} \cdot \frac{v_{\text{UD}} \cdot c_{\text{GSM}}(v_{\text{UD}})}{\text{Comm. cost GSM (per MByte)}} + v_{\text{DR}} \cdot c_{\text{GSM}}(v_{\text{DR}}) \right).
\]  

(3)

### 4.3 Measuring Financial Savings from Demand Response Systems

While the previous section assessed the (communication) cost perspective of Demand Response, we now focus our attention towards potential savings. We rely on approaches proposed in previous literature (Feuerriegel & Neumann, 2014). These models use linear optimization problems to determine Demand Response decisions. To deduce these, the model is affected by several parameters, namely, electricity prices, electricity load and the Demand Response potential. The latter varies across both industries and time of day. Furthermore, each individual DR-capable device (e.g., washing machine, A/C) or industry is subject to the extent its electricity consumption can be moved in time and, thus, the actual Demand Response potential is specified by a set of external, time-dependent variables.

## 5 Evaluation

In the following section, we assess our mathematical model using historic market data. The results achieved are used to evaluate the above research questions.

### 5.1 Datasets

To achieve a model configuration that is as realistic as possible, we utilize market data that is available from a number of (public) sources. This allows for deriving reasoning from the evaluation that is valid and credible. For our evaluation setting, we consider a typical German retailer delivering electricity to 290,000 residents. The retailer’s overall annual energy demand accounts for 2000 GWh (E-Control, 2012). The distribution of retailer’s customers is as follows (Styczynski, 2011): 25% households, 25% commercial customers and 50% industrial customers. Industrial customers are excluded from the calculation of DR saving potentials, since industrial customers hardly participate in load shifting, but instead reduce their energy consumption when granted financial incentives. All prices for energy derivatives and spot auctions are based on the historic hourly data of the European Energy Exchange, EEX for short (EEX, 2012). We
use the amount of balancing energy provided by E.ON Mitte\textsuperscript{1} for the year 2011. The original values account for 1.5 million inhabitants, so we scale it down to 290,000. The penalty price of balancing energy is provided by Transnet BW\textsuperscript{2} for the year 2011. All volumes and prices for tertiary control reserve are published on an Internet platform (Regelleistung, 2012). The capabilities of Demand Response vary considerably among both industry and households. Klobasa (2007) analyzes the market penetration of Demand Side Management and its overall potential for Germany. This DR potential is scaled to the electricity demand of the retailer and weighted by time-dependent coefficients; see Feuerriegel and Neumann (2014) for details.

The electricity retailer employs an ICT system to enable demand response, which is characterized by the following parameters. We consider a DR system characterized by the following parameters. The volume-based costs for GSM communication follow a logarithmic cost function; a higher data volume per meter leads to a cheaper price per transferred megabyte. The hardware costs for a single, plain smart meter are defined as € 60. A GSM resp. PLC communication module implies additional costs of € 35 and € 20. The overall number of installed smart meters is computed as 220,000 based on an annual energy consumption of 3500 kWh on average per residential household and 6500 kWh per commercial customer. Based on an assumed mean of meters per residential building resp. commercial customer, the number of communication modules is computed as 130,000. Thereof a share of 15\% communicates via GSM networks; the remaining 85\% are PLC-based modules. We assume that all meters are rolled out and put into operation at the same time.

5.2 Results

This section introduces a metric for measuring the value of information in Demand Response applications. Based on this metric, we subsequently present the financial outcomes for each of the defined scenarios according to the given dataset.

5.2.1 Information Value in a Demand Response System

In the smart grid realm, the usage data records that are regularly collected from the smart meters can be considered the core information piece. The collected data records enable numerous use cases, such as optimization and automation of the billing process. Here, we focus on the value that can be tapped by optimization of the electricity demand side with the help of DR programs. Both the additional revenue potentials from trading the DR resources on the energy markets and the saving potentials when avoiding penalties are opposed by significant costs for setting up and operating the required infrastructure. Combining these two perspectives, we introduce an expedient metric: the information value per readout of Demand Response. The information value per readout specifies the surplus a retailer is able to generate per single usage data record in a given scenario. Let $T$ denote the total number of smart meter readouts per year. Determination of the revenue varies across the scenario. For scenario A, let the revenue potential $r$ resemble the difference between, on the one hand, paying the penalties, and, on the other hand, optimizing the situation with the help of DR Response. In scenario B, for the calculation of the retailer’s revenue potential $r$, the earnings from trading positive and negative reserve energy have to be added up. Similarly, the savings from load shifting are used in scenario C. Taken altogether, this leads to the following definition of the information value per readout.

\footnotesize
\begin{itemize}
  \item \textsuperscript{1} E.ON Mitte AG (2013). Differenzbilanzierung. Web: http://www.eon-mitte.com/de/netz/veroeffentlichungen/strom_/veroeffentlichungen_nach_12 Abs_3_stromi
\end{itemize}
**Definition (Information Value per Readout).** The information value per readout for Demand Response expresses an electricity retailer’s profit per usage data record that is collected from a smart meter. Based on the annual revenue $r$, related annual costs $c_{\text{OP}}$ and $c_{\text{COM}}$, and the number of readout events per year $T$, the information value is calculated as

$$IV_{\text{DR}} = \frac{r - (c_{\text{OP}} + c_{\text{COM}})}{T}. \quad (4)$$

### 5.2.2 Scenario A: Trading Demand Response Potential at the Exchange for Reserve Energy

In our setting, reserve energy has to be activated 6895 times within the observation period (i.e. one year). Accordingly, 6895 communication activities have to be initialized, which leads to extra annual communication costs of €313 k. In addition, the DR system infrastructure generates operating costs and further communication costs (€0.890 M) for daily transfer of usage data records. The revenue potentials from traded and served reserve energy accumulate to €125 k per year. This corresponds to an average earning of €18 per activation.

In summary, the total annual running costs of the DR system significantly exceed the additional revenue potentials, which the retailer could realize by offering DR potential at the reserve energy market. The revenues cannot even cover the expenses for the additional communication activities that are caused by the reserve energy activations; in our setting a loss of €4 k is generated.

### 5.2.3 Scenario B: Use Demand Response to Avoid Balancing Energy

Scenario B aims to avoid the penalty costs associated with requested balancing energy. The German retailer faces total costs of around €798 k. These costs account for all deviations in forecasted and actual electricity demand that occurred during the year 2011. As shown in Table 2, Demand Response shows a possible path as to how these costs can be significantly decreased. By using Demand Response programs, penalties are reduced, as almost all balancing energy can be avoided, down to a staggering €1.7 k.

Scenario B requires a constant information exchange (i.e. every 15 minutes) between the retailer and the consumer (cp. Table 1). Compared to scenario C, this means significantly more communication activities. This again leads to a much higher communication overhead. The communication costs add up to €0.801 M per annum. In addition, the DR infrastructure generates annual operating costs to the amount of €2.540 M. Taken together, this results in running costs of €3.341 M.

This cost pool strongly exceeds the expected revenue potentials for scenario B. The DR infrastructure produces an annual loss of €2.544 M. Here, the huge initial investments (i.e. €24.419 M) have not even been considered. However, the additional revenue potentials of using DR instead of balancing energy outweigh the costs that are directly related to communication. Hence, setting up the DR infrastructure and employing it for multiple use cases, including scenario B, could be a viable approach.

<table>
<thead>
<tr>
<th>Without DR</th>
<th>Using DR</th>
<th>Relative change</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total expenditures</td>
<td>€798.4 k</td>
<td>€1.7 k</td>
<td>-99.8 %</td>
</tr>
<tr>
<td>Required balancing energy</td>
<td>95.28 MWh</td>
<td>1.92 MWh</td>
<td>-98.0 %</td>
</tr>
</tbody>
</table>

*Table 2. Comparison of expenditures for penalties for balancing energy.*
5.2.4 Scenario C: Use Load Shifting to Optimize Electricity Procurement

For scenario C, we fall back on results from our previous work (Feuerriegel & Neumann, 2014). The retailer’s saving potential is computed as €3,360 M (cp. Table 3). In contrast, the DR system generates annual running costs of €3,117 M. This leads to a slightly positive information value of €0.05 per 1000 smart meter readouts.

5.2.5 Comparison

When the prior evaluation results are combined (cp. Table 3), a clear answer concerning Research Question 1 can be formulated: scenario C, i.e. using load shifts to optimize electricity procurement, provides the largest benefit for the electricity retailer. It is the only scenario that generates a surplus at all; the two other scenarios are not profitable and, as a result, exhibit a negative information value. However, it should be noted that for scenario C, the situation changes as soon as the required capital expenditures are taken into account as well. Then the revenue potentials implied by the DR system can hardly cover the overall costs (cp. results in Feuerriegel et al., 2013). The capital expenditures in our defined scenarios amount to more than €24 M each. With a constant annual profit of €776 k, as in scenario C, the infrastructure has to be operated (without fresh investments) for more than 30 years. This is more than double the value of 15 years, which is frequently assumed to be the realistic lifetime for such an Information System (PWC Austria, 2010). However, even if the DR system is not profitable today, the assumed cost increases for control reserves and balancing energy could lead to a positive financial case in the medium term.

<table>
<thead>
<tr>
<th>Scenario A: Reserve energy</th>
<th>Scenario B: Balancing energy</th>
<th>Scenario C: Load shifting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue potentials</td>
<td>€0.124 M</td>
<td>€0.797 M</td>
</tr>
<tr>
<td>Annual running costs</td>
<td>€3.430 M</td>
<td>€3.341 M</td>
</tr>
<tr>
<td>... operative costs</td>
<td>€2.540 M</td>
<td>€2.540 M</td>
</tr>
<tr>
<td>... communication costs</td>
<td>€0.890 M</td>
<td>€0.801 M</td>
</tr>
<tr>
<td>Capital expenditures</td>
<td>€24.419 M</td>
<td>€24.419 M</td>
</tr>
<tr>
<td>Information value per 1000 meter readouts</td>
<td>€−0.40</td>
<td>€ -0.26</td>
</tr>
<tr>
<td>Annual GSM data volume</td>
<td>1.18 terabyte</td>
<td>1.01 terabyte</td>
</tr>
<tr>
<td>... per smart meter</td>
<td>5.61 megabyte</td>
<td>4.81 megabyte</td>
</tr>
</tbody>
</table>

Table 3. Summary of revenue potentials, annual running costs and transferred data volumes in scenarios A, B and C.

5.3 Managerial Implications

The results illustrate that operations of a complex advanced metering infrastructure do not (or just hardly) pay off for an electricity retailer when solely executing DR programs. However, in terms of our second research question, this application scenario may open up the field for new players in the energy domain. Once usage data records have been collected, this dataset holds the potential to enable additional services beyond Demand Response that yield supplementary revenue for the operator. Applications for the collected dataset range from process improvements, such as automated billing, to innovative value-added services. Moreover, aggregators could create synergies when operating a central data processing infrastructure. This is particularly true for telecommunications providers that are able to resort to existing communication network infrastructure (e.g. concentrators). Only in this way, the prohibitively high initial investments can be compensated or decreased.
It seems obvious to combine the three scenarios for enabling and leveraging the reuse of collected data records. However, we restrict our evaluation to a singular consideration of each scenario, as they exhibit strong interdependencies when combined in a single optimization model. This would lead to even more complex computation for determining saving potentials.

6 Conclusion and Outlook

Due to the integration of intermittent resources of power generation, the amount of supplied energy will show unprecedented fluctuations. This challenge can be addressed by using Demand Response systems for shifting power demand according to the fluctuating supply side and, consequently, integrating Information Systems for DR control into electricity markets. As we have shown in this paper, a scenario where an actual German electricity retailer leverages Demand Response for the optimization of the energy procurement strategies is most profitable, compared with application scenarios of using DR resource as tertiary reserve or to avoid balancing energy penalties. However, this only represents a snapshot. Prices for reserve and balancing energy are assumed to rise significantly in the near future (Kladnik et al., 2012; Madrigal & Porter, 2012), which consequently leads to increased financial benefits for the retailer and, therefore, could make these scenarios financially rewarding.

Based on our evaluation, we have taken a look at business opportunities for aggregators. For them, setting up and operating a DR infrastructure might generate a viable business case since they can profit from synergies when offering the infrastructure to more than one electricity retailer. In addition, they may be able to reuse the infrastructure for additional valuable applications and services.

In future work, we plan to extend the financial perspective towards connected customers. First, customers need to be somehow incentivized to participate in the DR program – most probably, this would require a financial compensation. Second, the customers have to be equipped with Home Area Networks to enable DR mechanisms. So far, we have restricted the cost model to IS-related costs within the electricity retailer’s realm. Furthermore, we intend to further enhance the revenue model by allowing intra-day allocation and shifting of load. This would better reflect the effects of integrating renewables into the power grid. Hitherto, all market transactions are fixed day-ahead. All in all, this contributes to the discussion on the optimal information granularity. This research topic is not only restricted to DR, but is also extended to smart grid applications (cp. Dalen et al., 2013; Heinrich & Zimmermann, 2012) and has been gaining increasing traction within the IS community.

References


