Identifying the Economic Relevance of Smart Meter Reliability in Germany: A Cost-Benefit Analysis

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Abstract: The decarbonization and resulting energy transition has a lot of challenges for the future. Decentralized power generation and its stabilization of the power grid is a problem that can be solved by more accurate monitoring of power consumption using smart meters. The overall objective is to prevent blackouts. Therefore, the reliability of the used smart meter architecture is an important factor. In the present paper, a systematic cost-benefit analysis focused on Germany is performed to demonstrate the economic advantages of a reliability-optimised smart meter architecture.

1 INTRODUCTION

The Internet of Things has become an important factor in the modernisation of today's society (Kaufmann, 2021). Due an increasing number of networked devices and the resulting growing amount of data worldwide, the social transformation is being driven forward. Until 2025 there will be 75 billion networked devices worldwide (Statista, 2018) with a total data volume of approximately 80 zettabytes (O'Dea, 2021). The digitalisation of civil infrastructure facilities in particular is becoming especially relevant to society (BSI, 2020; European Union, 2022; European Commission, 2020). The services that are provided like the supply of water, electricity or gas are increasingly dependent on available and operating information technology. The so-called smart meters can record real consumption data and forward them to higher-level instances to provide these data for the overall management of whole ecosystems. Ensuring the uninterrupted supply of water, electricity or gas is essential for the economic, social and political functioning of any technological economy. According to the last European Commission report (European Commission, 2020) in 2020, the penetration rate of smart electricity meters is estimated to 43% (123 million) and of smart gas meters to 27% (31 million). In 2030, there will be a penetration rate of 92% (226 million) for smart electricity meters. Furthermore, a penetration rate of 44% (51 million) is projected for smart gas meters in 2024. As a result of this increased macroeconomic and societal dependency and future challenges, the security of supply is becoming more and more central to energy and economic governance. In order to make an economically efficient decision on the optimisation of the reliability of of smart meter architectures, it is important to have an objective comparison of the costs and the benefits.

Generally, smart metering systems are more failure-prone than conventional meters because of the more complex interaction of hardware and software components (EY, 2013). Therefore, implementing additional measures to assure the reliability appears sensible. Yet, this also comes with additional costs that have to be taken into consideration. This paper will focus exactly this issue - performing a cost-benefit analysis (CBA) that demonstrates the cost-effectiveness of optimising the reliability of a smart meter architecture. Based on the previous argumentation, we would like to answer the following research question:

RQ: *"What is the benefit-cost ratio for reliability optimisation of a smart meter architecture?"*

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To answer the mentioned research question, in section 2 the theoretical basis and the stepwise process of a CBA are presented. After that, the described approach is performed in section 3. In the final section, we summarize the paper and explain possible future work.

2 SYSTEMATIC COST BENEFIT ANALYSIS

This chapter presents the theoretical foundations of a CBA as well as the systematic procedure for performing a CBA. The different steps are described in a universal manner.

2.1 Basics of Cost Benefit Analysis

CBA is one of the most used tools for evaluating projects. It is well grounded in theory and has a long tradition and a wide area of applications (Gregersen& Contreras-Hermosilla, 1992; Layard& Glaister, 1996; Cubbage, Davis, Frey,& Behr, 2013; Sartori et al., 2014). CBA is often used in investment decisions, both by companies and governments. The CBA determines the relevance of the advantages and disadvantages of a project by the monetary value of Euros that the society is ready to pay for these outcomes. Therefore, it measures the social value of a project by quantifying the social impacts and making costs and benefits comparable in monetary terms (Koopmans& Mouter, 2020).

In 2015, the EU published a CBA on the roll-out of smart metering systems for the digital collection of electricity data (ICCS-NTUA& AF Mercados EMI, 2015). This identified the main cost and benefit factors for the expected roll-out and defined key findings and recommendations for the EU. Further, the paper by Vitiello et al. presents the highlights of the national CBA for the roll-out of smart meters in the EU member states and shows the current situation of the smart meter roll-out in 2020 (Vitiello, Andreadou, Ardelean,& Fulli, 2022). To build upon these findings, in the publication at hand, a CBA is performed to demonstrate the positive economic effect of optimising the reliability of a smart meter architecture.

2.2 Four Steps of Cost-Benefit Analysis

For systematically conducting a CBA, the following tasks are performed in chronological order as depicted in Figure 1 (Zahvoyska, Oksana,& Maksymiv, 2017) :

- **Project Identification:** In this step, the specifications of the project are defined. These include the necessary requirements, the planned objective and the scope, which describes the project focus in more detail
- **Financial Analysis:** This describes the data acquisition for the required cost and benefit values and quantifies them
- **Economic Analysis:** The next step presents the economic profitability on the basis of the monetary cost and benefit values, so that the relationship between used resources and achieved success is described
- **Risk Analysis:** The qualitative risk analysis focuses on the probability of occurrence of an event

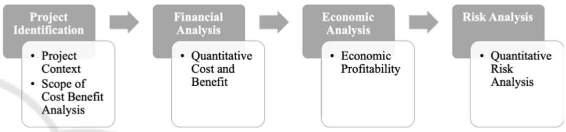

Figure 1: Four Steps of the Cost-Benefit Analysis.

The described sequence of the CBA constitutes a systematic approach to evaluate a project economically. Here, the project plan is specified from the generic to the detailed level. Fundamental key elements are the quantification of the costs and the benefits.

3 PERFORMING THE COST BENEFIT ANALYSIS

In this section, we will adapt the previously described procedure for performing a CBA to our use case. After the four steps shown in Figure 1 have been completed, we will consolidate and evaluate the results at the end of the section.

3.1 Project Identification

The primary objective of the reliability-optimised smart meter architecture is to avoid a blackout. A blackout is a major electricity outage that causes a large area without power for a long time, which has serious social and economic consequences (Leopoldina, 2023). The balance between electricity production and consumption is very important, because it guarantees the stability of the grid (BDEW, 2022). Currently, 55.4% of Germany's energy production is conventional power generation by power plants that run on coal or natural gas (BDEW, 2022). Based on the planned decarbonization, the separate large power plants will be replaced by flexible and decentralized capacities, such as wind or solar energy, in the future. In addition to decentralization, it will be more difficult to regulate the available amount of electricity in the power grid with solar and wind power. Therefore, the mentioned energy transition creates new challenges, which can be addressed by a more accurate monitoring of the power consumption (Leopoldina, 2023). For this reason, the widespread adoption of smart meters can help to achieve the overall objective, which is still to ensure grid stability.

The following CBA is used to demonstrate that the reliability optimisation of a smart meter architecture has a positive benefit-cost ratio. With this verification, we want to show that (from a purely financial perspective, not including the potential additional impacts of a blackout on society) the additional financial costs for higher reliability are likely to be amortized. The considered use case focuses on smart meters for electricity supply in Germany, because this is the economically strongest country in the EU (Eurostat, 2022) and has a very good data basis. The requirements for performing the CBA are the quantification of the costs and benefits on the basis of a determined value in the currency EURO. The details of the collection of these data are explained in the following section 3.2.

3.2 Financial Analysis

To determine the costs, it is necessary to have models of a smart meter architecture, which represent a traditional architecture and a reliability-optimised one (Altenburg, Staegemann,& Turowski, 2023). For this purpose, we will use the two architectures from Figure 2.

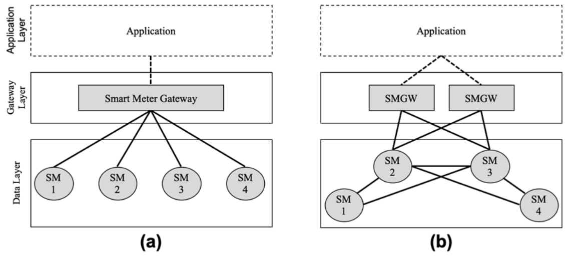

Figure 2: Model of a Smart Meter Architecture.

Figure 2a is the simplest approach and has no constructive reliability methods. All components of the smart meter architecture are connected to each other via a single channel so that a failure of the Smart Meter Gateway (SMGW) or an interruption of the communication channels between the smart meters and the SMGW or the SMGW and the application will affect the overall system immediately. Figure 2b shows a reliability-optimised smart meter architecture. The SMGW is redundant and the smart meters are clustered, so that two of the smart meters are defined as root nodes and aggregate all information of the subordinate smart meters (López et al., 2019; Jan et al., 2015). According to the model in Figure 2, we focus on non-households in the CBA, because a smart meter architecture with more than one smart meter for electricity measurement is almost exclusively used in the industrial or commercial sector.

The most significant cost driver is the meter and the related installation costs. Meter-related costs do vary significantly across the different EU member states because of the very different conditions, like the type and cost of the smart meter or the different costs for installation work (ICCS-NTUA& AF Mercados EMI, 2015). Therefore, we follow the example of the Federal Republic of Germany, as described in section 3.1. The Federal Network Agency in Germany has defined an annual price cap for the installation and operation of smart metering systems in electricity, which the metering point operator is obliged to comply with (BNetzA, 2023). As shown in Figure 3, there are two different service offers. It is either possible to order an individual smart meter or an intelligent metering system, which is a combination of smart meter and SMGW. While the former has a price cap of 20 EUR per year, for the latter, the annual consumption is used to calculate the costs. Therefore, for our calculation, we use the median costs of 150 EUR per year (BNetzA, 2023).

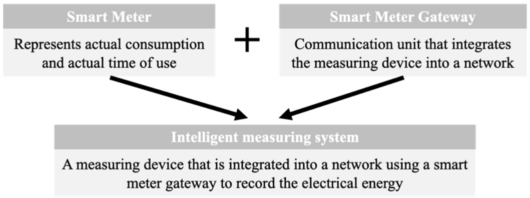

Figure 3: Intelligent Metering System.

For the presented CBA, the benefit is determined by the avoidance of blackouts. To be able to quantify the monetary benefit for Germany, we use the tool "blackout-simulator.com" (Schmidthaler& Reichl, 2016). With this online assessment tool, it is possible to determine the costs of blackouts for different private and commercial consumer groups. This offers an essential input for the economic decisions of the presented use case, in which we want to demonstrate the positive benefit-cost ratio of a reliability-optimised smart meter architecture. This simulation of a blackout is performed for the entire country within an hourly time interval.

3.3 Economic Analysis

In this section, we will perform the CBA calculations based on the requirements that are defined in sections 3.1 and 3.2. According to the Monitoring Report 2022 (BNetzA, 2022) of the Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway, there are 52.3 million metering locations in Germany. Out of these, 49.3 million metering locations are related to households and 3 million to industry and commerce. Based on the smart meter architectures from Figure 2 and the described cost basis, which we explained in Section 3.2, we have the following additional costs for a reliability-optimised smart meter architecture:

$$\begin{gathered}\text{Cost Architecture 2a} = \text{150 EUR} + \\ (\text{20 EUR x 3}) = 210\ EUR \\[1em] \text{Cost Architecture 2b} = (\text{150 EUR x 2}) + \\ (\text{20 EUR x 2}) = 340\ EUR \\[1em] \text{Costs for reliability optimisation} = \\ \text{340 EUR} - \text{210 EUR} = \mathbf{130\ EUR}\end{gathered} \tag{1}$$

As shown in Formula 1, the additional cost for the assumed reliability-optimised smart meter architecture is 130 EUR. Those have to be multiplied by the above mentioned 3 million metering locations for the industrial and commercial sector, so that we get additional costs of 390 million EUR. In order to get the monetary benefit, we use the online assessment tool "blackout-simulator.com" to assess the damage caused by a blackout. It quantifies the monetary damage that is caused when for certain regions, that can be selected by the user, no electricity is supplied to the industrial and commercial sectors. The size of the damage during a blackout depends on the time and most of all, the duration (Schmidthaler& Reichl, 2016). The diagram in the following Figure 4 shows the linear increase of the benefit-cost ratio with the duration of the blackout. Even when preventing a blackout with the duration of one hour, the reliability-optimised smart meter architecture has a positive benefit-cost ratio. This means that the additional costs already amortize. By avoiding an even larger blackout of about three hours, the benefit-cost ratio is already two, which means that the monetary benefit becomes twice as high as the additional costs invested through the optimisation of reliability.

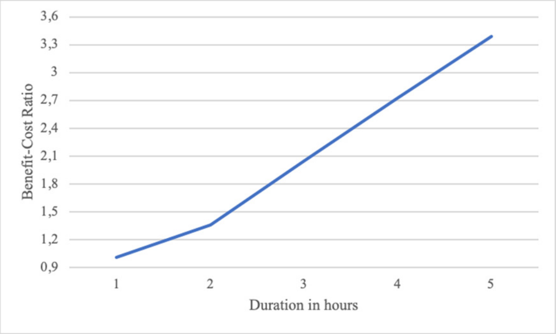

Figure 4: Impact of blackout duration on the Benefit-Cost Ratio.

3.4 Risk Analysis

Generally, the probability of a blackout in Germany is relatively low (BNetzA, 2022; BDEW, 2022; Leopoldina, 2023). The sum of unplanned interruptions in the German power grid was less than 13 minutes per consumer in 2021 (BNetzA, 2022; Leopoldina, 2023). However, the decentralisation and increasing digitalisation of the energy system described in section 3.1 do have an impact on the risk of a blackout (Leopoldina, 2023). With the progress of the energy transition and the resulting digitalisation by monitoring energy consumption using smart meters, the possibility of a power outage can be better estimated than today. Currently, it is very difficult to quantify the probability of a possible power outage with adequate accuracy. To illustrate the impact a blackout can have, a summary of six major blackouts (Hooper, 2003; BBC, 2012; Al-Mahmood, 2014; Melvin, 2015; Associated Press, 2019; Mogul, Saifi,& Syed, 2023) over the past twenty years is shown below in Table 1. For orientation, these data provide a very good overview of the severity that blackouts can have.

Table 1: Six biggest blackouts of the last twenty years.

Country	Year	Affected	Duration
Italy	2003	56 M	18 h
India	2012	620 M	15 h
Bangladesh	2014	150 M	12 h
Turkey	2015	70 M	9 h
Indonesia	2019	120 M	8 h
Pakistan	2023	230 M	12 h

4 CONCLUSION AND FUTURE WORK

Decarbonization and the resulting energy transition have a lot of challenges to ensure grid stability. In the future, accurate data collection of electricity consumption by smart meters will have an important societal impact. In this paper, a systematic cost-benefit analysis of a smart meter architecture optimized for reliability was performed. Based on the annual limits in Germany, the additional costs for a reliability-optimised smart meter architecture could be estimated at EUR 130. This value has been adapted to the German industrial and commercial sector with 3 million metering locations. Afterwards, the obtained total costs were compared with the benefits that were quantified by a simulation and it was determined that even after an avoided outage time of one hour, those additional costs are amortized. It is important that the monetary benefit increases linearly with the duration of the blackout.

In addition to the results of this paper, a more detailed analysis and concretisation of the probability of a blackout could be a possible future work. Furthermore, the extension of the CBA by increasing the scope could be a topic for future work.

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