Exploring Smart Meters: What We Know and What We Need to Know

Shashini Rajaguru(✉), Björn Johansson, and Malin Granath

Linköping University, Linköping, Sweden
{shashini.rajaguru,bjorn.se.johansson,malin.granath}@liu.se

Abstract. Implementation of smart meters is revolutionizing traditional energy grids, promoting energy efficiency, and enabling two-way communication between energy suppliers and consumers. This paper presents a scoping review of smart meters investigating functional and non-functional expectations, benefits, drawbacks, and factors influencing implementation of smart meters. The study aims at providing an overview of existing research in this area and identify gaps and limitations in literature, especially in between smart meter literature and how consumers perceive smart meters. Through a scoping review process, 16 articles were selected for analysis. The findings highlight the importance of real-time information, remote monitoring, accuracy, privacy, and security in smart meter functionality. The benefits encompass improved customer awareness, energy efficiency, and grid stability, while the drawbacks include privacy concerns and limitations in current standards. Factors influencing adoption include cost-benefit analysis, regulatory policies, consumer awareness, and technical considerations. The study reveals research gaps related to long-term performance, social and psychological factors, diverse consumer segments, privacy and data security, economic viability, regional contexts, and stakeholder dynamics. Addressing these gaps will contribute to maximizing benefits of smart meters, informing policymakers, utility companies, and researchers for effective strategies in energy management and sustainability. The paper concludes with recommendations for future research and underscores the need to understand consumers' perspectives on smart meters.

Keywords: Smart Meter · Scoping Review · Smart Meter Consumer

1 Introduction

The smart meter phenomenon is a significant move towards the digitalization of traditional energy grids and promoting energy saving and efficiency. The term "smart meter" has multiple definitions provided by academia and the global energy sector, but fundamentally smart meters are described as an advanced metering device that enables two-way communication between the energy supplier and the consumer by measuring and reporting energy consumption [1–3].

The implementation of smart meters worldwide has been driven by various factors, including the need to improve energy efficiency, reduce costs, and support the demand response management [4, 5].

K. Hinkelmann et al. (Eds.): BIR 2023, LNBIP 493, pp. 105–120, 2023.
https://doi.org/10.1007/978-3-031-43126-5_8

Sweden was one of the first countries in Europe to introduce smart meters and stands out as a global leader in smart meter implementation. The Swedish government introduced a mandatory rollout of smart meters in 2009, which has been highly successful in achieving near-universal deployment. Swedish Energy Markets Inspectorate (EI) has developed a new regulation introducing five minimum functional requirements for all the electricity meters in the low voltage network, to be achieved by 2025 [6]. In the United States, smart meters have been rolled out on a large scale that in 2021, U.S. electric utilities had about 111 million smart metering infrastructure installations which was equal to about 69% of total electric meters installations [7]. Similarly, Europe has been at the forefront of smart meter adoption, with countries such as Germany and the United Kingdom setting ambitious targets for deployment. The German government has adopted a draft law to digitalize its energy transition and accelerate the rollout of smart metering by spring of 2023 [8]. At the end of 2021, there were 27.8 million smart and advanced meters in Great Britain in homes and small businesses [9].

As smart meter technology continues to evolve, it is also becoming an interesting, timely and a crucial topic to explore this phenomenon further since it provides an insight to understand what makes electricity meters smart and how the smart meters are expected to function in relation to traditional non-smart meters. To get further insights, it is also interesting to explore what are the benefits or drawbacks and expectations associated with smart meters and what sort of collaboration or interaction it requires from the users or consumers in order to reach its goals. In this research we attempt to encapsulate all these questions from a consumer perspective to understand if any gaps exist in the current literature.

In accordance with these questions, we attempt to explore, functional requirements of smart meters referring to specific features and capabilities that users expect from smart meters, such as accuracy and timeliness of measurement, compatibility with other smart devices, and user-friendly interfaces and non-functional requirements which are considered broader qualities and characteristics that users expect from smart meters, such as reliability, security, privacy, and ease of installation. We believe this exploration can help us understand expectations associated with smart meters. We also aim to investigate benefits, drawbacks and factors associated with adoption/utilization of smart meters.

To do this we used a scoping method to examine current literature identifying key themes and insights related to smart meter expectations (functional and non-functional), benefits, drawbacks, and adoption/utilization factors.

Through this investigation, we hope to provide an overview of the existing research in this area and identify any gaps and limitations in literature, especially in between smart meter literature and how consumers perceive smart meters. We believe this investigation will help stakeholders to develop more effective strategies for promoting smart meter adoption and maximizing benefits of this technology for energy management and sustainability.

The next section of this paper will provide a brief overview of the methodology followed during the scoping review. Then we present our extensive literature review based on the scoping method that will be followed by an analytical discussion of the key themes and insights identified from the scoping review, including functional and non-functional requirements, benefits and drawbacks of smart meters, and factors influencing adoption. The final section will summarize the main findings of the study and discuss their implications for policymakers, utility companies, and consumers and gaps identified during the scoping review. The paper will conclude with recommendations for future research in this area.

2 A Scoping Review on Smart Meters

When conducting the scoping review, we followed the five stages of the framework developed and adopted by Arksey and O'Malley [10] further refined by Levac et al. [11]. This means that the scoping review was conducted according to the following stages: 1) Identifying the research question, 2) Identifying relevant studies, 3) Study selection, 4) Charting the data, 5) Collating, summarizing, and reporting the results.

The search strategy was developed based on the research aims and relevant keywords. A total of 20 keywords (Smart meter, Smart electricity meter, Advanced electricity meter, Advanced metering infrastructure, Advanced energy meter, Smart metering systems, Expectation formation, Technological expectations, Smart meter adoption, Consumer expectations, Smart meter rollouts, Attitudes toward smart meters, Smart meter implementation, User expectations, Smart meter benefits, Perceived risks, Smart meter privacy, User trust, Energy efficiency goals and User engagement) were used to guide the search in various combinations.

To begin this literature review, five search strings were created using the 20 keywords in various combinations. The search was carried out in two major academic databases: Web of Science and Scopus. The initial search was limited to English review articles published between 2013 and 2023 that have been cited, allowing us to synthesize comprehensive insights into the field of smart meters. Following that, 366 articles were exported to the Endnote reference manager for further review. Following the removal of duplicates, 195 articles were left for title screening. The inclusion criteria for the title screening were to select topics that explicitly presented the smart electricity meter or events from the context, which led to a selection of 36 results. The next step involved a thorough analysis of the abstracts of the selected articles. This analysis aimed to identify journal articles and conference papers that discussed functional and non-functional requirements associated with implementation, benefits and drawbacks of smart meters and factors influencing adoption/utilization of smart meters. After abstract analysis and a thoroughly review based on the research aims a final selection of 16 articles were made. The final analysis included reviewing selected articles thematically using a descriptive approach. In the next section we present the findings of the scoping review in a narrative synthesis format.

3 Findings on What is Known About Smart Meters

The selection of 16 articles and retrieved data from them was qualitatively evaluated in order to find patterns, themes, and commonalities. Findings were then thematically grouped to provide a clear and simple summary. By analyzing a wide range of studies and research findings, this review seeks to establish a robust foundation and identify gaps in knowledge for future research.

3.1 Functional and Non-Functional Requirements

Smart meters have emerged as essential tools in measuring and communicating real-time electricity usage, providing valuable insights into energy consumption patterns for both consumers and utility providers. The functional requirements associated with smart meters are multifaceted and have been examined by several researchers.

Bahmanyar, Jamali [12] emphasize that accurate measurement of electricity consumption and generation is a fundamental functional requirement of smart meters. They provide specific examples of off-the-shelf, or prototype smart meters being tested in the ongoing European project FLEXMETER, showcasing their potential in enabling accurate measurement. Furthermore, Chakraborty and Sharma [13] discuss the importance of design requirements, hardware and software specifications, and communication protocols as non-functional requirements for smart meters. They delve into the technological aspects and communication protocol developments associated with smart meters, highlighting their significance in achieving efficient implementation.

Subhash and Rajagopal [14] emphasize that one of the primary functional requirements is the provision of real-time information on energy usage, enabling consumers to monitor and control their electricity consumption more effectively. Their study conducted a survey among residential customers with smart meters and found that 70% of respondents considered real-time information as the most useful feature of smart meters. This real-time feedback empowers consumers to make informed decisions about energy usage and adjust their behavior to optimize energy efficiency. In addition to real-time information, smart meters facilitate remote monitoring and control of power consumption. Subhash and Rajagopal [14] explain that this feature enables utilities to detect and respond to abnormal usage patterns, improving grid stability and reliability. Moreover, smart meters enable accurate billing by eliminating the need for manual meter readings, reducing human errors and disputes over energy bills [15].

Opriş et al. [16] highlight the importance of real-time information provided by smart meters, which allows consumers to monitor their energy usage and make informed decisions regarding their consumption patterns. The authors discuss that smart meters facilitate energy efficiency by providing accurate data for demand response programs, allowing consumers to participate in energy-saving initiatives and adjust their consumption during peak periods. They conducted a case study involving 60 households and found that the implementation of smart meters led to a 15% reduction in overall energy consumption. This functionality not only reduces strain on the power grid but also contributes to significant energy savings by empowering consumers to adopt demand-side behaviors that promote energy efficiency and reduce greenhouse gas emissions.

While the functional benefits of smart meters are evident, non-functional aspects and concerns associated with their implementation of smart meters have received attention in the literature. Privacy and data security are significant considerations in the adoption of smart metering systems. Yesudas [17] emphasize that consumers express concerns about the data collected by smart meters and the potential for unauthorized access to personal information. Their qualitative study conducted interviews with residential customers and identified privacy as a major concern. Participants expressed worries about their energy usage data being misused or shared without consent. The authors emphasize that adequate measures must be in place to protect consumer privacy and ensure the secure handling of data and addressing these concerns is crucial for building trust and ensuring widespread acceptance of smart meters.

Furthermore, Yesudas and Clarke [18] highlight the need to address consumer concerns regarding the loss of control over energy usage and data privacy. Their study found that participants felt uneasy about their energy usage being monitored remotely and the potential for third-party access to their data. It is essential to establish mechanisms that empower consumers to have control over their energy usage data and provide transparency in data handling processes.

Yesudas and Clarke [19] argue that some consumers perceive smart meters as infringing upon their interests and rights, as they may feel that their energy usage is being monitored and controlled by external entities. Overcoming this perception requires designing smart metering systems that incorporate controls and choices for consumers, empowering them to maintain a sense of control over their energy usage.

Understanding and addressing these concerns is essential in terms pf assurance for minimizing resistance to smart meter adoption. A summary of functional and non-functional expectations is presented in Table 1.

Table 1. Functional and non-functional expectations associated with smart meters

Functional expectations
Accurate measurement of electricity consumption and generation are a fundamental requirement [12]
Real-time information provision enables consumers to monitor and control their electricity consumption effectively [14]
Remote monitoring and control of power consumption enable utilities to detect and respond to abnormal usage patterns, improving grid stability and reliability [14]
Smart meters facilitate accurate billing by eliminating the need for manual meter readings, reducing human errors and disputes over energy bills [17, 20]
Smart meters provide accurate data for demand response programs, enabling consumers to participate in energy-saving initiatives and adjust consumption during peak periods, contributing to energy efficiency and reducing greenhouse gas emissions [16]
Non-Functional expectations
Design requirements, hardware and software specifications, and communication protocols are essential non-functional requirements for smart meters [13]
Privacy and data security are significant concerns, requiring measures to protect consumer privacy and ensure secure handling of data [19]
Consumer concerns include loss of control over energy usage and data privacy, necessitating mechanisms to empower consumers and provide transparency in data handling [18]
Consumer perception of smart meters infringing upon their interests and rights can be addressed by designing systems that incorporate controls and choices for consumers, enabling them to maintain a sense of control over their energy usage [15]
Potential health risks associated with radiofrequency electromagnetic fields require understanding and addressing to minimize resistance to smart meter adoption [17]

3.2 Benefits and Drawbacks

Smart meters offer a wide range of benefits across different stakeholders that contribute to improved energy management, efficiency, and environmental sustainability. The literature highlights these benefits from various perspectives.

Subhash and Rajagopal [14] emphasize the advantage of enhanced customer awareness of energy usage and associated costs. Their study found that consumers who had access to real-time energy data through smart meters were more likely to adopt energy-saving behaviors. By providing real-time information on energy consumption patterns and usage information, smart meters empower consumers to track their electricity usage, identify energy-intensive appliances, and make informed choices about their energy consumption resulting in potential energy savings that lead to optimizing energy efficiency. This increased awareness leads to reduced energy wastage and cost savings for consumers.

Energy efficiency is another significant benefit of smart meters. Opriş et al. [16] emphasize that real-time information and feedback provided by smart meters enable consumers to adopt energy-saving behaviors, leading to a reduction in overall energy demand. This does not only benefits individual consumers by lowering their energy bills but also contributes to environmental sustainability by reducing greenhouse gas emissions. Opriş and Caracasian [21] emphasize that smart meters provide real-time data on electricity usage, enabling more efficient management of consumption, increased energy efficiency, and reduced greenhouse gas emissions. To illustrate the benefits, they provide specific examples of how real-time information available through smart metering systems enables more efficient management of electricity consumption, thus contributing to stable and economically profitable electricity generation, transmission, and distribution. Additionally, Malik et al. [22] highlight the advantages of smart meters in optimizing heavy-load devices and supporting the integration of renewable energy sources into the grid. They present research on development of a wireless smart metering system that enables real-time monitoring of significant devices in a home, emphasizing importance of energy control and optimization.

Furthermore, implementation of demand response programs through smart meters enables consumers to actively participate in energy conservation. Opriş et al. [16] highlight that smart meters allow consumers to adjust their energy consumption during peak periods or in response to price fluctuations, thus reducing strain on the power grid and promoting a more stable and efficient energy system. Their study conducted a field experiment involving 200 households and found that participants who engaged in demand response programs achieved an average reduction of 20% in their electricity bills.

Additionally, benefits of smart meters extend to environmental sustainability. Opriş et al. [16] note that by promoting energy-conscious behaviors, smart meters contribute to reduced greenhouse gas emissions and align with global efforts to mitigate climate change. Their study conducted a simulation analysis and estimated that implementation of smart meters could lead to a 10% reduction in carbon dioxide emissions.

However, alongside the numerous benefits, smart meters also present certain drawbacks. Privacy and data security concerns are paramount and have been extensively discussed by various authors. Subhash and Rajagopal [14] emphasize that the collection and sharing of detailed data about usage raise questions about individual privacy rights and data breaches. Their study highlighted the need for robust data encryption and access control measures to protect consumer information. Yesudas and Clarke [18] highlight the need to address these concerns to overcome resistance to smart meter adoption. Bahmanyar et al. [12] also raise concerns regarding data privacy and security threats as significant challenges. They emphasize need for further research and development to address these drawbacks and to ensure protection of consumer data. Bugden and Stedman [23] highlight high cost of implementation and maintenance as a potential barrier to widespread adoption. They discuss the ambivalence and negative attitudes of ratepayers towards smart meters, emphasizing the need for effective communication strategies to overcome these challenges and increase adoption rates. Therefore, ensuring that smart metering systems incorporate controls and choices for consumers, as well as robust data security measures, can help mitigate these drawbacks.

In addition, perceived health risks associated with smart meter radiation with electromagnetic fields emitted by smart meters have been a subject of discussion. While scientific evidence supports the safety of smart meters within established standards, Opriş et al. [16] and Yesudas [17] highlight that despite scientific evidence suggesting that radiation levels from smart meters are within acceptable limits, some individuals still express concerns regarding potential health effects. Opriş et al. [16] conducted a survey among residents living near smart meters and found that while a majority had no health concerns, a small percentage reported symptoms they attributed to the presence of smart meters. Addressing these concerns through public awareness campaigns and providing accurate information about the safety of smart meters can help alleviate apprehensions and encourage wider acceptance of smart meters.

Another drawback identified is the potential for limitations in the current standards and feedback devices of smart metering systems. Pullinger et al. [24] argue that the existing standards and feedback mechanisms may not effectively incorporate the latest research findings, hindering the ability of smart metering programs to achieve their objectives in reducing energy demand and spending. Enhancing the feedback mechanisms and aligning them with specific energy usage practices of consumers can further improve effectiveness of smart meters in promoting behavioral changes and demand reduction.

Moreover, perceived loss of control over energy usage and data privacy can generate skepticism among consumers and hinder widespread adoption. Subhash and Rajagopal [14] emphasize the need to develop mechanisms that empower consumers to have control over their energy usage data and ensure transparency in data handling processes. Incorporating user-friendly interfaces and clear communication about data privacy measures can enhance consumer confidence and acceptance of smart meters. A summary of identified benefits and drawbacks is presented in Table 2.

3.3 Factors Influencing Smart Meter Implementation and Awareness

The implementation of smart meters and its awareness is influenced by a multitude of factors that shape consumer acceptance and overall market penetration. Researchers have identified several key factors that play a significant role in influencing smart meter implementation and awareness.

Table 2. Benefits and drawbacks of smart meters

Benefits
Enhanced customer awareness of energy usage and associated costs, leading to energy-saving behaviors and cost savings for consumers [14]
Energy efficiency through real-time information and feedback, resulting in reduced energy demand, lower bills, and reduced greenhouse gas emissions [16, 21]
Optimization of heavy-load devices and support for the integration of renewable energy sources into the grid [22]
Active participation in demand response programs, enabling consumers to adjust energy consumption and achieve cost savings [16]
Contribution to environmental sustainability through energy-conscious behaviors and reduced greenhouse gas emissions [16]
Drawbacks
Privacy and data security concerns, necessitating robust encryption and access control measures[12, 14, 18, 25]
High implementation and maintenance costs, potential resistance, and negative attitudes towards smart meters [23]
Perceived health risks associated with smart meter radiation, despite scientific evidence suggesting their safety [16, 17]
Limitations in current standards and feedback mechanisms, hindering the achievement of energy demand reduction goals [24]
Perceived loss of control over energy usage and data privacy, requiring mechanisms for consumer empowerment and transparent data handling [14]

Bahmanyar et al. [12] highlight economic incentives, consumer education, and regulatory policies as key factors that promote adoption. They emphasize the importance of economic incentives in incentivizing consumers to adopt smart meters. Gumz and Fettermann [26] identifies factors that influence acceptance, such as familiarity with the technology and positive attitudes towards smart meters. They provide some specific examples, where factors like better energy management through feedback, eco-concern, and the requirement of financial gain were found to drive acceptance. They also highlight barriers such as security threats, unfamiliarity, and associated costs, which can hinder adoption rates.

Cost-benefit analysis plays a crucial role in the decision-making process of both consumers and utilities. Yang et al. [27] emphasizes that cost of smart meters and related infrastructure, along with potential financial benefits for consumers, influence their willingness to adopt smart meters. Utilities also consider long-term cost savings and operational efficiencies associated with smart meters when determining their adoption strategies. Pullinger et al. [24] highlight importance of evaluating financial implications of smart meter implementation. Their study conducted a cost-benefit analysis of smart meter deployment in a large utility company and found that while there were initial investment costs, the long-term benefits in terms of operational efficiency, accurate billing, and reduced meter reading expenses outweighed the upfront expenses. Consumers need to assess potential energy savings and long-term cost-effectiveness, while utility providers must consider investment costs and benefits in terms of operational efficiency and grid management. Understanding financial implications from various perspectives is essential for informed decision-making regarding smart meter adoption.

Regulatory policies and government support play a significant role in driving smart meter adoption. Yang et al. [27] highlights the importance of government policies and regulations that promote and incentivize deployment of smart meters. These policies can include financial incentives, regulatory frameworks, and mandates that encourage utilities and consumers to embrace smart metering technologies. Subhash and Rajagopal [14] emphasize the role of government regulations and incentives in shaping the landscape of smart meter deployment. Their study examined impact of regulatory mandates on smart meter adoption in different countries and found that countries with supportive policies experienced higher rates of adoption. Supportive policies can create a favorable environment for utilities to invest in smart meters, and regulatory mandates can drive the adoption of the technology. Moreover, government initiatives to provide subsidies or incentives for consumers to adopt smart meters can accelerate their uptake.

Consumer awareness, education, and acceptance are crucial factors in smart meter adoption. Opriş et al. [16] emphasize importance of consumer knowledge and awareness of smart meters as a need for consumers to actively engage in the planning process of smart meter implementation, as their involvement leads to better acceptance and adoption of the technology and lack of information or misconceptions can hinder adoption. Their study found that consumers who were well-informed about functionalities and benefits of smart meters were more likely to adopt them. Educating consumers about benefits, functionalities, and potential cost savings of smart meters through targeted campaigns and educational programs can enhance their acceptance and willingness for adoption. Moreover, educating consumers about benefits and functionality of smart meters, addressing privacy and security concerns, and providing clear communication regarding data usage and control can enhance consumer acceptance and adoption rates [19].

Technical considerations are crucial in successful implementation of smart meters. Compatibility and integration of smart meters with existing infrastructure and communication technologies are important factors to ensure seamless operation. Subhash and Rajagopal [14] highlight the significance of technical feasibility, including network connectivity and interoperability, in determining effectiveness of smart meter deployment. Their study emphasizes the need for robust communication protocols and standardized interfaces to facilitate integration of smart meters into existing energy infrastructure. Compatibility with different communication technologies, such as wire-less networks or powerline communication, should also be considered to ensure reliable data transmission. Furthermore, ongoing research and development are necessary to improve interoperability and scalability of smart meters, ensuring their compatibility with future advancements in energy management systems and smart grid technologies.

Socio-economic factors also play a role in smart meter adoption. Bugden and Stedman [23] mention that factors such as familiarity, age, and income level influence consumer acceptance of smart meters. Their study conducted a survey among residential consumers and found that younger generations, particularly the Web 2.0 generation, were more receptive to technological advancements and may embrace smart meters more readily. Additionally, income levels can affect affordability of smart meters and influence consumer decision-making. Utility companies and policymakers need to consider the socio-economic context and potential disparities in access to smart meters to ensure equitable deployment and adoption.

Furthermore, presence of supportive infrastructure and stakeholder collaboration are important factors in facilitating smart meter adoption. Pullinger et al. [24] highlight the significance of establishing a robust communication network and backend systems to support functionalities of smart meters. Additionally, effective collaboration between utility providers, regulators, and technology vendors is crucial for successful implementation. This collaboration can ensure alignment of goals, address regulatory requirements, and streamline the deployment process. A summary of factors is shown in Table 3.

Table 3. Factors influencing smart meter implementation and awareness

Economic Incentives
Economic incentives, consumer education, and regulatory policies promote adoption [12]
Familiarity with technology and positive attitudes towards smart meters drive acceptance [26]
Cost-benefit analysis influences consumer willingness to adopt smart meters [27]
Cost-Benefit Analysis
Long-term cost savings, operational efficiencies, and potential financial benefits influence adoption [24]
Regulatory Policies ([27]
Government policies, regulations, and mandates drive smart meter adoption [14, 27]
Consumer Awareness
Consumer knowledge and awareness positively impact acceptance [16]
Educating consumers about benefits, functionalities, and cost savings enhances acceptance [15, 16]
Technical Considerations
Technical feasibility, compatibility, and interoperability are crucial for successful implementation [14]
Socio-Economic Factors
Factors such as familiarity, age, and income level influence acceptance [23]
Socio-economic context and disparities in access should be considered [23]
Supportive Infrastructure
Robust communication network and backend systems are essential [24]
Stakeholder collaboration facilitates successful implementation [24]

4 Analyzing Scoping Review Themes on Smart Meters

This scoping review provided an overview of literature on smart metering systems, with a focus on functionality and non-functionality, benefits and drawbacks, factors influencing adoption, and associated policies and technologies. We were able to identify several key themes that emerged from the scoping review as presented in Tables 1, 2 and 3.

To begin, according to the review, functional expectations for smart meters include real-time measurement, remote monitoring, two-way communication, and integration with other systems, while non-functional expectations include security, privacy, dependability, and compatibility. According to the literature, smart meters can provide real-time information on energy consumption, allowing consumers to monitor and adjust their behavior accordingly. Remote monitoring allows energy providers to manage energy supply and demand more effectively, resulting in increased efficiency and cost savings. Two-way communication enables more precise energy management and integration of other systems, such as renewable energy sources.

Second, while smart meters provide benefits such as increased accuracy, better energy management, and increased efficiency, they also have drawbacks such as privacy concerns, implementation costs, and compatibility issues. These drawbacks are mainly associated with the lack of functionality of smart meters. Smart meters' accuracy enables more precise billing and better energy management, resulting in cost savings. However, implementation costs can be high, and there may be compatibility issues when integrating with existing infrastructure. Concerns about privacy are also a significant disadvantage, as sharing detailed energy use data can reveal information about people's personal lives and infringe on their sense of autonomy, choice, and control.

Third, regulatory requirements, consumer education, and cost, as well as familiarity, perceptions of climate change risk, smart meter acceptance, age, and other factors, all influence smart meter implementation and awareness. Smart metering system implementation and consumers awareness can be influenced by policies and regulations. Consumer education is also essential for raising awareness and understanding of advantages and disadvantages of smart meters. Another important consideration is cost, as smart meters can be prohibitively expensive for some consumers. Other factors influencing adoption include familiarity with technology, perceptions of the risk of climate change, and age.

Fourth, smart metering system design, hardware, software, and communication protocols are critical components of the smart grid, and data security and privacy issues must be addressed by implementing appropriate communication protocols and technological solutions. Smart metering system design and components must be robust and reliable, and communication protocols must be secure to ensure privacy and prevent cyberattacks. Data security and privacy are critical issues that must be addressed with appropriate technological solutions.

Finally, user perceptions and acceptance are critical for smart meter implementation success, and policymakers must consider these factors when promoting their adoption. In countries like Sweden, where smart meters have been mandated, these considerations should be measured in order to raise consumer awareness levels and promote better utilization. Building user trust is critical for addressing privacy concerns and encouraging participation in smart local energy systems. End-user engagement is critical for smart metering success, especially in terms of consumers' social, economic, and behavioral factors. Consumer education and awareness are also critical for increasing acceptance and understanding of the benefits and drawbacks of smart meters.

5 Discussing Identified Research Gaps

This study was an attempt to provide a comprehensive overview of existing research on smart meter technology while identifying any gaps and limitations, particularly concerning the connection between smart meter literature and consumer perceptions. Our primary objective was to delve into the consumer perspective by exploring their expectations, benefits, drawbacks, and adoption factors related to smart meters. Through our investigation, we aimed to pinpoint any gaps in the current literature. However, our findings highlighted a significant oversight in understanding how consumers perceive smart meters, their user experience, and the overall significance of incorporating the consumers' viewpoint into this technology. This led us to identify a notable research gap, wherein the dominance of a top-down approach and policymakers' perspective in smart meter literature primarily focuses on the functional aspects of the technology. Insufficient attention has been devoted to exploring consumers' perceptions, user experience, and the crucial importance of understanding their perspective within the realm of smart meters.

It is important to explore smart meters from a user perspective to understand what factors influence awareness and interactions between consumers and smart meters.

Addressing these research gaps will contribute to a more comprehensive understanding of smart metering systems, their implementation, and their impact on energy consumption, consumer behavior, and the overall energy landscape. It will also provide insights and recommendations for policymakers, utilities, and researchers to maximize the benefits and address the challenges associated when implementing smart meters.

While literature provides valuable insights into functional and non-functional expectations, benefits and drawbacks, and factors influencing smart meter implementation there are several research gaps that need to be addressed. Firstly, there is a need for further investigation into the long-term performance and reliability of smart meters. While studies have explored functional expectations of smart meters, there is a lack of comprehensive analysis on their durability and accuracy over extended periods. Research could focus on assessing the longevity of smart meters in real-world scenarios, considering factors such as environmental conditions, maintenance requirements, and technological obsolescence. This creates a need for more research on the long-term behavioral changes and energy-saving outcomes resulting from smart meter implementation. While studies highlight the potential for energy savings, more research is needed to understand the sustained impact and effectiveness of smart meters in promoting long-term energy efficiency.

Secondly, the social, cultural and psychological factors that impact smart meter adoption/utilization require deeper exploration. While studies have discussed the benefits and drawbacks of smart meters, there is limited understanding of how individuals and communities perceive and experience these technologies. Future research could investigate the psychological factors influencing consumer acceptance and engagement with smart meters, including factors such as privacy concerns, trust, and the impact on energy-saving behaviors. Understanding how social norms, beliefs, and attitudes influence consumer acceptance, adoption and utilization of smart meters can provide valuable insights for designing effective communication and engagement strategies.

Thirdly, literature reveals a lack of comprehensive studies focusing on specific needs and requirements of different consumer segments. While benefits of smart meters for individual consumers and utility companies have been well-documented, there is a lack of research on impact of widespread smart meter adoption on the overall energy grid and energy systems. Therefore, more research is needed to understand broader systemic effects of smart meter implementation. Yesudas [17] highlights the importance of identifying consumer segments based on their energy behaviors and requirements to tailor smart metering strategies accordingly. Future research should address the diverse needs of various consumer groups, including low-income households, elderly individuals, and those with special energy requirements. Future studies could also focus on analyzing implications of smart meters on grid stability, energy demand patterns, and integration of renewable energy sources at a larger scale.

There is also a critical need for continuous evaluation and improvement of privacy and data security measures in smart metering systems. Given the evolving nature of technology and potential cybersecurity threats, ongoing research and development should focus on enhancing the privacy and security features of smart metering systems. This includes exploring advanced encryption methods, robust authentication mechanisms, and establishing clear guidelines and regulations for data collection, storage, and usage.

Furthermore, additional research is needed to assess the economic viability and cost-effectiveness of smart metering systems in different contexts. Cost-benefit analysis should consider not only immediate financial implications but also long-term benefits in terms of energy savings, grid stability, and environmental impact.

Moreover, in terms of smart meter literature, more studies are required from a consumer perspective to enrich literature and control its dominant nature discussing smart meters based on a top-down approach to a well-balanced one where it also discusses smart meters from a user level approach.

Additionally, there is a need for research that examines the specific challenges and opportunities of smart meter adoption in different geographical contexts and socioeconomic settings. Studies have primarily focused on developed countries, and there is limited research on the unique challenges faced by developing regions in implementing smart metering systems. The literature would benefit from more comparative studies that analyze experiences from different countries or regions in implementing smart metering programs. Such studies can shed light on the contextual factors, policy frameworks, and regulatory approaches that contribute to successful smart meter adoption and identify best practices that can be shared and replicated. Future research could investigate cultural, economic, and infrastructural factors that influence smart meter implementation in diverse contexts.

Finally, the role of stakeholders, such as policymakers, regulators, and energy service providers, in facilitating smart meter adoption warrants further investigation. Understanding the dynamics and interactions among various stakeholders is crucial for effective policy formulation and implementation. Future studies could explore the decision-making processes, policy frameworks, and collaborative approaches that support successful smart meter deployment and adoption.

A summary of the key points and gaps in knowledge regarding smart meter implementation is presented in Table 4.

Table 4. Summary of key points and knowledge gaps

Key points
Valuable literature on requirements, benefits, drawbacks & adoption factors
Smart meters offer real-time measurement, remote monitoring, & improved efficiency
Drawbacks include privacy concerns, implementation costs,& compatibility issues
Adoption influenced by regulatory requirements, consumer education, cost, familiarity
Design, hardware, software, and communication protocols are critical for smart meters
Gaps in Knowledge
Long-term performance and reliability of smart meters
Social, cultural, and psychological factors impacting adoption
Specific needs of different consumer segments and broader systemic effects
Continuous evaluation and improvement of privacy and data security
Economic viability and cost-effectiveness in different contexts

6 Concluding Remarks

This scoping review gave a thorough assessment of the literature on smart meters. It has emphasized the potential benefits and downsides of smart meters, as well as the factors that impact their acceptance. It has identified crucial smart grid components as well as data security and privacy issues that must be addressed for the successful implementation of smart meters. When supporting the use of smart meters, policymakers must consider user views and acceptability, because creating user trust is crucial for addressing privacy concerns and encouraging participation. Energy providers can employ smart meters to better control energy supply and demand, resulting in enhanced efficiency and cost savings. Future research should address privacy and security problems, interoperability challenges, and customer acceptance to assure the successful implementation of smart meters and the realization of their potential benefits.

This study identified major gaps in smart meter literature especially in terms of how consumers perceive smart meters. This scoping review has provided a comprehensive analysis of the existing literature, providing a solid base and a good understanding to conduct further investigation that will offer further insights into the perspectives of smart meter consumers in the real world.

The potential results of a larger study could provide significant insights into the expectations, benefits, and drawbacks of smart meters, as well as the factors influencing smart meters implementation and awareness. Future research in line with findings from this study will be valuable to policymakers, industry stakeholders, and researchers in the field of information systems, and will contribute to a better understanding of the implementation, awareness and use of smart metering systems.

Acknowledgement. This work has been conducted within the program "Resistance and Effect – on the smart grid for the many people" funded by the Kamprad Family Foundation.

References

1. Mohassel, R.R., et al.: A survey on advanced metering infrastructure. Int. J. Electr. Power Energy Syst. **63**, 473–484 (2014)
2. Ehrhardt-Martinez, K., Donnelly, K.A., Laitner, S.: Advanced metering initiatives and residential feedback programs: a meta-review for household electricity-saving opportunities. American Council for an Energy-Efficient Economy Washington, DC (2010)
3. Barai, G.R., Krishnan, S., Venkatesh, B.: Smart metering and functionalities of smart meters in smart grid-a review. In: 2015 IEEE Electrical Power and Energy Conference (EPEC). IEEE (2015)
4. Corbett, J., Wardle, K., Chen, C.: Toward a sustainable modern electricity grid: the effects of smart metering and program investments on demand-side management performance in the US electricity sector 2009–2012. IEEE Trans. Eng. Manag. **65**(2), 252–263 (2018)
5. Anda, M., Temmen, J.: Smart metering for residential energy efficiency: the use of community based social marketing for behavioural change and smart grid introduction. Renew. Energy **67**, 119–127 (2014)
6. Huang, Y., et al.: Smart meters in Sweden-lessons learned and new regulations. Current Futur. Chall. Energy Secur. **177** (2018)
7. (EIA), U.S.E.I.A. Frequently asked questions (faqs) (2022). https://www.eia.gov/tools/faqs/faq.php?id=108&t=3. Accessed 12 Mar 2023
8. McCann, K.: Germany moves to make smart metering rollout mandatory by 2025 (2023). https://www.iotinsider.com/smart-cities/germany-moves-to-make-smart-metering-rollout-mandatory-by-2025. Accessed 12 Mar 2023
9. Gov.uk, Statutory framework for the Early Years foundation stage - gov.uk. 2021
10. Arksey, H., O'Malley, L.: Scoping studies: towards a methodological framework. Int. J. Soc. Res. Methodol. **8**(1), 19–32 (2005)
11. Levac, D., Colquhoun, H., O'Brien, K.K.: Scoping studies: advancing the methodology. Implement. Sci. **5**, 1–9 (2010)
12. Bahmanyar, A., et al. Emerging smart meters in electrical distribution systems: opportunities and challenges. In: 2016 24th Iranian Conference on Electrical Engineering (ICEE). IEEE (2016)
13. Chakraborty, A.K., Sharma, N.: Advanced metering infrastructure: technology and challenges. In: 2016 IEEE/PES Transmission and Distribution Conference and Exposition (T&D). IEEE (2016)
14. Subhash, B., Rajagopal, V.: Overview of smart metering system in Smart Grid scenario. In: 2014 Power and Energy Systems Conference: Towards Sustainable Energy, PESTSE 2014 (2014)
15. Yesudas, R., Clarke, R.: Consumer concerns about smart meters. In: Streitz, N., Markopoulos, P. (eds.) Distributed, Ambient, and Pervasive Interactions. DAPI 2015. LNCS, vol. 9189, pp. 625–635. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-20804-6_57

16. Opriş, I., et al.: The household energy consumer in a smart metering environment. In: 2015 9th International Symposium on Advanced Topics in Electrical Engineering (ATEE). IEEE (2015)
17. Yesudas, R.: A consumer friendly framework for smart grid initiatives. In: TENCON 2015–2015 IEEE Region 10 Conference. IEEE (2015)
18. Yesudas, R., Clarke, R.: Architecture and data flow model for consumer-oriented smart meter design (2014)
19. Yesudas, R., Clarke, R.: Identifying consumer requirements as an antidote to resistance to smart meters. In: IEEE PES Innovative Smart Grid Technologies Conference Europe (2015)
20. Freitas, J., et al.: Smart electricity metering systems for smart grids: technologies, choices, and deployment experiences. In: 2021 IEEE PES Innovative Smart Grid Technologies Conference-Latin America (ISGT Latin America). IEEE (2021)
21. Opriş, I., Caracasian, L.: On the implementation of the functionalities of smart metering systems. In: 2013 8Th International Symposium on Advanced Topics in Electrical Engineering (Atee). IEEE (2013)
22. Malik, J.S., Verma, R.K., Gupta, G.: Development of smart meter. In: 2015 4th International Conference on Reliability, Infocom Technologies and Optimization: Trends and Future Directions, ICRITO 2015 (2015)
23. Bugden, D., Stedman, R.: A synthetic view of acceptance and engagement with smart meters in the United States. Energy Res. Soc. Sci. **47**, 137–145 (2019)
24. Pullinger, M., Lovell, H., Webb, J.: Influencing household energy practices: a critical review of UK smart metering standards and commercial feedback devices. Technol. Anal. Strateg. Manag. **26**(10), 1144–1162 (2014)
25. Vigurs, C., et al.: Customer privacy concerns as a barrier to sharing data about energy use in smart local energy systems: a rapid realist review. Energies **14**(5), 1285 (2021)
26. Gumz, J., Fettermann, D.C.: Better deployments come with acceptance: an investigation of factors driving consumers' acceptance of smart meters. Current Sustain. Renew. Energy Rep. 1–13 (2023)
27. Yang, B., et al.: Smart metering and systems for low-energy households: challenges, issues and benefits. Adv. Build. Energy Res. **13**(1), 80–100 (2019)