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Work in Progress -Potential Use Cases of Digital Twins for Prosumers in the Electricity Sector

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Abstract

The electricity sector is currently undergoing a significant transformation, accompanied by a multitude of challenges. The digital transformation is driven by various technologies that might be a solution to some of the challenges. Furthermore, prosumers, that are both consumers and producers, play an integral part within the energy transition. This article explores the use cases of digital twins for prosumers in the electricity sector, that might be a solution for some of the challenges, the electricity sector is facing now. The research is grounded in the design science research methodology, in which a literature review was conducted to generate the results.

Keywords: Digital twin; Prosumer; Energy sector; Complex 3D model; Electricity sector

Abbreviations: V2G: Vehicle-to-Grid; AISeL: Association for Information Systems eLibrary; IEEE: Institute of Electrical and Electronical Engineers

Introduction

The energy sector is currently navigating through a period marked by various changes and challenges. Important examples are the energy transition to renewable energy [1,2], the implementation of Smart Grid Concepts [3] or Vehicle-to-Grid (V2G) concepts [3] and their consequences for the grid. The electricity market has undergone substantial transformations in recent years, starting with transitioning from fossil fuels to renewable energies and experiencing an increasing integration of electric vehicles. These developments entail the need for advanced technologies to address the challenges that are accompanying these transformations. The digital transformation can fundamentally alter how we consume and utilize energy. Particularly in the field of electricity, the concept of the "digital twin" has proven to be an effective solution for increasing efficiency and reducing costs. Digital Twins are virtual models of real objects or systems that allow their behaviour and performance to be simulated under various conditions. In the context of electricity, they can aid in optimizing energy consumption, improving energy supply reliability, and promoting the integration of renewable energies. In this article, we examine the application areas of digital twins in the electricity market, particularly for prosumers. We will provide a comprehensive overview of the current application areas of digital twins in the electricity market, including their role in enhancing energy efficiency, promoting renewable energies, and supporting prosumers.

Scope of the Paper

The energy sector encompasses a wide range of entities. Beyond the electricity sector, it encompasses the supply of gas, heating, and cooling [4]. Within each of these sectors, a multitude of different market roles exist [5]. Moreover, within this intricate landscape, the digital transformation emerges as a comprehensive topic, encapsulating a multitude of subtopics. Due to the outlined complexities, the first step towards the presented analysis was the narrowing and specification of its focus. The specification of the topic underwent a three-step process:

i. Initially, we focused our analysis to the electricity sector.

ii. In a second step, we analysed the roles. Market roles in the electricity sector are, for instance, the supplier, the grid operator, the metering point operator and the data provider etc. [5]. We decided to focus on the prosumer as an emerging market role. Within the energy transition, prosumers have become increasingly important. Prosumers combine the roles of a producer and a consumer to a new role capable of producing and consuming energy/electricity. The role of a prosumer enables former consumers to participate actively in the energy market. This is essential for the energy transition and important to reach the climate protection goals [6].

iii. In the third step, the focus transitioned to the digital transformation, with this paper exclusively examining the technology of the digital twin. The digital twin is one of the major technologies of the digital transformation. While various and varying definitions of the digital twin exist, these definitions all agree on a digital twin as a virtual representation of a physical asset or process [7]. The content of the virtual representation, whether it's a single value, an entire set of real-time values or a complex 3D model, depends on the specific definition and use case intended for the digital twin. The chapter "Results and Discussion" shows different characteristics of digital twins in the electricity sector. Due to the digital twins' ability to combine real-time data from smart meters and other sources to create a single reliable information source for the prosumer, their use leads to a better understanding and controlling of the prosumers' energy needs. This leads to increased autonomy of the prosumer and a more significant commitment to renewable energies.

Therefore, the conceptual background of the potential use cases of digital twins for prosumers in the electricity sector is based on two assumptions:

i. The first assumption is that the energy sector, and specifically the electricity industry, faces some significant challenges. This assumption gets supported by a recent literature review in the databases of the "Association for Information Systems eLibrary" (AISeL) and the "Institute of Electrical and Electronical Engineers" (IEEE). Those databases were selected because they are two major databases within the field of information systems. The primary focus in the literature search was set on conference papers and journal articles published in 2023. The search was conducted with the same terms ("energy industry" and "energy sector") in both databases (AISeL and IEEE), and each search was conducted once without and once with the additional search term "challenges". The results show that within the AISeL database, most hits deal with challenges (314 out of 353 and 212 out of 229). Within the IEEE database, that share is smaller (992 out of 5430 and 412 out of 1617). Nevertheless, the challenges are sufficiently addressed. These results support the current significance of the energy sector's challenges. The search terms and hits can be viewed in Table 1.

ii. The second assumption is that it is possible to achieve future-proof value creation over different sectors through digital transformation. The digital twin is one technology within the digital transformation [7,8]. The digital twin might solve some of the problems the electricity industry faces. As already laid out, there are many different definitions of the term "digital twin". As a part of the research, we conducted a literature review of the different types of digital twins in the electricity sector.

Derivation of Potential Use Cases of Digital Twins in the Electricity Sector

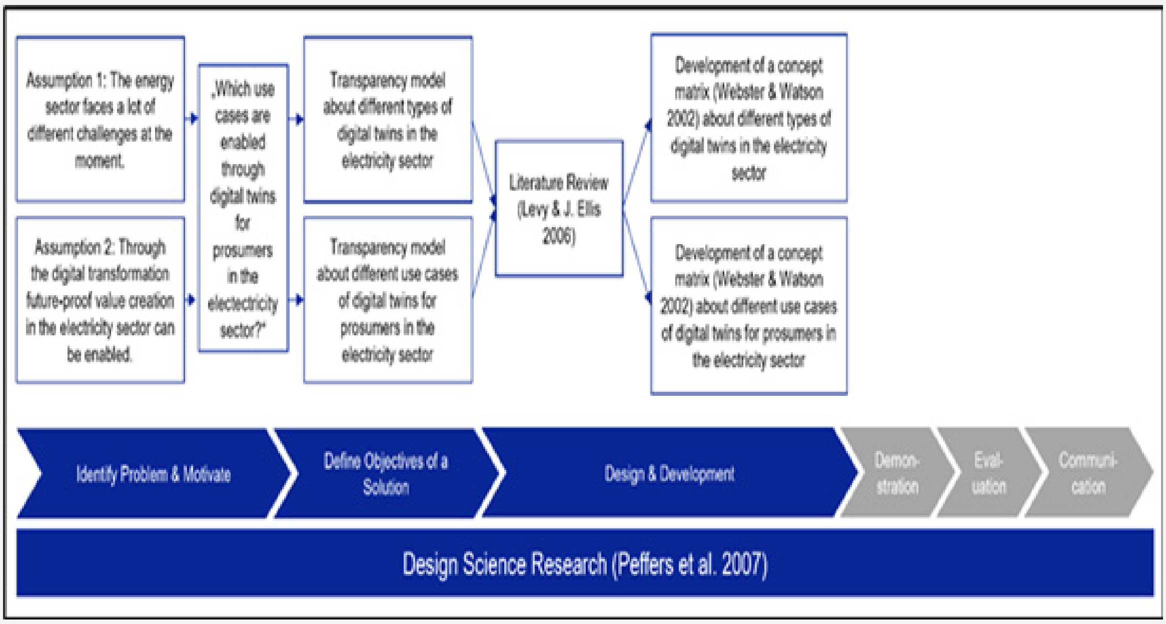

Figure 1: Methodological approach this of the literature review.

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To find out more about the potential use cases of digital twins for prosumers in the electricity sector the authors conducted literature research. The literature research was based on first three steps of the Design Science Research Methodology [9]. 1) Identify Problem & Motivate, 2) Define Objectives of a Solution, 3) Design & Development. The research process is depicted in Figure 1.

i. **Step 1:** The problem identification and motivation are based on the two assumptions described in the previous chapter. The research question was defined based on these assumptions. It follows: "Which use cases enable digital twins for prosumers in the electricity sector?"

ii. **Step 2:** After defining the research question, the objectives of a solution were determined. They consist of two transparency models—the first deals with different types of digital twins in the electricity sector. The second model shows different use cases of digital twins for electricity consumers.

iii. **Step 3:** A literature review was conducted to answer this question, according to Levy und J. Ellis [10]. The authors conducted a keyword search, as shown in Table 2. During the literature search process, saturation (in the used databases and with the used search terms) was achieved. The number of newfound literatures was decreasing tremendously, and at that point, the author decided to finish the literature search.

After finishing the literature search the hits were selected by title and keywords to determine which articles might be relevant to answer the research question. They were considered as relevant if the title or the keywords included terms like "digital twin", "prosumer" and "electricity sector" or terms that can be seen as synonyms. Thus, resulted in 26 articles of which we reviewed the abstracts with the research question in mind. The decision of classifying a paper as relevant was based on whether an answer to our research question was available in the abstract The final selection of the seven remaining articles is shown in Table 3.

Results and Discussion

Based on the results of the review of the articles presented in Table 3, two concept matrices were developed. The first concept matrix answers the question of which types of digital twins can be identified in the electricity sector (Table 4). One major characteristic that was mentioned by five out of seven authors is "real time/live data". All the other characteristics, apart from "historic data" were mentioned twice. This supports that "real time/live data" is a main characteristic of digital twins in the electricity sector. "Historic data" seems less important as it was only mentioned once. The abilities to have a "realistic visualisation", a "physical-based model", the "same behaviour as the real asset" and the ability to "control the real asset" seem more important as they are mentioned twice and in different combinations with other characteristics - supposedly based on different use cases. The following overview in Table 4 shows characteristics found in the given literature and is solely focused on the electricity sector – hereby we do not claim to be exhaustive. The second concept matrix shows different use cases for prosumers in the electricity sector that are enabled through different forms of digital twins (Table 5). For some of those use cases some specific characteristics of the digital twin may be needed. In addition, it is possible to combine different use cases and enable them with the same digital twin.

Table 1: Short literature review to support the first assumption.

Database	Search	Year	Hits	Conference papers	Journal articles
AISeL	challenges energy industry	2023	314	97	65
AISeL	energy industry	2023	353	113	70
AISeL	challenges energy sector	2023	212	65	38
AISeL	energy sector	2023	229	73	38
IEEE	challenges energy industry	2023	992	511	349
IEEE	energy industry	2023	5.43	2.881	1.917
IEEE	challenges energy sector	2023	412	298	61
IEEE	energy sector	2023	1.617	1.235	231

Table 2: Literature search in this research.

Database	Search	Coverage	Hits	Reviewed
AISeL	energy prosumer digital twin		2	1
	prosumer digital twin		3	1
	prosumer electricity	2023	6	1
	prosumer electricity digital twin		2	1
	prosumer energy market	2023	7	1
	prosumer energy market digital twin		1	1

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IEEE	energy prosumer digital twin	2019 - 2023	13	8
	prosumer digital twin	2019 - 2023	14	8
	prosumer electricity	2019 - 2023	947	0
	prosumer electricity digital twin	2019 - 2023	7	3
	prosumer energy market	2019 - 2023	814	0
	prosumer energy market digital twin	2019 - 2023	4	1
Total			1820	26
Without duplicates			-	12
relevant			-	7

Table 3: Literature list after removing duplicates.

Author	Title	Year	Relevant
Adu-Kankam, Kankam O.; Camarinha-Matos, Luis M.	Modelling “Delegated Autonomy” in Cognitive Household Digital Twins	[11]	No
Andryushkevich, Sergey K.; Kovalyov, Serve P.; Nefedov, Evgeny	Composition and Application of Power System Digital Twins Based on Ontological Modeling	[12]	Yes
Bluhm, Saskia; Staudt, Philipp; Weinhardt, Christof	Ensuring Energy Affordability through Digital Technology: A Research Model and Intervention Design	[13]	No
Idrisov, Ildar; Veretennikov, Ilya; Vasilev, Stepan; Gutierrez, Sebastian; Ibanez, Federico	Microgrid Digital Twin Application for Future Virtual Power Plants	[14]	Yes
Kannari, Lotta; Piira, Kalevi; Biström, Henri	Energy-data-related digital twin for office building and data centre complex	[15]	Yes
Mohammadi, Fazel; Saif, Mahrdad	Blockchain Technology in Modern Power Systems	[16]	No
Moussa, Sonia; Slama-Belkhodja, Ilhem	HIL-based Digital Twin of Grid-connected Prosumer of a LVAC Residential Microgrid	[17]	Yes
Sangeeth L R, Silpa; Mathew, Saji K.; Potdor, Vidyasagar	Information Processing view of Electricity Demand Response Systems: A Comparative Study Between India and Australia	[18]	No
Testasecca, Tancredi; Lazzaro, Marilena; Sirchia, Antonino	Towards Digital Twins of buildings and smart energy net-works: Current and future trends	[19]	Yes
Tsado, Yakubu; Jogunola, Olamide; Olatunji, Femi O.; Adebisi, Barmidele	A Digital Twin Integrated Cyber-Physical Systems for Commu-nity Energy Trading	[20]	Yes
Urbano, Eva M ; Martínez-Viol, Víctor; Romeral, Luis	Optimization of industrial plants for exploiting energy assets and energy trading	[21]	Yes
Xiong, Gang; Tamir, Tariku Sinshaw; Shen, Zhen; Shang, Xiuqin; Wu, Huaiyu; Wang, Fei-Yue	A Survey on Social Manufacturing: A Paradigm Shift for Smart Prosumers	[22]	No

Table 4: Concept matrix of different characteristics of digital twins.

	real time/ live data	historic data	realistic visualisation	physical-based models	same behavior as the real asset	controls the real asset
Andryushkevich et al. [12]	x				x	
Idrisov et al. [14]	x					x
Kannari et al. [15]			x		x	
Moussa and Sla-ma-Belkhodja [17]	x			x		
Testasecca et al. [19]	x	x	x	x		
Tsado et al. [20]	x					x
Urbano et al. [21]						

Table 5: Concept matrix concerning use cases of digital twins for prosumers in the electricity sector.

	planning	development	forecasting	predictive monitoring	simulation	evaluation	calibration of models	verification of models	testing	visualising	performance improvement	training	energy management	management support	real-time control
Andryushkevich et al. [12]		x	x	X		X	x	X	x			x			
Idrisov et al. [14]											x			x	x
Kannari et al. [15]			x							x			x		
Moussa and Slama-Belkhodja [17]					x						x				
Testasecca et al. [19]	x													x	
Tsado et al. [20]		x			x				x						
Urbano et al. [21]											x		x		

The overview in Table 5 illustrates the use cases extracted from the literature and is focused on prosumers in the electricity sector - as before, we do not claim to be exhaustive. The number of use cases for prosumers in the electricity sector enabled through digital twins shows a wide variety. Most use cases are only described in one or two of the reviewed articles. This underlines that the scientific interest in the topic is just emerging. "Performance improvement" is an exception as it is mentioned by three authors. Performance improvement seems to be a more important use case for the digital twin, but it is also rather unspecific and can possibly be achieved in more than one way. Moreover, Andryushkevich et al. [12] highlight a substantial potential in the digital twin for prosumers in the electricity sector by delineating eight distinct use cases. In contrast, other authors present only two or three use cases, suggesting a more modest outlook on the potential of the digital twin for prosumers in the electricity sector. In summary, the reviewed literature indicates a variety of digital twin types designed to facilitate diverse use cases for prosumers in the electricity sector [23]. It seems that it is a current topic in which many different approaches exist, and it remains unclear which ones hold the most promise. This underscores the relevance for further research in this field.

Next Steps

This paper explores the application of digital twins in the electricity sector, with a particular focus on prosumers. The electricity sector is undergoing significant changes and requires advanced technologies to address these challenges. Based on the information provided, the following steps could be considered for future work: Conduct further literature reviews: A more comprehensive literature review should be conducted to gain a deeper understanding of the current state of digital twins in the electricity sector. The literature review, which focuses primarily on information systems, should be significantly expanded, and broadened to include other scientific disciplines. This would provide a broader perspective on the potential of digital twins in the electricity sector.

In conclusion, the literature reviewed suggests different types of digital twins designed to facilitate different use cases for prosumers in the electricity sector. However, it remains to be seen which is the most promising, highlighting the need for further research in this area. In addition to a pure literature analysis, the following steps seem necessary. Real-world implementation and testing: Once a clear understanding of the potential use cases and benefits of digital twins in the electricity sector has been established, the next logical step would be to implement these technologies in real-world settings. This could involve setting up pilot projects or trials to assess the practical feasibility and effectiveness of using digital twins in the electricity sector. Working with industry experts: Given the complex nature of the electricity sector and the technical requirements for implementing digital twins, it would be beneficial to collaborate with industry experts. This could include partnering with companies that specialise in digital twins or reaching out to professionals in the energy sector for their insights and expertise. Develop user interfaces and tools: As part of the implementation phase, it would be crucial to develop user interfaces and tools that make it easier for prosumers to

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interact with digital twins. This could include the development of software applications or web-based platforms that allow users to easily access and control digital twins. Monitoring and evaluation: Once digital twins have been implemented, ongoing monitoring and evaluation would be needed to ensure their effectiveness and identify areas for improvement. This could include tracking key performance indicators, collecting user feedback and regularly updating the digital twins to reflect changes in the electricity sector.

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