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Structuring The Digital Energy Platform Jungle: Development Of A Multi-Layer Taxonomy And Implications For Practice

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Abstract

Rising and volatile energy prices are forcing production companies to optimize their consumption patterns and reduce carbon emissions to remain competitive. Demand-side management (DSM) or energy flexibility (EF) is a promising option for the active management of electricity demand. With DSM, energy procurement costs can be effectively reduced, for example, by reducing peak loads and taking advantage of volatile energy prices. In addition, renewable energies can be better integrated to reduce carbon emissions while stabilizing the power grid. Although the benefits of DSM for production companies are well known, implementation is not yet widespread. A key barrier is the high requirements of IT systems and the associated effort and complexity involved in setting them up. Companies often lack appropriate IT systems or have historically grown systems that do not allow continuous communication from the machine to the energy market. A variety of different platforms promise solutions to address these challenges. However, when selecting platforms, it is often unclear which aspects and functionalities of a platform are relevant for a company's specific application. To address this gap, we developed a multi-layer taxonomy of digital platforms for energy-related applications in the industry that includes a general, as well as a more specific data-centric and transaction-centric perspective. We develop, revise, and evaluate our taxonomy using insights from literature and analysis of 46 commercially available platforms or platforms developed through research projects. Based on our taxonomy, we derive implications for research and practice. Our results contribute to the descriptive knowledge of digital platforms in energy-related applications. Our taxonomy enables researchers and practitioners to classify such platforms and make informed decisions about their deployment.

Keywords

Digital Platform; Taxonomy; Demand-Side-Management; Energy Flexibility; IT Systems

1. Introduction

Adverse effects of human-induced climate change afford targeted and effective measures for achieving the climate goals set out in the international climate agreements [1]. The phase-out of coal and nuclear power generation was adopted as a key measure by the German government [2]. To meet electricity demand, the share of electricity generation from renewable energy sources is expected to increase to 80% of electricity consumption by 2050 [3]. This shift in the electricity generation portfolio will pose major challenges for power grids, and price volatility is expected to increase significantly [4]. The highly fluctuating, weather-dependent electricity generation from renewable energy sources such as wind and solar power, which is only adaptable to a limited extent, requires new solutions for a secure electricity supply. Besides the expansion of power grids, the increase of storage capacities, and the use of potentials of sector coupling, demand-side management (DSM) offers a competitive solution to address the expected challenges by increasing the energy flexibility of the demand side [5]. Considering that the industrial sector accounts for almost 44% of electricity consumption in Germany, it offers significant potential for balancing fluctuations in the power grid by adjusting electricity consumption to the electricity supply [6]. Typically, energy-intensive industrial companies can shut down, shift, or regulate their (production) processes and plants deviating from their regular use in order to adjust their electricity demand [7]. With DSM, companies can benefit from reduced energy procurement costs by responding to volatile electricity prices or lowering their grid charges by avoiding peak loads [6]. While companies benefit monetarily from DSM, they moreover support the integration of renewable energy by adjusting power consumption to minimize carbon emissions while stabilizing the power grid [8]. Although the benefits of DSM for production companies are well known, implementation is not yet widespread, and concerns exist [9]. A major obstacle to the implementation of DSM in production companies is the high requirements for IT systems and the associated expense and complexity of setting them up [10]. These high requirements result from information flows beyond company boundaries, the interaction of diverse optimization services, and automation through transparency and standardization of the entire process of energy flexibility marketing [6,11]. Companies often lack appropriate IT systems or have historically grown systems that do not allow them to meet the requirements [12,13]. In addition, continuous communication in an often-heterogeneous IT system landscape is not possible due to a lack of interfaces [6,13]. In the meantime, the market of available platforms has grown considerably, and there are a variety of different platforms that promise (partial) solutions to these challenges [14,10,13]. However, for companies that intend to implement DSM and need to select suitable platform solutions, it is often unclear which aspects and functions of a platform are relevant for them. The evaluation of available platforms is time-consuming, and tools and assistance such as a pre-classification of platforms and their characteristics do not exist. This study, therefore, aims to address this pertinent gap in research and practice.

Therefore, we develop a multi-layer taxonomy of digital platforms for DSM applications in industry that includes a general, as well as a more specific data-centric and transaction-centric perspective. For this purpose, we develop, revise, and evaluate our taxonomy following the iterative multi-step method of Berger et al. [15]. We use insights from literature and analysis of 46 commercially available platforms or platforms developed through research projects. Based on our taxonomy, we derive implications for research and practice contributing to the descriptive knowledge of digital platforms in DSM applications. Our taxonomy enables users to classify such platforms and make informed decisions about their deployment.

2. Background

2.1 Demand-Side Management

The aim of demand-side management (DSM) is the management of demand for grid-based services among consumers in industry, commerce, or private households [16]. DSM generally adjusts the energy demand without having to increase or decrease the energy supply and can therefore be a sufficient solution for the energy transition to decentralized and highly volatile electricity generation [17]. Especially the energy-intensive industries such as metal production, chemicals, or the paper industry offer high potential for industrial DSM since they are responsible for approximately two-thirds of the industrial electricity consumption in Germany [18]. Studies showed that the potential for DSM in energy-intensive processes, e.g., aluminum electrolysis, is remarkable [19]. In addition to reducing energy procurement costs, e.g., by minimizing peak loads or shifting electricity consumption to times with lower electricity prices, the use of flexibility can generate additional benefits and potential revenue streams, such as by offering ancillary services [6]. When operationalizing industrial DSM, the impact of flexibility measures and flexible processes on energy demand and the resulting influences on production systems and schedules must be considered in order to avoid a negative impact on logistical production goals [8]. Flexibility measures can be used at different production system levels and address different business areas and operating resources of a production company. The control of complex processes and flexibility measures therefore requires suitable IT systems that ensure transparency and enable the automation of DSM [6,11].

2.2 Energy Platforms

In recent years, digital platforms have emerged in many business areas to bring customers and providers together and offer innovative services [14]. The term platform is used very frequently, but its meaning is not clear and uniform [20]. IT platforms are already being used today for the digitization and optimization of production. Digital services such as predictive maintenance or the optimization of production planning are used [21]. However, most existing and commercially available IT platforms are tailored to the products and services offered by the respective provider. They tend to use proprietary rather than open interfaces and protocols, forming a closed ecosystem [22]. As a result, neither interactions with external systems nor interoperability with other platform providers are possible. In addition to traditional digital platforms for optimizing production processes regarding logistical targets, many providers offer software products in the area of energy management. These products optimize the energy flow in production processes [23]. Energy management platforms are mostly used for capturing, processing, and monitoring energy flows within a company. Also, decision support systems for energy procurement and optimization are established in the market. The offered services range from electricity market forecasts to solutions for production scheduling optimization considering electricity market prices [24]. To sum up, there are established platforms and IT systems with a strong focus on production (systems) and infrastructure, offering a wide range of possible solutions for companies [13]. Even though there is research on architectural features of industrial Internet of Things platforms [25], on taxonomies of products and platforms for energy feedback technologies [26], or energy-efficient resource management technique taxonomies in platforms as service clouds [27], there is to the best of the authors' knowledge no taxonomy or structuring element in literature that focuses on digital platforms and IT systems for DSM applications in production companies. This study, therefore, aims to contribute to this research vacuum and support companies in practice.

3. Methodological Approach

To address the elaborated gap in research and practice, and to structure the complex and heterogeneous field of digital energy management platforms, the development of a taxonomy is the adequate method. Taxonomies, also referred to as frameworks or typologies, serve to classify objects according to their characteristics and help to better understand, analyze, and structure knowledge and objects [15]. A taxonomy contains various dimensions, which in turn consist of at least two (mutually exclusive) characteristics allowing objects to be classified according to their characteristics. Nickerson et al. [28] proposed a method for developing taxonomies in an iterative process that is now well established, frequently used, and further developed in business information systems research.

For our work, we apply the iterative multi-step method of Berger et al. [15], who extended the method of Nickerson et al. [28] to include validation after taxonomy development. We, therefore, determine the meta-characteristic as well as objective and subjective ending conditions, which serve as an orientation and basis for the taxonomy development, in a first step. In accordance with our research goal, we define the meta-characteristic as "key distinguishing features of energy platforms in terms of their structure and main functions." We adopt the conditions given by Nickerson et al. [28] and Berger et al. [15] as objective ending conditions that must be checked for fulfillment after each iteration of taxonomy development: (1) each characteristic is unique within its dimension, (2) each dimension is unique and not repeated within the taxonomy, and (3) each object has been studied, (4) at least one object must be identified per characteristic and dimension, (5) the characteristics of a dimension are mutually exclusive, (6) no new dimensions or features have been added or changed in the last iteration. For the subjective final conditions, we also followed previous research and decided that the taxonomy must be assumed by all authors to be concise, robust, comprehensive, extendible, and explanatory [28]. In a second step, we develop our taxonomy in four iterative rounds of conceptual-to-empirical and empirical-to-conceptual approaches until all ending conditions are met. Nickerson et al. [28] allow for an iterative combination of conceptual-to-empirical and empirical-to-conceptual approaches during taxonomy creation. Within the conceptual-empirical approach, we elaborate dimensions and their characteristics incorporating findings extracted from a literature review on existing platform research. We thereby test the dimensions and characteristics identified by assigning digital energy platforms to them. For the empirical-conceptual approach, we build on existing commercially available platforms and those available within research projects. First, we group the platforms. Second, we inductively derive the taxonomies dimensions and characteristics. To do so, we conducted online research and identified 163 platforms as a first selection. These include IoT platforms and energy management platforms, as well as aggregators and platforms for trading energy and flexibility. Since it was not possible to include all 163 platforms during the taxonomy creation process, but all platform types still had to be considered equally. A stratified sample selection was performed according to Quatember [29]. In doing so, 46 different platforms were identified, which are listed in Table 1. In our work, we alternate between a conceptual-empirical and an empirical-conceptual approach until in the fourth iteration all ending conditions were met. While conducting the iterations, we found that mutual exclusion of the characteristics is not possible for some dimensions without having to forego relevant information. Therefore, we tried to keep this condition as far as possible and to omit it only for dimensions that absolutely require it. Similar findings have already been made in other works on taxonomy development [30,31].

Table 1: Considered platforms during taxonomy development

Platform type	Platforms
Trading platforms	Cordinet Project, Cornwall Local Energy Market, Electron Platform, ETPA, Flexible Power, FutureFlow, GoFlex, Nextra, Nodes Market, Piclo Flexibility Marketplace, wepower
IoT platforms	AWS IoT Core, Bosch IoT Suite, CELOS, Cloud der Dinge, Connected Factories, Connected Factories 2, Enterprise IoT Platform, FIWARE, Google IoT Core, IBM Watson, ITAC.MES.Suite, LITMUS, OpenIoTFog, Productive 4.0, PTC Thingworx, Siemens Mindsphere, tapio, Virtual FortKnox
Energy management platforms	Bosch Energy Platform, DEXMA Platform, EMPURON EVE, EnCoMOS, ennex OS, ITC Power Commerce EnMS, KMUPlus - Energy Intelligence, opti.node, PHI-Factory, SIMATIC Energy Suite, Smart Energy Hub
Aggregators	Balance Power, BayWa r.e. CLENS, Centrica Business Solutions, e2m, Entelios, Next-Kraftwerke

In a third step, after all, end conditions were met, we validated the developed taxonomy by conducting interviews with eleven collaborators from the Connected Factories, DEXMA, CELOS, Internet of Things, Litmus IoT, Nodes Market, PHI-Factory, Thingworx, SIMATIC Energy Suite, Smart Energy Hub, and tapio platforms and had them categorize their platforms into the taxonomy. No problems occurred during the validation, and all persons were able to fully classify their platforms into the taxonomies. Therefore, the taxonomy could finally be approved, and the creation process completed. We then discussed and derived implications for research and practice in the last step.

4. Results

Using this three-step approach, we identified 15 dimensions with their specific characteristics for digital energy platforms and subdivided them into general, data-centric, and transaction-centric dimensions.

4.1 General Dimension of Energy Platforms

The platforms examined are operated either by an independent company, by a consortium consisting of several companies and institutions, or by an aggregator (*platform operator*). An aggregator administrates a virtual power plant with energy flexibilities of several companies, thereby acts as a third party compared to the first two options. *Access* to the platforms is possible via a web app using any internet browser, a native app installed on hardware, or via specific programming interfaces, via which data can be imported, exported, and exchanged with other systems. Depending on the access design, stronger or weaker lock-in effects may occur. There are various options for the *operational concept*. In on-premise operation, the platform is operated by the customers on their own IT infrastructure. In this case, the control and management of all data lie entirely with the customers, and the platform can be operated and maintained independently of the providers once it is up and running [32]. Alternatively, the platform can be operated in the cloud, which includes private clouds and public clouds. The on-premises and cloud operating modes can also be combined into a mixed form, which is called hybrid. Customers can decide for themselves which data should be processed in the private sphere and which can be uploaded to the cloud [33]. If the platform offers free access, clients can register without restrictions. Often, however, certain criteria must be met. These are checked by the platform providers as part of a prequalification. Some platforms require the use of certain devices, e.g., specific hardware for data collection (*access requirements*). The *platform structure* also shows different characteristics. It is either fixed by the operator, modular without external interfaces, whereby customers can freely choose additional functions or extensions but are bound to the operator's offer, or modular with external interfaces, whereby the platform can be supplemented with external offers in addition to those of the operator.

4.2 Data-Centric Dimensions of Energy Platforms

Platforms can correspond to two basic models (*platform type*) [34,32]. Software-as-a-Service (SaaS) refers to applications that can be used directly by the customers. In contrast, Platform-as-a-Service (PaaS) offers an environment in which applications can either be provided or developed. By definition, both models are offered via the cloud, whereby the required infrastructure is also provided by the service providers. However, since in practice, the on-premises operation is often also possible, and the operators themselves refer to their platforms as SaaS or PaaS, we use these terms in our characteristics. *Communication* via the platform may proceed either as one-to-many or many-to-many, depending on how the individual participants communicate with each other. Participants are the users or devices (systems, machines) connected to the platform. If several participants communicate exclusively with the platform, this is called one-to-many. In many-to-many communication, the platform not only communicates with several partners, but these also communicate with each other [35]. The *data flow* is also characterized by two different features. Either the data only flows in one direction, for example, from the devices to the platform (unidirectional), or the data flow takes place in more than one direction (bidirectional), for example, from the devices to the platform and vice versa. This also includes data flow between individual devices. *Data processing* can be either transactional or analytical. If the data is processed transactionally, data from transactions or interactions is used to trigger certain processes. Analytical data processing is divided into two different characteristics, namely visual analysis and data-driven analysis [31]. The former contains descriptive analyses, which mainly aim at preparing the data. The feature data-driven analysis, on the other hand, contains more in-depth forms of data analysis, where the data is used for further calculations, such as in machine learning applications [36,37]. The processed data is gained from different sources (*data sources*). Many platforms offer the possibility to connect devices to it to process their data. However, data can also be obtained from the cloud, where data either comes from external sources (e.g., energy price forecasts) or from the company itself (e.g., from enterprise-resource-planning systems).

4.3 Transaction-centric Dimensions of Energy Platforms

The dimension *main function* addresses the fact that platforms can pursue a different central objective. In the case of transaction-centric energy platforms, we found that this is either electricity trading, where producers and consumers can sell or buy electricity (via over-the-counter (OTC) trading or exchange access), energy flexibility trading, which enables generators or consumers to market energy flexibility directly to grid operators or, virtual power plants, that bundle (decentralized) electricity consumers and electricity producers, market their generated electricity and offer system services. Stock exchanges (e.g., EPEX SPOT), markets for system services, or OTC trading can serve as a *trading venue* on these platforms. Different *flexibility types* are traded on these trading venues. Market flexibility can be used to respond to market signals such as volatile prices on short-term markets to reduce energy costs. System flexibility serves to maintain electricity grid stability and is therefore used by the transmission system operator, whereas grid flexibility is intended to avoid critical situations in the local electricity grid [38]. If the *market design* of a platform is closed, the platform users are bound to a specific buyer, an aggregator, a fixed trading venue, or to the platform itself, and parallel use of several solutions is not possible. In an open market design, there is no lock-in, and customers can use additional solutions. According to [39], energy platforms use three different mechanisms to set prices (*pricing*) (for marketing energy flexibility). In free pricing, prices are formed without restrictions. In the case of free pricing with regulatory elements, there are restrictions imposed by the platform operators, for example, by imposing surcharges on freely formed prices or by setting price caps. In regulated pricing, prices are formed according to set procedures, or there are fixed prices. However, some platforms do not allow for their own price formation but only pass on prices from certain trading venues.

4.4 A Multi-Layer Taxonomy for Digital Energy Platforms

	Dimensions	**Characteristics**				**Exclusivity**
General dimensions	Platform operator	Company	Consortium	Aggregator		E
	Access	Web-App	Native-App	Specific interface		NE
	Operational concept	On-Premise	Cloud	Hybrid		NE
	Access requirements	Free Access	Certain criteria to fulfill	Certain devices necessary		NE
	Platform structure	Fixed structure	Modular structure without external interfaces	Modular structure with external interfaces		E
Data-centric dimensions	Platform type	SaaS	PaaS			E
	Communication	One-to-Many	Many-to-Many			E
	Data flow	Unidirectional	Bidirectional			E
	Data processing	Transactional	Visual analysis	Data-driven analysis		NE
	Data source	Device	Cloud			NE
Transaction-centric dimensions	Main function	Electricity trading	Energy flexibility trading	Virtual power plant		E
	Trading venue	Stock Exchange	Markets for system services	OTC		NE
	Flexibility type	Market flexibility	System flexibility	Grid flexibility		NE
	Market design	Open	Closed			E
	Pricing	Free	Regulated	Free with regulating elements	No pricing	NE

Figure 1: Combined use of the developed taxonomies with general, data-centric, and transaction-centric dimensions

Energy platforms are often characterized by either a strong data-centric or a transaction-centric focus. The main function of transaction-centric platforms is to serve as a marketplace. Data-centric platforms focus on processing data [40]. Since transaction-centric and data-centric platforms differ significantly in some respects, we developed two different taxonomies for digital energy platforms. Thus, all platforms can be classified exactly and according to the requirements of a taxonomy. The taxonomy consists of the general combined with the data- or transaction-centered dimensions, regarding the analyzed platform. Among the energy platforms, there are some that, based on their main functions, can be classified as transaction- or data-centered platforms, but at the same time also have individual functions of the other category such as the platform solution illustrated in [6]. To classify holistic platforms by using our taxonomies the transaction- and data centric taxonomies can be united to a combined taxonomy as shown in Figure 1~~figure 1~~. The individual characteristics are indicated for each dimension in the corresponding row. The item exclusivity also indicates whether the characteristics are mutually exclusive (E) or non-exclusive (NE).

5. Implications and Conclusion

This paper addressed the lack of methodology to characterize digital energy platforms. Following Berger et al. [15], we developed a taxonomy for digital energy platforms. Our result, the developed and validated taxonomy, has several implications for practice and research. First, the taxonomy serves as a structuring element and allows companies to determine the status quo of existing platforms and IT systems. Therefore, the taxonomy can be used for "auditing purposes" to examine which functions and features are already covered by existing IT systems. Second, in addition to the status quo, the taxonomy can also sharpen a target image for functionalities and characteristics of IT systems and platforms and elicit requirements. Third, using a fit-gap analysis [41] and our taxonomy, companies can easily compare existing digital energy platforms and select the platform that best meets their needs. The selected platform can then be implemented to accelerate the adoption of DSM. Fourth, the results and the comparison of the platforms used during development show that most of the platforms focus on the data-centric or transaction-centric dimensions and cover these functionalities. Consequently, it can be concluded that for the best possible digitalization and automation of flexibility marketing, a mix of different IT systems and platforms is evident in most cases. Considering existing IT systems and platforms, attention must therefore be paid to integration interfaces during implementation to ensure communication without media discontinuity. Only in this way can systems be operated in an interoperable manner. Fifth, researchers can classify their work using our taxonomy and clearly distinguish it from existing studies. Consequently, the taxonomy can serve to structure research and identify future research fields. Sixth, to sum up, our taxonomy provides researchers and practitioners with an easy-to-use methodology to classify digital energy platforms and make informed decisions about which platform best fits the needs of the business. This enables researchers to strengthen the focus of their research and helps companies leverage the potentials of DSM.

Naturally, our work has some limitations as any research endeavors but likewise gives prospects for further research. First, the taxonomy was developed with platforms known today and consequently with their characteristics. Against the background of the rapid development of platforms of various types, the developed taxonomy may only be used for a limited time, and further development will be necessary for the future. In this way, not yet considered functions and features can be considered to provide a valid taxonomy. Second, the taxonomy was built upon the analysis of a subset of all available energy platforms. In total we identified 163 digital energy platforms. Using the method of Quatember [29] we built a subset of 46 platforms to create our taxonomy. This reduction of the set might affect the completness of the taxonomy. Third, in addition to the pure classification of platforms, the taxonomy might be used in further research to derive platform archetypes allowing to group platforms with similar characteristics. Third, the taxonomy dimensions are at a relatively high level and do not, for example, take into account details regarding the exact interfaces of platforms. Consequently, our taxonomy is suitable for an initial platform selection. Future studies might build on our work and develop a more detailed taxonomy. A focus on technical details might thereby enhance readability and simplify its use. Despite these limitations, we hope to provide a viable solution to structure digital energy platforms for production companies and support researchers and practice.

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