# Towards Smart Distribution Grids: A Structured Market Engineering Review

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**Abstract**

The changes taking place in the energy sector, the transition towards smart grids and an increasing share of renewable energy sources (RES) generate the need for new market designs as well as new business models on the level of distribution grids. This work applies the market engineering framework to markets in smart distribution grids. First, a systematic overview of research approaches in the respective fields is given. Second, by viewing intermediaries as market engineers in their own one-sided market, existing industry projects from intermediaries are compared along the market engineering framework.

*Keywords:* Energy and Mobility Services, Market Engineering, Smart Grid

## 1. Introduction

New proposals for energy market designs on both national [4] and EU level [12] call for a better integration of the increasing share of RES as well as opening the market to more actors in order to utilize their flexibilities. In particular, distribution system operators (DSOs) and aggregators could leverage flexibility from consumers to further generate revenue from new business models. Moreover, flexibility products and services as well as other measures

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beneficial to the grid and security of supply are necessary. In the following, this work gives a structured overview and analysis of current research approaches and real-world industry projects in Germany regarding smarter distribution grids along the elements of the market engineering framework. Moreover, all components of the market engineering framework are analyzed and illustrated by examples.

## 2. Related Work

The market engineering framework [44] serves as a basis for the development of a layout for markets in distribution grids. Along the elements in the framework, this work will analyze current developments in research, politics and industry related to the design of future local markets. In the framework, every market is surrounded by an economic and legal environment. The good traded between parties in a market is called transaction object. According to the market engineering framework, the market structure itself consists of the microstructure, the IT-infrastructure and the business structure. The microstructure defines the market mechanism, i.e., pricing and allocation rules. All facilities required in order for markets to function on a technical level form the IT-infrastructure. The business structure encompasses the business and pricing model as well as possible trading fees in auctions [45, 5]. Perceiving new companies in the energy market as single markets themselves allows for analysis of new business models in the context of the market engineering framework. Finally, the market outcome (or performance) constitutes the result of a market by which different markets can be compared.

## 3. Smart Distribution Grids: A Market Engineering Overview

This section elaborates on current research agendas by reviewing publications and projects for (local) markets in smart grids along the elements of the market engineering framework. In the following, this work broadens the focus from the perspective of the market engineer to additionally incorporate the role of market intermediaries, or aggregators, which can also take the role of a market engineer, whose market environment depicts a one-sided market, sometimes with a fixed price strategy. In addition, engineering a business structure and designing appropriate transaction objects remains an important task.

## *3.1. Economic and Legal Environment*

Both on European Union (EU) as well as on national level, efforts towards achieving ambitious energy targets, such as the EU 2030 targets [12] or the exit from nuclear power generation [3], are driving changes to the current legal and economic environment which governs energy markets. Recently, the EU started working on proposals for a new energy market design, which envisions a market design that should allow innovative companies to provide for the energy needs of consumers by using new technologies, products and services [12]. Opening the market to more actors, therefore allowing access to flexible demand and new energy service providers, e.g. aggregators, remains a priority. In late 2015, German policy established measures that target the development of an advanced electricity market – the *electricity market 2.0* [4]. The electricity market 2.0 draft tackles issues concerning the improvement of market mechanisms, fostering the market participants' flexibility, as well as the integration into the EU's internal energy market (IEM).

## *3.2. Market Outcome*

Markets are designed to achieve a desired outcome, i.e., an allocation and pricing result [44]. Concerning the design of markets for distribution grids, market efficiency is crucial in order to ensure a continuous balance of supply and demand. Considering system stability, incentives of agents should be aligned with security of supply in mind to prevent market failure. The following suggestions for outcome objectives of secondary nature represent promising goals towards the success of local markets in smart grids. (i) Consumer privacy must be protected in light of the large amount of high-resolution data collected by smart meters. (ii) In order to integrate customers into such markets, intermediaries such as aggregators are required. These in turn will only operate given viable business models. Thus, a market outcome should also consider revenue streams not only for the market engineer but also for its participants. Focusing on aggregators, the main market outcome is to allocate and in turn provide balancing power to ensure grid stability by efficiently controlling small power plants or to manage a pool of consumer batteries efficiently.

### *3.3. Agent Behavior*

Agent behavior results from the transaction object and market structure. Therefore, it is not the goal of the market engineer to influence this behaviour directly, but instead analyze and anticipate behavior and characteristics of agents [44, 45]. In context of the smart grid, agents are expected to offer their flexibility to a market or market intermediary [1]. Flexibility corresponds to deferring or reducing loads over time [43] and increasing production, for different types such as storable, shiftable, curtailable, base load and self-generation [21, 36]. In addition, other approaches to stimulate agent behavior might include: (i) Gamification, i.e., using game design elements such as rankings in non-game contexts [9] to support the consumers' value creation [25]. (ii) Hidden markets [40] can influence and mediate user behavior with the graphical user interface of a market. (iii) Following the sharing economy [2, 19], peer-to-peer (P2P) platforms present an opportunity to communicate and share different transactions objects with close neighbors or friends. When looking at real-world examples of intermediaries, for example the strategy of employing hidden markets can be observed. Most of the time, it is reasonable not to inform customers about details behind the intermediaries' business models. Existing companies putting this approach into practice are for example Next Kraftwerke, Caterva, LichtBlick and Beegy.

### *3.4. Market Structure*

Focusing on distribution grids, strengthening the role of DSOs in markets and enabling the participation of flexible users and intermediaries, i.e., businesses that facilitate the participation of flexible users on (new) markets, represent the main challenges [3]. New transaction objects and market microstructures are emerging, while IT infrastructure considerations on privacy and security need to be addressed.

*Microstructure.* The market microstructure describes the mechanism under which resources are allocated and priced. It consists of a market's trading rules and systems, considers structural characteristics of markets and the form in which information is exchanged, i.e., the bidding language [44]. Different decentralized mechanisms which aim at reducing peak loads [37], using balancing markets [23], and incentivizing agents to reveal true preferences [30] have been proposed. When applying the microstructure element of the framework to intermediaries, the market mechanism corresponds to the general terms and conditions of the respective intermediary. They basically define the rules of the trade, such as the delivery of the product and the payment period. The customers do not submit bids to an auction but rather inquire (customized) offers. As can be seen in table A.1, some companies offer customized products and services with individual pricing, while others have a general fixed price product portfolio.

*IT Infrastructure.* IT infrastructure is deemed a fundamental and critical component in the smart grid as it is responsible for ensuring a reliable system operation. Firewalls and encryption mechanisms must ensure reliable system operation [33]. Authentication solutions [32, 28], extensions of current architectures [35] as well as complete system architectures [33] have been proposed. Moreover, smart meter data must be protected [15] and consumer anonymity must be ensured [10, 31, 27]. Standards can facilitate the information flow in a heterogeneous landscape of devices in the smart grid [17, 16]. Moreover, interfaces to the market are required to allow and encourage agent participation [40, 41]. For existing intermediaries/virtual power plants (VPPs) for example, the communication with the distributed power plants plays a crucial role and happens via DSL connection or mobile (GSM) communication. Besides, the communication between intermediary and customer often is done completely through web portals and mobile applications. The individual characteristics of each of the surveyed companies are summarized in table A.1 below.

*Business Structure.* Business structure concerns the charges for accessing the market, as well as fees for using the communication means and for executing orders [44]. Important revenue streams of current energy markets like the European Energy Exchange include fees for connectivity and trading.[1] By means of aggregators, or VPPs, consumption and production capacities could be pooled and sold accordingly [24, 18, 22]. Use cases include wind [34] or electric vehicle (EV) pooling [7, 26, 11]. Moreover, tariff and coordination models are explored [8, 29]. Current startups such as Next Kraftwerke aggregate several types of plants. From a market perspective their revenue stream

[1] `https://www.eex.com/blob/65974/e8b0e854878e50ae201afd097495c704/membership-options-technical-access-data.pdf`

through one time sales of hardware for connection to the pool corresponds to initial connectivity fees. The second major revenue stream, keeping a share of the revenues from flexibility marketing, corresponds to costs for trading.

*Transaction Object.* The good traded between parties in a market is called transaction object. In general, this can be a product or a service [6]. Early research suggests to differentiate products, i.e., tariffs, along temporal and spacial components [39]. Similarly, concepts for quality of service (QoS) level indicators for new tariffs [20] and electric mobility [14] are suggested. While electricity will remain a homogeneous good regarding its technical properties (voltage and frequency), a product differentiation along non-functional quality attributes of electricity services presents an emerging approach. In particular, temporal and curtailment flexibility as well as reliability requirements constitute promising characteristics to further raise efficiency not only on the local, but also on the global electricity market level [38, 42, 13]. Existing intermediaries in smart grids offer various types of transaction objects, like hardware products for the connection and integration into the swarm, intelligent management software and a wide range of different services.

*Summary.* As shown before, initial solutions from the industry exist already today. The findings are summarized in table A.1, structured according to the market engineering framework.

## 4. Conclusion and Outlook

This work highlights that local markets in distribution grids are a promising way to cope with the challenges posed by the transformation of the energy sector. Therefore, a survey of current research is conducted and subsequently structured according to the market engineering framework. By defining intermediaries in distribution grids as one-sided markets on their own, they can be included in the analysis.

Future research opportunities regarding market engineering in smart distribution grids include the application of the structured market engineering process [44], which allows achieving specific market design goals in a systematic and structured way. Besides, it would be valuable that the research approaches mentioned above are elaborated, refined and adjusted to a rapidly changing economic and political environment.

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## Appendix A. Market Engineering Overview Table

Table A.1: Overview of prominent products and services from industry (● = Fulfilled, ○ = Not fulfilled or unknown)

| | Next Kraftwerke | Beegy | LichtBlick SchwarmEnergie | Sonnenbatterie | Tesla | Caterva |
|---|---|---|---|---|---|---|
| **Market outcome** | | | | | | |
| Ensure grid stability through efficient allocation | ● | ● | ● | ● | ● | ● |
| Generate revenues through flexibility marketing | ● | ● | ● | ○ | ○ | ● |
| **Agent behavior** | | | | | | |
| Private households | ● | ● | ● | ● | ● | ● |
| Industry consumers | ● | ● | ● | ○ | ● | ○ |
| Solar generation installed | ● | ● | ● | ○ | ○ | ● |
| Wind generation installed | ● | ○ | ○ | ○ | ○ | ○ |
| **Microstructure** | | | | | | |
| Custom prices | ● | ● | ● | ○ | ○ | ○ |
| **(IT) infrastructure** | | | | | | |
| Internet access required | ● | ● | ● | ○ | ○ | ● |
| Mobile (GSM) access available | ● | ○ | ○ | ● | ○ | ● |
| Provides mobile application | ● | ● | ○ | ● | ○ | ● |
| **Business structure** | | | | | | |
| One-time sale | ● | ● | ● | ● | ● | ● |
| Subscription | ○ | ● | ● | ○ | ○ | ● |
| Brokerage fee/ Shared revenue | ● | ● | ○ | ○ | ○ | ● |
| **Transaction object** | | | | | | |
| Physical product | ● | ● | ● | ● | ● | ● |
| Service | ● | ● | ● | ○ | ○ | ● |

Own data from 2015/11.