Enabling Flexibility from Demand-Side Resources Through Aggregator Companies

Ioannis Lampropoulos, Machteld van den Broek, Wilfried van Sark, Erik van der Hoofd and Klaas Hommes

Abstract In recent years, several business models of the aggregator company have emerged in Europe, in response to a general quest for flexibility in power system operations. A systematic approach of analysing the organisational arrangements underlying a business model is still lacking, whereas the available information on the potential of aggregated resources in electricity markets is limited. This work contributes to the systematic development of the business model concept of an aggregator company, and provides insight into its economic potential. A set of elements is identified that can be used for analysing the various implementations of a business model. A revenue analysis is performed based on historical data from the day-ahead market and the imbalance settlement system in the Netherlands. The case study is about a hypothetical implementation of the aggregator company with focus on residential demand-side resources. The results show a significant theoretical potential and suggest an interesting business case.

Keywords Demand-side flexibility · Aggregator companies · Renewable energy · Energy management in buildings · Consumer empowerment · New business models

I. Lampropoulos (✉) · M. van den Broek · W. van Sark
Energy & Resources Group, Copernicus Institute of Sustainable Development,
Utrecht University, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands
e-mail: i.lampropoulos@uu.nl

M. van den Broek
e-mail: m.a.vandenbroek@uu.nl

W. van Sark
e-mail: w.g.j.h.m.vansark@uu.nl

E. van der Hoofd · K. Hommes
Department of Customers & Markets, TenneT TSO, Utrechtseweg 310,
6812 AR Arnhem, The Netherlands
e-mail: erik.vander.hoofd@tennet.eu

K. Hommes
e-mail: klaas.hommes@tennet.eu

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1 Introduction

The increasing integration of intermittent renewable energy sources in power systems and the ongoing deregulation of electricity markets have resulted in a quest for flexibility both for system security and market optimisation (Van Hout et al. 2014). Flexibility is defined as a "general concept of elasticity of resource deployment providing ancillary services for the grid stability and/or market optimisation" (CEN-CENELEC-ETSI 2012). Until now, flexibility was mainly sourced from large generators at the supply-side. Currently, the focus of enabling flexibility is increasingly placed at the demand-side through flexible loads, distributed generation units and energy storage devices in the industry, commercial, and residential sectors. Unlocking the flexibility at the demand-side is considered a key factor for an effective energy transition which requires the active participation and empowerment of customers (EG3 2015). Besides the active involvement of customers, most of the energy resources in the built environment cannot contribute to flexibility services on their own because of limited capacity and controllability. Aggregator companies are organisations that can combine these distributed and dispersed energy resources into a single system resource, which can be utilised for the provision of flexibility services.

The concept of the aggregator company, a new entrant in the energy market, is connected with smart grid development, which subsequently links to the smart city notion due to the importance of energy at the urban level. Urban environments are highly dependent on reliable energy supply to sustain their functions. At the same time, cities are expected to contribute considerably in addressing global environmental challenges, though, the implementation of appropriate actions are subject to limited financial resources (Maltese et al. 2016). At European level, the sustainable development of urban areas has been recognised as a challenge of key importance. The current framework programme for research and innovation, implemented by the European Commission, addresses particular topics for smart cities and communities by focusing on integrated solutions in the areas of energy, transport and information and communication technology (ICT). A relevant example is about the aggregation of electric vehicles through ICT for the provision of ancillary services to the grid and market optimisation purposes. The coordinated scheduling of the charging processes and procurement of services between the aggregator company and the system operator can enhance the efficiency and security of a power system and reduce its environmental impact (Ortega-Vazquez et al. 2013). Integrated approaches recognise the inter-dependencies between urban systems, and offer various advantages by exploiting existing assets. Other identified objectives in research and innovation in relation to the development of urban areas in Europe are about enhancing citizen involvement and affecting user behaviour (Maltese et al. 2016). By taking advantage of new technology, new entrants in the energy market and innovative energy service companies should enable all consumers to fully participate in the energy transition (European Commission 2015). Aggregator companies can deliver new value propositions to customers, particularly by better linking wholesale and retail energy markets. Aggregator companies can also take advantage of the increasing introduction of new technologies in urban environments, such as distributed generation, storage and energy-efficient buildings equipped with advanced control systems and demand-response schemes (Calvillo et al. 2016), in constructing their flexibility portfolios. The smart city notion highlights the importance of using common infrastructures and appropriate standards to enable parties across different disciplines and sectors to work together in researching, developing and deploying advanced technological solutions. Smart technologies and appliances, under appropriate standards, will enable users, procurers and service providers of flexibility, including aggregator companies, to develop novel grid and retail products and services (EG3 2015).

Aggregator companies have to agree with their associated customers on the commercial terms and conditions for the procurement, dispatch and remuneration of flexibility. The financial benefits for the customers may be in the form of energy bill savings or other financial incentives. Demand-side flexibility could be used by various actors to serve several purposes and provide multiple benefits and sources of revenues (EG3 2015). An aggregator company might utilise flexibility to take advantage of price differences between wholesale and retail markets for electricity, to participate in ancillary services markets, and to provide *over-the-counter* services to other market parties. Unlocking the flexibility from an aggregation of demand-side resources involves technical, organisational and economic challenges. Several control schemes for demand response and aggregation entities have been proposed in the technical literature (Lampropoulos et al. 2013). Research activities have focused on the technical issues, but have not systematically analysed the organisational arrangements underlying the business model of an aggregator company, whereas the available information about potential and costs of demand response resources in the Netherlands is limited (Van Hout et al. 2014).

This work contributes to the process of systematically structuring the business model concept of an aggregator company. Insight is provided into the value creation and value capture by focusing on two developed markets in the Netherlands, i.e. the day-ahead market and the imbalance settlement system. First, a set of elements is identified that can be used for describing the various implementations of emerging business models around the concept of an aggregator company. These elements can also be used for identifying and analysing different organisational arrangements within the various business model concepts. Subsequently, the economic potential of one of these organisational arrangements is assessed in a hypothetical case study. In this case study, the aggregator company is organised in such a way that it combines the roles of the energy supplier and the balance responsible party (BRP). The focus is on an aggregation of demand-side resources of residential customers. An evaluation of the potential revenue that could be achieved with respect to the specified applications is performed through computer simulations by utilising an optimisation model, measured energy profiles and historical market data from the Netherlands.

The paper is structured as follows: In Sect. 2, the business model of the aggregator company is elucidated, based on a literature review; and the case study is presented. Insight into the value creation and value capture is provided in Sect. 3, where the research findings and results are presented and analysed. The paper ends with discussion and conclusions.

2 Literature Review and Research Methods

In this section, the literature review and the research methods are presented. The first part of the analysis is based on a literature review to identify those characteristics that outline the various possible implementations of the business model concept of an aggregator company, and subsequently the focus is placed on a case study.

In recent years, the business model concept has received significant consideration both from academia and industry. Despite this increasing momentum, there is still no commonly accepted framework or language to reconcile research and development efforts (Zott et al. 2011). To ensure the relevance of the research and to facilitate future progress on the topic, the performed analysis builds on a definition that has been given in the context of doing business electronically, including trade and the provision of services. A business model is defined as “an architecture of the product, service and information flows, including a description of the various business actors and their roles; a description of the potential benefits for the various business actors; a description of the sources of revenues” (Timmers 1998). Accordingly, the overall system architecture of the physical power system and the electricity sector organisation in Europe, including a description of the main actors and their roles, is presented in Sect. 2.1. This conceptual architecture allows for mapping the various system entities, domains, actors and their interactions, and can be used for describing the business model concept of an aggregator company. An actor represents a participant in a business transaction, and might consist of a composition of one or more roles (ENTSO-E 2015). In Sect. 2.2, a set of characteristics that can be used for describing the business model variations around the concept of an aggregator company is identified by reviewing emerging models in Europe. Emphasis is given on both the technical aspects and the organisational arrangements that drive the various variations of emerging business models. The case study about a hypothetical implementation of the aggregator company is presented in Sect. 2.3.

2.1 System Architecture and Overview of Main Actors and Roles

The liberalisation process of the electricity market and the directives for non-discriminatory access to the network, implemented in Europe (EP-CEU 2009), have significantly contributed towards the creation of competitive markets and a restructuring of the electricity sector. In Europe, each control area of the interconnected power system (ENTSO-E 2015) is operated by the associated Transmission System Operator (TSO), the legal institution that monitors the transmission network, ensures the connections with other control areas, and organises the markets for operating reserves and cross-border capacity and exchanges. A single control area might involve one or more Distribution System Operators (DSO), but every regional distribution system is associated to a single DSO company that operates as a natural monopoly. DSO companies connect individual system users to the transmission network, and provide the distribution of electricity through medium voltage and low voltage (LV) networks, which subsequently feed a large number of system users at the LV distribution level. Grid operators, i.e. TSO and/or DSO companies, are potential users of flexibility services, through the procurement of ancillary services, to perform their core tasks, to defer network reinforcements and investments, and to reduce grid losses (EG3 2015).

In Fig. 1, the residence of a system user, i.e. a residential customer, is illustrated as a private network interconnecting a number of energy demand and/or generation resources, such as distributed energy storage devices, generation units and loads. The resources of a residential customer can be characterised as: (a) non-flexible, i.e. critical loads, which are difficult or impossible to be displaced in time and amount without creating a sense of discomfort to the users, and uncontrollable generators, such as wind turbines and photovoltaic (PV) installations; and (b) flexible, i.e. non-critical loads, which are characterised by some degrees of flexibility, controllable generators and energy storage. The private network of a single customer is connected to the LV distribution grid at the point of connection (or main metering point), where the energy products of the respective user are measured or computed to support business processes such as calculation of energy volumes, financial settlement etc. For each connection point to the grid there is one associated supplier, i.e. a party that is sourcing, supplying, and invoicing energy to its customers, and a BRP, i.e. a party that has a contract proving financial security and balance responsibility (ENTSO-E 2015). The Dutch electricity market is open to competition for small-size system users since July 2004, and residential customers can switch to the supplier of their preference. For residential customers the roles of both the supplier and the BRP are typically taken on by the same market party. Suppliers and BRP could use flexibility services for portfolio optimisation and/or generation capacity adequacy (EG3 2015).

In Fig. 2, the overall system architecture of the physical power system and the electricity sector organisation, in the European context, is illustrated. The system

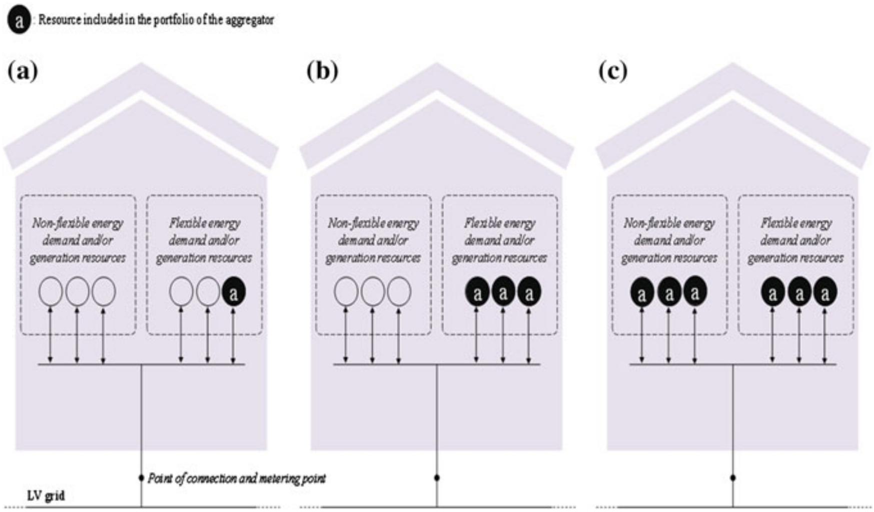


Fig. 1 Residential customers, i.e. system users, with both flexible and non-flexible resources. The aggregator company might include in its portfolio: **a** only one specific flexible resource, or **b** more than one flexible resource, or **c** all resources behind the point of connection of a given customer. The different possibilities outline the interest (or indifference) of an aggregator company to a specific target technology and subsequently different business models

entities (and domains) of the physical power system are attributed to the relevant actors (or roles), whereas both the power flows and the information flows are depicted. Note that the scheme illustrated in Fig. 2, maps the relationships within contemporary systems and indicates envisioned interactions at the distribution level. The main idea is that flexibility shall be combined as much as possible to serve different purposes and various actors. This can be enabled by developing a flexibility market at system level, where all flexibility offers are accompanied by a location tag to make possible also the provision of location specific services, such as network congestion management and/or peak-shaving at the distribution level. A DSO company is excluded by regulation from directly managing the energy resources within their customers' premises (behind the meter). In the future, a DSO might procure ancillary services from system users, if needed, in a similar way that the TSO procures ancillary services for balancing purposes. By setting a framework where DSO can buy flexibility options such as peak-shaving services, if needed, this creates a situation with natural incentives for the DSO to upgrade an aged network where peak-shaving services become necessary more frequently and subsequently more expensive. In the case that a DSO procures flexibility services, which might be in contrast with a request by the TSO for downwards (or upwards) regulation, it is essential to formulate exact criteria based on conditions and to outline an interaction framework between the TSO and DSO to avoid conflicting requests and inefficient operations. The system users that provide the flexibility

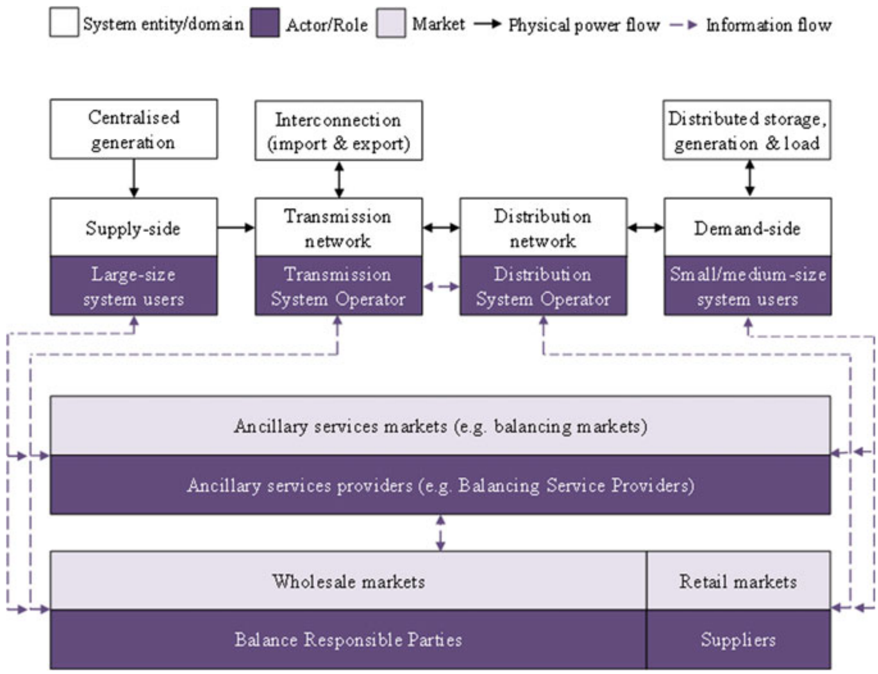


Fig. 2 Conceptual architecture of the physical power system and the electricity sector organisation in the European context. Inspired from Kling (2002)

services are expected to first act to solve a local problem when there is a relevant request, i.e. the modes of operation are prioritised. The logic is that local problems should primarily be addressed by the resources that are located close to the fault occurrence, whereas global challenges, such as system imbalances, can be addressed by all system resources. In the case of service provision at the distribution level, e.g. peak-shaving, the remuneration should not be valued less than other ancillary services so that market parties have a natural incentive to reserve resources for this purpose, e.g. these services should be valued at least at the same level with balancing services.

An aggregator company is in principle responsible for acquiring flexibility from an aggregation of system users, constructing a flexibility portfolio, developing and offering flexibility services to different markets and actors, with the aim of creating value and sharing it with its stakeholders. Value creation, through business models, involves an interconnected set of exchange relationships and activities among multiple actors (Zott et al. 2011). An overview of the main actors (and their roles) involved around the business model of an aggregator company, is provided in Table 1. Terms and roles have been aligned with those used in USEF (2015), and by ENTSO-E (2015; 2016).

Table 1 Main actors and roles around the business model of an aggregator company

Actors/roles	Description
System user	System users are the natural or legal persons that supply, or are being supplied by, a transmission or distribution system (ENTSO-E 2015). The system users are all the producers and consumers of electricity that own and operate within their premises any generation unit, load and/or storage device
Balance responsible party (BRP)	A BRP carries the role of energy nomination at the wholesale level (ENTSO-E 2015), and is responsible for balancing supply and demand for its portfolio
Balancing service provider (BSP)	The term BSP is used for the market participant that provides balancing services to its connecting TSO or in case of the TSO-BSP model, to its contracting TSO (ENTSO-E 2016).
Supplier	The role of the supplier is to source, supply, and invoice energy to its customers. The supplier and its customers agree on commercial terms for the supply and procurement of energy (USEF 2015). The supplier must be assigned the metering points of the customer it supplies (ENTSO-E 2016).
(Transmission) System operator (TSO)	A party that is responsible for a stable power system operation (including the organisation of physical balance) through a transmission grid in a geographical area (ENTSO-E 2015).
Distribution system operator (DSO)	A natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution network in a given area and, where applicable, its interconnections with other networks; and for ensuring the long-term ability of the network to meet reasonable demands for the distribution of electricity (ENTSO-E 2016).

2.2 *Emerging Concepts of the Aggregator Company in Europe*

In recent years, several organisations, either new or traditional players in the energy sector have attempted to explore the emerging opportunities for the provision of flexibility services from aggregated demand-side resources. In this section, a set of characteristics is identified around the business model concept of an aggregator company by reviewing historical cases and emerging models in Europe (Lampropoulos et al. 2013; USEF 2015).

The Aggregator Company and Targeted Flexible Technologies or Resources The system users that are associated with an aggregator company might participate in its portfolio with either a few or all of their resources. In the case of a residential customer that is characterised by both flexible and non-flexible types of resources, as illustrated in Fig. 1, an aggregator company might have an interest to include in its portfolio either only one specific flexible resource, more than one flexible resource, or all the resources, flexible and non-flexible, that are located behind the main metering point at the point of connection of that customer.

The different options unveil the interest (or indifference) of an aggregator company to a specific targeted technology and subsequently outline different business models. In the case of an aggregator company that includes in its portfolio all the resources of a system user, the conditions that influence the position of that system user are direct and unambiguous, and measurements at the point of connection are sufficient for settling any imbalance with the associated BRP and/or supplier. In the case of an aggregator company that is interested to include in its portfolio only one or a few selected resources of a system user, the measurements at the point of connection might be insufficient for settlement purposes. Presumably, additional requirements are created for sub-metering behind the point of connection to support the settlement process with the associated supplier and/or BRP. A historical case from France reveals the complications, due to the interdependence of commodities, when different market parties are representing the same system user in different markets but their actions are not coordinated or communicated. In that case, an aggregator company used to aggregate flexibility by offering to residential customers a device, which could switch off their electrical heating and space conditioning appliances. Consecutively, the aggregator company was placing the aggregate flexibility bids to the French TSO market for operating reserves. The call of those bids was resulting into imbalances at the position of the associated supplier, and the dispute whether the aggregator company should compensate the supplier or not was sent for settlement in the Council of State (Lampropoulos et al. 2013).

The Aggregator Company and Targeted Customer Segments An aggregator company might target particular customer segment, e.g. residential, commercial, or industrial customers. In this work, the focus is on residential customers, who are in principle non-professionals and are characterised by limited capacity and controllability. Larger system users, such as commercial and industrial customers, that are characterised by significant capabilities of flexibility can also perform within an aggregate portfolio and might even act as aggregator companies for optimising their own portfolios (USEF 2015).

The BRP and the Supplier Roles At the point of connection of a system user to the grid there should be assigned a BRP and a supplier. In Fig. 3, the possible organisational arrangements between two system users, and their associated BRP and suppliers, are illustrated. The aggregator company might take on either: (a) the role of the supplier; (b) the role of the BRP; (c) both of these roles; or (d) none of these roles. In the latter situation, the associated suppliers and BRP must be compensated for the energy supply and any energy imbalance entailed in their positions due to the provision of flexibility services from system users, with whom they have contractual relationships. In such a business model, the aggregator company acts as a third-party that aggregates flexibility from system users and sells it at its own risk to potential buyers, thus creating the need to formalise all the interactions with other market players (USEF 2015). In the situation that the aggregator company takes on the BRP role, all optimisations are performed directly within the combined portfolio. Otherwise, the aggregator company shall define

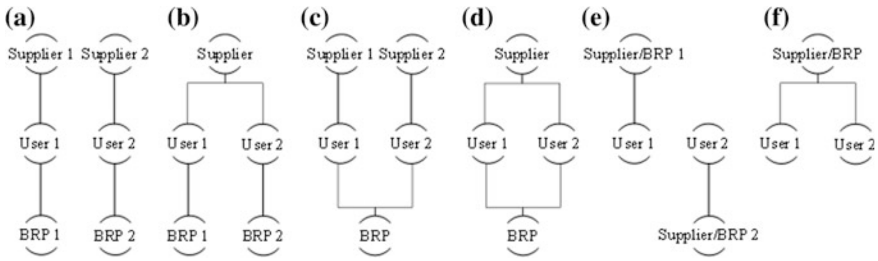


Fig. 3 Possible organisational arrangements between two system users, and their associated BRP and suppliers, when the roles of the supplier and the BRP are either distinct or combined. **a** Different BRP and suppliers. **b** Different BRP but a single supplier. **c** Different suppliers but a single BRP. **d** A single supplier and a single BRP. **e** The roles of the supplier and the BRP are combined, and the system users are associated with a different supplier/BRP. **f** The roles of the supplier and the BRP are combined and the system users are associated with a single supplier/BRP

contractual relationships with one or more incumbent BRP, but can also propose a new BRP to its associated system users. In the situation that the aggregator company takes on the supplier role, it becomes possible to offer to its associated system users a supply contract including flexibility options. The supplier can be the incumbent supplier, but the aggregator company can propose a new supplier to its associated system users (USEF 2015).

The Aggregator Company as a Pure Service Provider An aggregator company might act as a pure provider of flexibility services for one of the other roles, i.e. the aggregator company provides the means to aggregate flexibility and offers it to one of the other market parties in the value chain instead of trading flexibility at its own risk (USEF 2015). This type of business model might be implemented by organisations that have specific knowledge on particular technologies and techniques, e.g. ICT, computer science, etc.; and act as providers of integrated technical solutions.

Ancillary Service Provision to Grid Operators An aggregator company might provide balancing services as a BSP to its connecting TSO. Future conceptualisations consider aggregator companies as potential providers of a broad range of ancillary services to the TSO and/or DSO institutions.

2.3 *The Case Study*

The case study is about a hypothetical implementation of the aggregator company that combines the roles of the supplier and the BRP. The focus is on an aggregation of residential customers with local PV generation and energy storage capabilities. An evaluation of the potential revenue is performed with respect to the applications of energy arbitrage in the day-ahead market and passive contribution in system balancing (separately and in combination), based on historical market data from the Netherlands. In this section, the research design and the data collection are presented.

The scope is the economic optimisation of the aggregate energy storage system, i.e. the maximisation of profits or minimisation of costs, within the context of two developed electricity markets in the Netherlands, i.e. the day-ahead market (APX 2016), and the imbalance settlement system (TenneT 2010). The optimisation sub-problems are solved by utilising an energy storage model to schedule the charging and discharging processes over a time horizon. For the revenue analysis, the energy storage is modelled as a lossless process, i.e. excluding efficiency dependencies and associated energy losses. This design choice was driven by the research objective of computing the theoretical maximum revenues and presenting those in a generic form, i.e. per energy unit of effective storage capacity, without attributing those to a specific resource or technology, e.g. demand response of certain flexible loads, battery-based storage etc. The detailed model and the mathematical formulations of the different control strategies can be found in (Lampropoulos et al. 2015), including a sensitivity analysis about the effect of the storage system efficiency to the overall economic performance. Three control strategies are considered which address respectively, the application of energy arbitrage within the setting of the Dutch day-ahead auction in stand-alone mode; the passive contribution in the Dutch imbalance settlement system in stand-alone mode; and the combined energy arbitrage in the day-ahead market and passive contribution in the Dutch imbalance settlement system, i.e. hierarchical optimisation approach. The objective of the day-ahead optimisation is to maximise revenues from energy arbitrage in the APX day-ahead market, which is based on the two-sided auction model (APX 2016). By utilising available forecasts of the PV generation, the residential demand and the market clearing prices, the constrained optimisation problem is formulated as the minimisation of a cost function over a horizon of 24 h with discrete steps of 1 h. The passive contribution within the imbalance settlement system of the Netherlands is a voluntary scheme for participation in system balancing, which is attributable to the Dutch system organisation (TenneT et al. 2011). The Dutch TSO publishes the bid price ladder balancing table (TenneT 2016a), which includes price information for capacity bids offered for balancing; and the balance delta table (TenneT 2016c), which shows the most recent quantities that were requested for its operations. This combined information can be used by market participants to estimate the imbalance settlement prices. The imbalance settlement in the Netherlands is based on the net energy volumes per settlement period of 15 min (TenneT 2010).

For the day-ahead optimisation, historical data of the APX day-ahead market from 2000 to 2015 were utilised (APX 2016), whereas for the optimisation of balancing contributions the input consisted of historical data from the Dutch imbalance settlement system from 2001 to 2015 (TenneT 2016b). For the consumption profiles of the residential customers, the standard electricity consumption profiles of 2015 were utilised for the type of 3×25 A connections with single tariff counter (NEDU 2016). These profiles have been prepared on behalf of the

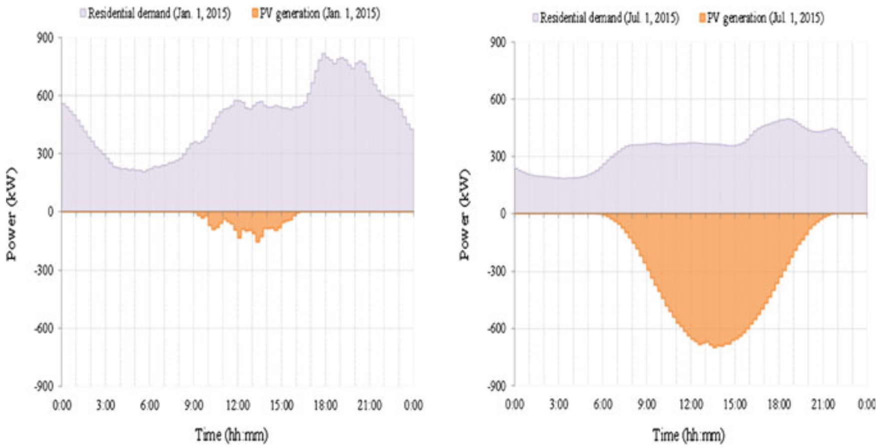


Fig. 4 Illustration of residential demand and PV generation power profiles for an aggregation of 1000 residences with a total of 1 MWp installed PV capacity for January 1st, 2015, and July 1st, 2015. Note that PV power generation is depicted in negative values

association of Dutch electricity grid operators, and represent the electricity demand per 15 min as a percentage of the annual electricity demand of a typical residence. In 2012, the average annual consumption of a typical residence in the Netherlands was 3495 kWh (Energie-Nederland 2014), and this figure was also used in this study. The PV generation profile was synthesised, based on actual metered data from 2015 with a resolution of 15 min. These data were collected from distributed PV systems, in the area of Utrecht, of an aggregate installed capacity of ~450 kWp, and were extrapolated to represent an aggregate installed capacity of 1 MWp. Missing data (due to errors with the data loggers) were completed with figures from adjacent dates. More information about the PV metered data can be found in (Vaz et al. 2016). The resulted profile provides a realistic potential of the annual PV generation. An example of the daily residential demand and PV generation is provided in Fig. 4.

3 Findings, Results and Analysis

3.1 *Elements of the Business Model Concept of an Aggregator Company*

Following the review in Sect. 2.2, a number of elements were identified that outline the various variations of emerging business models around the aggregator company concept. In this section, these elements are classified, under two categories, as *activity-specific* and *service-specific* characteristics. *Activity-specific* characteristics link to the particular knowledge of an aggregator company, e.g. regarding a process, resource, technology, technique, customer segment etc. *Service-specific* characteristics link to the focal services provided by an aggregator company, in relation to the distinct roles and responsibilities in deregulated environments. The following classification of identified elements is considered an advance in the process of systematically analysing and structuring the business model concept of an aggregator company. First, it supports the process of understanding the logic that drives the various business model implementations. Secondly, it can be used to identify potential organisational arrangements, within the various business model concepts; and to inquire the compatibility of those with established market designs and regulatory frameworks.

Identified elements of the business model concept of an aggregator company

- Activity-specific characteristics.
  - Targeted types of (flexible) technologies, e.g. aggregation of specific flexible technologies such as the charging of electric vehicles, versus aggregation of different types of flexible technologies.
  - Targeted types of (non-flexible and/or flexible) resources, e.g. aggregation of both flexible and non-flexible resources, versus aggregation of only flexible resources, which might be subject to additional requirements for sub-metering.
  - Targeted types of customers, e.g. aggregation of resources of specific types of customers such as residential, commercial, and industrial, versus aggregation of different types of customers.
  - Targeted techniques, e.g. utilisation of specific techniques for forecasting, communication, optimisation, and control purposes.
- Service-specific characteristics.
  - Energy trade at the wholesale level (BRP role).
  - Energy trade at the retail level (supplier role).
  - Pure service provision and no interaction with energy markets (service provider for another market party).
  - Balancing service provision to the TSO (BSP).
  - Other ancillary service provision to the TSO and/or DSO.

Each business model variation can be mapped to the above set of characteristics, and through this process it is possible to frame relevant requirements for implementation purposes. An example is provided in Table 2, where the aggregator company of the case study is mapped to the above set of characteristics; and to a number of pertinent requirements. By reviewing the above classification list of characteristics, it becomes apparent that, depending on the business model implementation, an aggregator company can potentially reach and build a wide range of relationships with various stakeholders. The stakeholder theory suggests that the idea of value creation in business is connected to the idea of creating value for stakeholders and questions what kinds of relationships the organisational members

Table 2 Mapping of identified characteristics to the aggregator company of the case study

Characteristic		Mapping of characteristics and pertinent requirements
1(a)	Targeted types of technologies	Non-specified types of flexible technologies, i.e. an aggregation of different technologies of energy storage and/or demand response
1(b)	Targeted types of resources	All types of flexible and non-flexible resources of an associated customer, i.e. PV generation, residential demand and flexible resources. Requirement for metering at the point of connection
1(c)	Targeted types of customers	Residential customers. Requirement for creating value for the associated residential customers
1(d)	Targeted techniques	Forecasting techniques for energy demand, PV generation and market developments, and optimisation techniques
2(a)	Wholesale trade	Requirements for being acknowledged as a BRP
2(b)	Retail trade	Requirements for being acknowledged as a supplier
2(c)	Pure service provision	N/A
2(d)	Balancing service provision	Passive contribution to balancing, which does not involve any additional requirements other than those related to 2(a)
2(e)	Other ancillary service provision	N/A

want and need to create with their stakeholders (Freeman et al. 2004). This seems to be a relevant question for every researcher or developer that conceptualises or implements business models around the concept of the aggregator company.

3.2 Case Study Results

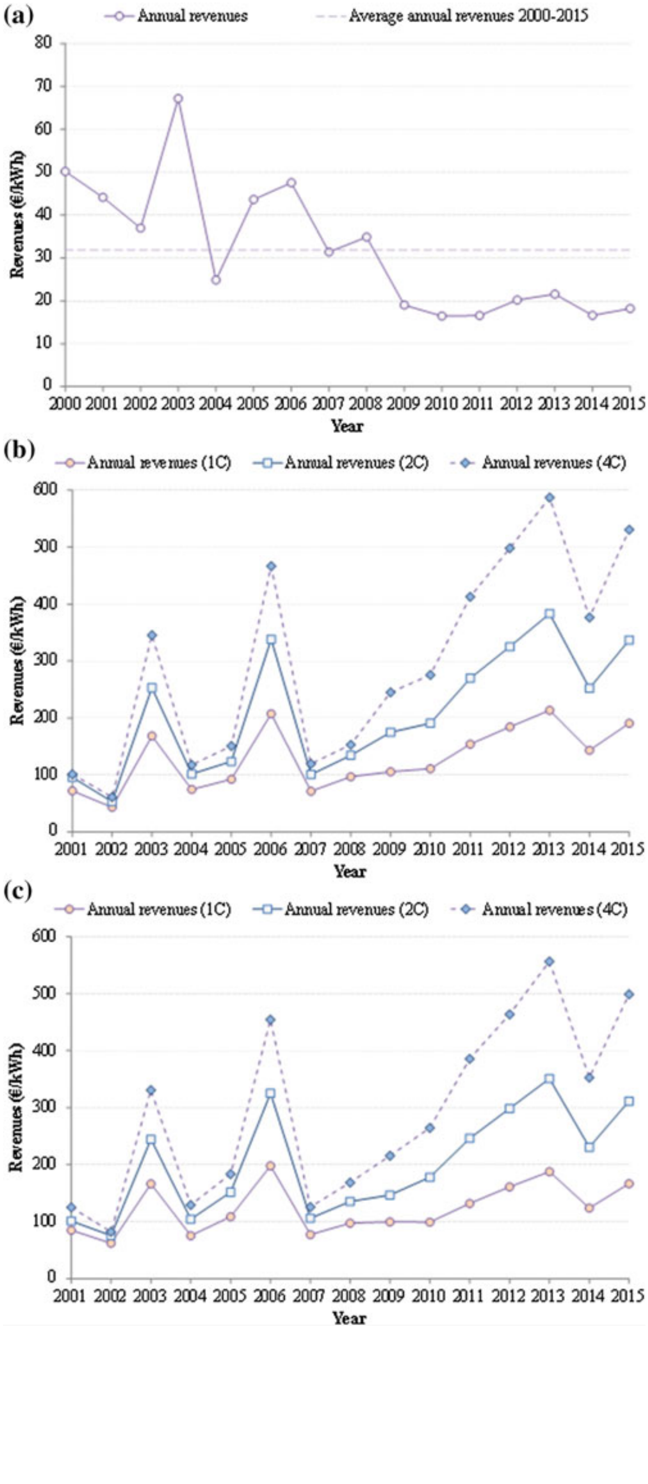
Business models seek to explain value creation and value capture (Zott et al. 2011). Although value is created by organisational members, it is argued that value capture is determined by the perceived power relationships between economic actors (Bowman and Ambrosini 2000). In order to determine value capture, a case study is performed which is about the hypothetical implementation of the business model of an aggregator company that combines both the roles of the supplier and the BRP. The focus is on an aggregate system, which consists of residential customers, local PV generation and distributed energy storage. An evaluation of the potential revenue from energy storage optimisation is performed with respect to the applications of energy arbitrage in the day-ahead market and passive contribution in system balancing (separately and in combination), based on historical market data from the Netherlands. The electricity demand costs with respect to the retail and wholesale market prices are estimated for both cases of including/excluding local PV generation.

In Fig. 5, the potential annual revenues are presented on a per (energy) unit basis and for all the years since the beginning of the day-ahead market and the imbalance settlement system in the Netherlands. These results can also be interpreted as performance indicators of the development of both markets through the years. The results reflect the optimisation of an energy storage system that can be fully charged/discharged within 1 h, 30 min and 15 min respectively, in analogy with the battery charge rates 1, 2 and 4C. Note that the charge rate of a battery, which is often denoted as C-rate, signifies a charge or discharge rate equal to the capacity of a battery in 1 h. For our purposes, a higher charge rate represents a more flexible resource. For the day-ahead market, it is indifferent to distinguish between 1, 2 and 4C, as the settlement period is 1 h and the results would look identical. However, the settlement period in the imbalance settlement system is 15 min, and therefore it is of interest to assess the results for different C-rates.

The day-ahead optimisation results are presented in Fig. 5a. Overall, the computed revenues from day-ahead market arbitrage are declining throughout the years; and are about 2.8 times less in 2015 compared to 2000, but this is also the case for the historical price volatility in the APX day-ahead market (Lampropoulos 2014), thus suggesting that market opportunities are decreasing with respect to the specified application. Price volatility is expected to be an important driver for the development of flexibility options, such as energy storage and demand response, which can take advantage of price differences. A study has attempted to determine volumes and prices of flexibility on the future day-ahead market given a scenario with increasing levels of intermittent renewable energy generation (Van Hout et al. 2014). The results show that next to an increase in the demand for flexibility, there will also be an increase in price volatility and the average price in the year 2023 will be considerably higher compared to 2012 and 2017, given the assumptions for higher coal and gas prices in 2023.

In Fig. 5b, the computed revenues are depicted for the case of the stand-alone passive contribution in the imbalance settlement. As can be seen in this figure, the general trend is that the potential revenues from passive balancing are increasing throughout the years; and are about 2.6, 3.3, and 5.3 times larger in 2015 compared to 2001 for the charge rates of 1, 2 and 4C respectively. The random distribution of potential annual revenues, depicted in Fig. 5b, is mainly driven by the development of system states and imbalance prices throughout the years. The nature of the imbalance market is highly stochastic. The development of system states and the amplitude of imbalances, within a control area, are driven by a number of factors related to cross-border trade, weather phenomena, and the portfolios of BRP, whereas the development of imbalance prices is also driven by the bidding strategies of BSP. Passive contribution in system balancing can be an additional source of revenues for decentralised market participants, though, the provision of control energy through passive contribution is delivered at the participant's own risk and might jeopardise any contractual payments (TenneT et al. 2011; Lampropoulos 2014).

In the case of hierarchical optimisation, the output of the day-ahead optimisation is employed as input in the optimisation for passive balancing, which results to


(a)
Annual revenues
Average annual revenues 2000-2015
Revenues (€/kWh)
0
10
20
30
40
50
60
70
80
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015
Year
(b)
Annual revenues (1C)
Annual revenues (2C)
Annual revenues (4C)
Revenues (€/kWh)
0
100
200
300
400
500
600
2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015
Year
(c)
Annual revenues (1C)
Annual revenues (2C)
Annual revenues (4C)
Revenues (€/kWh)
0
100
200
300
400
500
600
2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015
Year

◂**Fig. 5** Computed maximum annual revenues from energy storage optimisation. **a** Exclusive participation in the APX day-ahead market, i.e. stand-alone day-ahead market arbitrage optimisation. **b** Exclusive contribution in the Dutch imbalance settlement system, i.e. stand-alone passive balancing optimisation. **c** Combined energy arbitrage in the day-ahead market and passive contribution in the Dutch imbalance settlement system when part of the capacity has been committed for the day-ahead market, i.e. hierarchical optimisation approach

additional constraints due to day-ahead commitments. In Fig. 5c, the computed revenues are depicted for the case of the hierarchical optimisation approach, i.e. combined revenues from both energy arbitrage in the day-ahead market and passive contribution in the imbalance settlement system. The simulation results show that, on average, the computed revenues for the case of the hierarchical optimisation approach are slightly less compared to the case of the stand-alone passive contribution in the imbalance settlement system. This is mainly due to the energy commitments that are made day-ahead, which restrict the full potential in the imbalance market.

In order to analyse the potential of an aggregate system, the simulation scenarios address an aggregation of 1000 residential customers, equipped with the options of local energy generation based on distributed PV technology (1 kWp per customer), and energy storage or demand response (equivalent to 1 kWh per customer). In Fig. 6, the results for all the different simulation scenarios are illustrated on a per customer basis for the reference year 2015.

The scenarios address: the electricity demand costs (scenarios 1–4) with respect to the retail and wholesale market prices, for both cases of including/excluding PV generation; and the potential revenues from energy storage optimisation (scenarios 5–11) with respect to the different control strategies described in Sect. 2.3. The focus is on the energy component, which effectively represents the possibilities for end-user cost reduction through switching to another supplier. In theory there should be an apparent relationship between retail and wholesale electricity prices, but in practice the correlation is low (Dromacque and Bogacka 2013). The scenarios 1–4 address the margin for retail customers cost reduction between the day-ahead wholesale and the retail price. The end-user electricity price (including taxes) in 2012 in the Netherlands was 19.28 c€/kWh, whereas the price breakdown corresponded to 43% for the energy component (including retail margins), 31% for distribution, 10% for energy taxes and 16 percent for value added tax (VAT) (Dromacque and Bogacka 2013). In the second half of 2014, the electricity price for residential customers (without taxes and levies) was 12.69 c€/kWh (Eurostat 2016). Assuming that 31% of the electricity price corresponds to distribution, based on the above mentioned price breakdown, the energy component (including retail margins) for the reference scenario corresponds to 7.32 c€/kWh. For the wholesale electricity price the APX day-ahead market clearing prices were utilised (APX 2016). In the case that PV generation exceeds the aggregate demand, the excess of energy is assumed to be supplied to the network at the corresponding retail or wholesale market price at that time period.

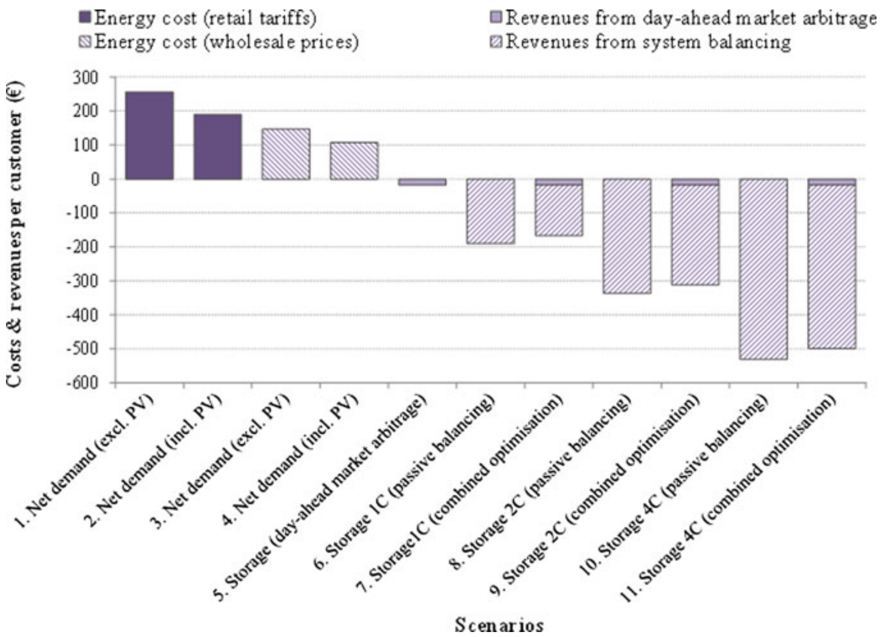


Fig. 6 Overview of annual costs and revenues per customer for all scenarios and for the reference year 2015. The case study is about an aggregation of residential customers where each customer is equipped with 1 kWp of PV capacity and with demand response or energy storage capacity equivalent to 1 kWh. Note that revenues are depicted in negative values

As can be seen in Fig. 6, the difference between the net demand costs for the two cases of retail and wholesale prices is about 42.5% when PV is excluded, and 43.3% when local PV generation is included, which outlines the opportunities for the aggregator company in taking advantage of price differences between spot markets and the retail price for electricity. In most of the energy storage optimisation scenarios 5–11, the revenues exceed the net demand costs corresponding to scenarios 1–4, outlining opportunities especially with respect to balancing contributions.

4 Discussion and Conclusions

Sustainable development of urban areas requires new, efficient, and user-friendly technologies and services, especially in the areas of energy, transport and ICT. In this context, the concept of the aggregator company, a new entrant in the energy market, is expected to take advantage of deployment synergies between smart grid technologies and smart city initiatives.

In recent years, several business models of the aggregator company have emerged in Europe, in response to a general quest for flexibility in power systems, which is mainly driven by the increasing integration of renewable energy sources and the ongoing deregulation of electricity markets. This work contributes to the systematic development of the business model concept of an aggregator company, and provides insight into its economic potential. The main contributions are about a set of identified characteristics that describe business model variations around the concept of an aggregator company, and a case study evaluation of potential revenues by focusing on two developed electricity markets in the Netherlands, i.e. the day-ahead market and the imbalance settlement system. The set of identified characteristics is an essential advance in the process of systematically structuring the business model concept as it supports the development of new flexibility services and appropriate regulatory frameworks. The outcome of computer simulations provided an informative insight into the historical potential of the investigated markets. Results show a significant theoretical potential of offsetting electricity costs and generating additional revenues for residential customers equipped with PV systems and with demand response or energy storage capacity. The simulation results show that the contribution to system balancing is a more profitable strategy, compared to the application of energy arbitrage in the day-ahead market; and this is mainly driven by the larger price spread and the more frequent occurrence of large price spreads in the imbalance market. However, the risks associated with the imbalance market are higher due to its stochastic nature. Therefore, through the hierarchical optimisation approach, the associated risks can be considerably compensated by giving preference to participation in the day-ahead market that is characterised by a diurnal pattern of prices, which makes the forecasting of day-ahead market prices more plausible.

A few limitations of this study should be considered. The electricity costs and potential revenues were computed under the assumption of accurate predictions, by utilising historical market data. Therefore, the computed revenues reflect the theoretically maximum. In a real-life application, forecast errors will inevitably occur and the potential revenues will always be dependent on the accuracy of the forecasting methods. An aggregator company has to plan and operate within an uncertain environment, and in order to deal with forecast errors and alleviate the adverse effects on its economic performance, robust control methods and risk management techniques should be developed. At last, the outcome of a revenue analysis alone cannot be considered as conclusive about the economic viability of certain business models. Emphasis was given on evaluating the potential revenues from the specified applications, although, in a real-life competitive environment the optimisation objective shall reflect the maximisation of profit, i.e. the excess of revenue over cost.

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