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Business models design space for electricity storage systems: Case study of the Netherlands

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ABSTRACT

Because of weather uncertainty and dynamics, power generation from some renewable energy technologies is variable. Electricity storage is recognized as a solution to better integrate variable renewable generation into the electricity system. Despite considerable growth in the research on the electricity storage, implementation of electricity storage systems (ESS) is globally negligible because of technical, institutional, and business model challenges. We use literature review and data analysis to provide a conceptual framework and a design space for ESS business models in the case of Dutch electricity sector by taking technological, institutional, and business model considerations into account. We provide a map of single-application business models for ESS in the Netherlands which can be used as a basis for making ESS application portfolios and evaluating ESS business models in other parts of the world as well. Furthermore, this research can be used to inform models that explore the evolution of ESS.

1. Introduction

The power sector contributes a considerable share of global CO₂ emissions [1], and a solution which has been followed by many countries to manage the emissions is development of renewable energy technologies. The Netherlands is required to meet targets of EU energy packages, and it has implemented some policies to meet the targets. For example, the EU 2020 climate energy package sets three targets for the year 2020. The targets are a 20% reduction in greenhouse emissions (from 1990 levels), a 20% increase in the share of renewables in energy consumption, and a 20% increase in the energy efficiency. However, power generation from many renewable technologies such as wind and solar PV is not fully controllable. The electricity generation from these technologies is variable, and there is a need to cope with the variations imposed by electricity generation from such renewable sources.

A possible solution to deal with variability of renewable generation is energy storage because it separates the time of generation from the time of consumption in an electricity system. Despite significant growth in research on energy storage systems [2], their implementation is still

negligible. Currently worldwide energy storage capacity is about 146 GW, and is dominated by conventional pumped hydro (more than 90% by the end of 2015) [3]. In the Netherlands, the energy storage capacity is about 16 MW (by mid-2017) [4].

Energy storage globally faces several technical, institutional, and economic challenges. Energy storage technologies are constrained by their technical characteristics, such as rated power, discharge duration, round-trip efficiency, etc. to provide their products and services. In addition, there are many regulatory barriers for operation of energy storage systems across the electricity sector. Furthermore, within the current regulatory frameworks, lack of viable business models is a challenge for implementation and operation of energy storage systems [5,6].

The objective of this paper is to provide a conceptual framework and a design space for electricity storage business models in the Netherlands. We use literature review and data analysis methods to develop the design space for potential single-application business model for electricity storage. The design space is constrained by technological, institutional, location, and business models considerations.

Abbreviations: ACM, authority for consumers and markets; APX, amsterdam power exchange; CAES, compressed air energy storage; CES, cryogenic energy storage; CS, capacitor storage; DSO, distribution system operator; ESS, electricity storage system; EPC, energy performance contracting; ESCo, energy service company; FES, flywheel energy storage; Li-ion, lithium-ion; NaS, sodium-sulfur; Ni-Cd, nickel-cadmium; PCR, primary control reserve; PHS, pumped hydro storage; RET, renewable energy technology; SCES, super capacitor energy storage; SCR, secondary control reserve; SMES, superconducting magnetic energy storage; T&D, transmission and distribution; TCR, tertiary control reserve; TSO, transmission system operator; VRB, vanadium redox battery; ZnBr, zinc bromine

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This paper is organized as follows: In Section 2, we elaborate on the status of energy storage systems (ESS) and the energy business environment in the Netherlands. In this section, we define ESS and its applications, the structure of the Dutch electricity sector, and the institutional barriers for implementation of ESS in the Netherlands. Then, in Section 3, we introduce business models and explain the main processes for design of business models. In Section 4, we elaborate on the components of an ESS business model in the context of the Netherlands. Section 5 combines business model components and synthesizes a design space for ESS business models. In Section 5, we provide an overview of single-application business models for ESS, and we elaborate on stacking of benefits, and uncertainty of ESS business models. We will conclude the paper by reviewing the main findings, limitations of our study, and opportunities for future research.

2. Background

2.1. Electricity storage systems (ESS)

2.1.1. Definition of electricity storage system (ESS)

Electricity storage system (ESS) is a class of energy storage system. The main function of energy storage systems is “moving energy over time” [7]. Generally, an energy storage system is described as a set of interacting components which enables receiving electricity at one time and dispatching it later. Energy storage involves three physical processes: (1) converting electricity to a medium, (2) storing the intermediate energy, and (3) converting this energy back to electricity [8]. The first and the third processes are charging and discharging processes, respectively. In the energy storage literature, these two processes might be analyzed under a single power conversion sub-system [9].

In addition to the three aforementioned processes, the monitoring and control process forms another important component of an energy storage system that governs the whole system [10]. Furthermore, the interface between the grid and the charging/discharging system can be a system itself [11]. The interface becomes important especially when the energy requirements of the charging system or output of the discharging system are not compatible with the grid energy. For example, if the charging system works with DC power, there is a need for an AC/DC conversion system as an interface between the charging system and the grid. Fig. 1 shows five components of an energy storage systems.

The storage unit which performs storage in the intermediate medium is the most important component of the system. The medium and the technology used in this component determine the main technical constraints of the whole system.

There are several classifications for energy storage systems. Energy storage systems can be classified into two groups based on mobility of the system: stationary storage and mobile storage [12]. Some energy storage technologies such as batteries can be employed by both stationary and mobile systems. A number of energy storage systems are naturally stationary systems because they adopt geographically dependent technologies and because they provide grid-scale services. The stationary energy storage has become more and more important in recent years [13]. In addition, energy storage systems can be classified based on types of their inputs and outputs. The input of an ESS is either electricity or heat. But the output can be electricity, heat, or different gaseous or liquid fuels [5,14]. When both input and output of the energy storage system are electricity, its process is called “power-to-power” process [14].

In this research, we investigate stationary power-to-power energy storage systems which is referred to as electricity storage systems (ESS) in the remainder of the paper.

2.1.2. Applications of ESS

ESS has variety of applications across the power sector. These applications can be classified in different ways [2,7,15–23]. Battke and Schmidt [16] provides a classification for potential energy storage applications which maps the services based on the source of economic value and the location of the services in the electricity value chain (see Fig. 2).

The sources of potential economic value for energy storage are: power quality, power reliability, higher utilization of assets, and arbitrage (Fig. 2). In the electric power systems, power quality refers to voltage, frequency, and waveform [24]. Energy storage can provide economic value by adjusting voltage and frequency. In addition, the location of services varies from the generation side to the consumption side. At the generation side, energy storage can provide economic value both for fossil fuel-based technologies, and for renewable energy technologies. At the consumption side, the size of consumers who deploy energy storage systems varies from industrial-scale consumers to households. As it is differentiated in Fig. 2, some energy storage applications are directly supporting integration of renewable energy

Fig. 1. Energy Storage Systems, synthesized and adapted from models of Zakeri & Syri [9], Quanta Technology [10], and Akinyele & Rayudu [11] - Main processes of energy storage systems include charging, keeping energy at storage unit, discharging, monitoring and control, and required conversions in interfaces.

^a RETs refers primarily to intermittent, non-deterministic renewable energy technologies

Fig. 2. Classification of potential energy storage applications, reproduced from Battke & Schmidt [16] – Sources of economic value for energy storage applications can be grouped into four groups: Power quality, Power reliability, Increased asset utilization, and arbitrage. The applications have benefits for various locations of the electricity system from generation side to end-consumer side. In addition, the potential ESS applications have different degree of relevance to renewable energy technologies (RET).

technologies (RETs), whereas some applications indirectly support integration of RETs. (for detailed description of ESS applications, see Battke & Schmidt [16])

With more penetration of renewables, and the important applications that ESSs can provide, we might expect a high implementation of ESS across the world. However, the global implementation of ESS is not significant yet. The sum of global installed ESS and thermal storage capacity is about 146 GW dominated by conventional pumped hydro capacity (as of the end of 2015) [3]. In the Netherlands, there is 16 MW of installed storage capacity (as of mid-2017) [4]. The low implementation of ESS in the Netherlands can be analyzed from the perspective of the electricity generation and the regulatory frameworks in the Netherlands.

2.2. Positioning ESS in the Dutch electricity Sector

2.2.1. ESS in the Dutch electricity supply

Generally, one incentive for implementation of ESS is supporting variable renewable generation, however the share of renewables in Dutch electricity generation is still low (see Fig. 3), and the Netherlands is generally behind its desired pace to achieve its 14% renewable energy target by 2020 which is set by the EU [25,26]. The installed power generation capacity in the Netherlands is highly dependent on natural gas and coal, thanks to the Dutch natural gas reserves, and relatively cheap imported coal. Due to this problem, renewable generation technologies are not competitive in the Netherlands. Therefore, the small share of renewable generation is one of the reasons for the low implementation of ESS in the Netherlands.

Furthermore, even in presence of more variable renewable

generation, the share of such generation must exceed certain levels to justify the development of the ESS. For example, in the US, up to 20% of variable renewable generation (on annual basis) can be economically accommodated by the grid itself, and for higher shares of variable generation, flexibility options will be required to manage the variable generation. In addition, when the flexibility options are needed, the options with lower costs such as demand response may outrank ESS [27].

Nevertheless, the Netherlands is seeking to reduce its carbon emissions to reach its environmental targets and it necessitates development of variable renewables. The electricity sector is very important in this policy as power generation (together with heating) has the highest share of CO₂ emissions in the Netherlands [25]. Although electricity generation in the Netherlands is highly dependent on fossil fuels, with the outlook of diminishing gas reserves and the climate challenges, various policies are formulated and pursued in the Netherlands to reach a sustainable energy system. Currently, the Energy Agenda [28] and the Energy Agreement [29] dictate the Dutch energy policy. In the Energy Agenda, the goal of the Netherlands is to reduce the CO₂ emissions of the Netherlands to about zero in 2050. In addition, although the Netherlands is active in the EU emission trading scheme, the Agenda provides additional measures to achieve CO₂ reduction goals. Furthermore, According to projections from the Energy Agreement, the share of electricity generated from wind and solar exceeds 32% in 2023 (see table A.13 in Ref. [30]).

2.2.2. ESS in the regulatory framework of Dutch electricity Sector

2.2.2.1. Roles and actors in the Dutch electricity Market.

The Dutch electricity market is a very competitive market, and many

Fig. 3. Electricity generation in the Netherlands by fuels type- data from [31].

actors are active in this market who play different roles and have different and even conflicting interests. The Dutch electricity sector used to be state-owned and vertically integrated before 1989, and its structure began to change by the Energy Act of 1989 [32]. Key elements of the evolution of the electricity market in the past three decades have involved the unbundling of activities, market liberalization, and regulation of natural monopolies. As van Damme [33] describes, the major step for liberalization of the electricity market was taken by the Energy Act of 1998. According to this act, all competitive activities needed to be legally unbundled from monopolistic activities. With enforcement of this act, the generation section became free of regulation, and the consumption section gradually liberalized. Following this act, DTe was established and appointed by Dutch government for supervision and regulation of the electricity market in the Netherlands. DTe is currently a department within Authority of Consumers and Markets (ACM) in the Netherlands. After implementation of the Act, Tennet was established as a regulated and state-owned Dutch transmission system operator (TSO). Tennet also bought APX, the operator of electricity markets. In addition, in late 2000s, the Dutch government opted for ownership unbundling of activities in the distribution grids which required separation of all monopolistic grid activities from commercial energy supply activities at the distribution level (see [34] for more details). Currently, next to Tennet which manages the high-voltage grid, there are eight regulated distribution system operators (DSOs) in the Netherlands which manage low-voltage grids [35].

Contrary to grid operation, which is a natural monopoly activity, other activities are competitive in the Netherlands and the government has no share in any of such businesses. At the generation side, there are four major **power generation companies** which operates 55% of installed capacity in the Netherlands [36], next to many other smaller power generation companies. In addition, the task of selling electricity to the **end consumers** is performed by other companies which are called **energy traders, suppliers, or retailers**. Energy suppliers use transmission and distribution grids and supply electricity to the end consumers in coordination with the grid operators. There are eight large energy suppliers in the Netherlands whereas, in total, more than 40 energy suppliers are currently active in this country [37]. In addition, all consumers have freedom to select their suppliers. The highest share of electricity consumption in the Netherlands belongs to the commercial sector (including public services, agriculture, and forestry); and the industrial and residential sectors hold the second and the third ranks in consumption, respectively [25].

In addition to the aforementioned actors, **energy service providers/suppliers or energy service companies (ESCO)** are emerging.

ESCO refer to a “natural or legal persons who deliver energy services or other energy efficiency improvement measures in a final customer’s facility or premises” [38]. ESCOs are not necessarily part of electricity market, but their activities can influence supply and demand of the main market participants.

Next to the government which formulates and enforces policies, other incumbent actors who are active in the Dutch electricity sector can be categorized into four groups: 1) regulated grid operators, 2) competitive energy companies, 3) end consumers, and 4) market operators.

2.2.2.2. Challenges of ESS in the Netherlands.

Competition with other market players is a key for ESS in order to develop in the Dutch electricity sector. However, the competition comes with a number of challenges and barriers. Generally, these barriers for ESS can be classified into regulatory barriers and market barriers. Regulatory barriers are those which are caused by laws and regulations, and market barriers refer to design and state of markets which influence the economic value of an ESS. The main barriers for implementation of ESS across the world have been studied by a number of researchers [6,39–41], and the most comprehensive list of ESS regulatory barriers is provided by Anuta et al. [6]. Most of the regulatory barriers have their root in the lack of legal classification for ESS, prohibition of grid operators from ownership of ESS, and lack of incentives for time-shift of generation/consumption. Here, we explain the most relevant ESS regulatory barriers in the Netherlands:

- **Lack of legal classification for ESS:** Because the current regulatory framework is set according to conventional technologies, ESS fall within the definition of both producer and consumer of energy. This increases the complexity of ESS development as operation of ESS needs to comply with both producers’ and consumers’ rules (further explanations can be found in [6,39–45]).
- **Double Taxation:** In the Netherlands, consumers of electricity need to pay tax for their consumption, and because there is no legal classification for energy storage in the current regulatory framework, energy storage needs to pay consumers’ tax at the charging time. Then, when it discharges and delivers electricity to its customers, the end-customers need to pay consumers’ tax again. This double taxation increases the costs of delivered energy and limits the profitability of ESS (See Refs. [6,40,44,46]).
- **ESS is not defined as renewable energy resource:** ESS can store and deliver the electricity from any source. The source can be a coal power plant, in which the ESS can even contribute to CO₂ emission (see an example in Ref. [47]). Therefore, although ESS enables

integration of renewable energy sources to the electricity grid, because it is not defined as a renewable source itself, it cannot benefit from renewable energy incentives (See Refs. [6] and [48]).

- **Prohibition of TSOs and DSOs from ownership of ESS:** Unbundling of activities resulted in prohibition of grid operators from ownership of ESS [45]. Following legislation of the Energy Act of 1998 and the EU third energy package, TSOs and DSOs are not allowed to undertake any commercial activity. Therefore, because ESS function falls within definition of production and consumption of energy, and it necessitates buying and selling of energy, ownership of ESS is prohibited for the regulated businesses. At the European level, there might be some exceptions where DSOs can operate ESS (see [49] for more details). In November 2016, the European Commission [50] published a proposal on clean energy for all Europeans (Winter Energy Package) which highlights the role of energy storage and declares some conditions in which DSOs can develop energy storage. However, at the national level, there were attempts to forbid TSO and DSOs from any form of trading electricity such as “voortgang energietransitie” proposal for Amendment of Act of Independent Network Management in 2017–2018 [51].
- **Lack of regulatory framework for provision of T&D investment deferral:** In the Netherlands, not only it is forbidden for TSOs and DSOs to own ESS, there is not a clear regulatory framework through which they can benefit from services provided by other ESS owners that helps deferral of grid reinforcement investments. Lack of framework for provision of such services can be a real challenge for ESS because the value it can provide for T&D investment deferral is potentially greater than value of many of its other applications according to some leading studies [19] (see Refs. [6] and [40]).
- **Net metering:** Consumption of electricity for the majority of Dutch consumers is measured by net metering systems. In case the consumers produce energy (such as households with PV systems on their rooftops), net-meters calculate and show the difference between consumption and generation of electricity. Net-metering is a great financial incentive and an inherent subsidy for decentralized generation by household. However, because the time of consumption or generation is not taken into account in net-metering scheme, it is a disincentive for behind-the-meter storage as it undermines the value of time shift of consumption or generation. A change from net metering scheme to smart metering scheme could be an incentive for behind-the-meter energy storage business models. (See Refs. [52–54])

Problems in the regulatory and market environments, and a lack of viable business models are considered as barriers for the development of ESS worldwide [5,6]. Therefore, there are two conceptual ways for supporting implementation of ESS in the Netherlands: 1) changing regulatory frameworks to support ESS, and 2) finding viable business models for ESS such that ESS can make a sustainable profit. Changing regulatory frameworks is a very complex and time-consuming process. On the other hand, implementation of ESS is not a goal for policy makers and regulators, and it is considered as a means to achieve the goals. What policy makers do, and need to do, is to insure a level playing field for all the technologies and solutions to enter the market and solve the economic and energy problems. Therefore, some minor amendments can take place in rules and regulations of the electricity market, but we do not expect revolutionary change in the regulatory framework. However, developing business models can be an option to support implementation of ESS.

3. Business models design

3.1. Business models

To have a feasible business, we need to think about how our business is going to perform and how can we make profit. Therefore, we

need a conceptual model for running the business. This model is called a “business model”. There are various ways to describe a business model [55]. Taran et al. [56] explains that there is an agreement in the literature that a business model is a “model of the way in which a company creates and delivers value so as to generate revenue and achieve a sustainable competitive position.”

As a common language for thinking about and communicating business models, several business model frameworks (or ontologies) have been developed [55–59]. Each framework is composed of a set of inter-related components, and the frameworks have some components in common. We investigate the components of business models for ESS in the context of the Netherlands’ electricity sector. The components are mostly selected from the Business Model Canvas of Osterwalder & Pigneur [59]. These components are 1) Customers, 2) Value Proposition, 3) Channels, 4) Revenue Streams, 5) Resources, and 6) Costs. In addition, we will analyze location of ESS as a component for its business model because of its relationship with value propositions and resources.

3.2. Design of business models

Developing business models for ESS can be translated to a design problem: “What set of choices for components of a business model can make the ESS business profitable and sustainable?” Herder & Stikkelman [60] explains a design process has various sub-processes including development of design goals, design objectives, design constraints, design space, and conducting tests, where the objectives are a selection of goals to be optimized, the constraints are a selection of goals to be met, and the design space is “superset of design components and variables”. In other words, the design space is a set of alternatives for design variables, and “designing is selecting an instance in the design space that meets the objectives and constraints” [60].

In this paper, we elaborate on the different alternatives for ESS business models components and their constraints in the context of the Netherlands.

4. Variables and constraints for ESS business models in the Netherlands

4.1. Customers for ESS products and services

The actors in the electricity market are introduced in Section 2.2.1. The actors enact various roles in the markets. Actors are classified based on their physical properties, and the roles they enact in the market. Energy companies can enact only an electricity generation role, retailer role, or trader role, or it can enact a combination of these roles. Grid operators can enact roles of either TSO or DSO. End-consumers can enact either role of end-consumer, or a combination of end consumer and electricity generation (prosumer).

Energy companies and end-consumers can buy both electricity and services from the ESS owner/operator, while grid operators are prohibited from buying electricity, but they may buy services from ESS owners/operators.

4.2. Value propositions

Value propositions of ESS are directly linked to ESS applications, however the declaration of value propositions could be slightly different from the name of a service or an application. Table 1 illustrates a way for formulating value propositions for classes of ESS applications previously discussed in Section 2.1.2.

4.3. Channels

Osterwalder & Pigneur [59] explain that ‘channels’ are ways through which a company can deliver its products and services to customers. Owners/operators of an ESS can reach their customers in

Table 1
Sample value propositions of ESS products and services.

Application/Service	Example declaration of value proposition
Load Following	Reduce sourcing or balancing costs [61]
RET Arbitrage	Reduce sourcing costs [61] Buy low and sell high [62] Reduce peak load [63]
Wholesale Arbitrage	Reduce sourcing costs [61] Buy low and sell high [62]
Area & Frequency Regulation	Maintain system stability and reliability [61]
Support of Voltage Regulation	Avoid grid reinforcement [61] Reduce the need for new equipment to manage reactive power [63]
Reserve Capacity	Maintain system stability and reliability [61]
T&D Investment Deferral	Delay/Avoid grid reinforcement [61] [64], Optimize asset use [61]
RET Firming	Reduce sourcing costs, Reduce risk of curtailment [64] Create dispatchable resource [62] Reduce amount of frequency regulation reserves [63]
Black Start	Reliability [62] Allow start-up of de-energized, isolated systems for restoration or to enable islanded operation [63]
RET Smoothing	Create dispatchable resource [62] Avoid penalty [65] Increase RET Profit [65] Reduce amount of frequency regulation reserves [63]
End-consumer Arbitrage	Reduce energy costs [61] Buy low and sell high [62]
End-Consumer Power Quality	Reduce/avoid negative effects and costs associated with poor power quality [66]
End-consumer Power Reliability	Reduce/avoid negative effects and costs associated with electrical service outages [66]
Increase of Self-consumption	Reduce sourcing costs [61]

various ways based on the customers, and the specification of products and services. In general, these channels can be classified into various markets. In the wholesale markets for electricity and services, in addition to bilateral negotiations, customers can be reached through a market operator. In addition, in the retail market for energy and services, customers can be reached directly by sale forces or through IT-based channels.

4.3.1. Wholesale Market, balancing, and ancillary services

There are a number of markets for the wholesale trade of electricity, and for keeping the balance of the electricity system (see Fig. 4 and [67] for more details). The electricity can be traded via traditional bilateral contracts or via spot markets. The spot markets are organized based on the time distance to delivery time and include forward and future, day-ahead market (DAM), and intraday market (IDM). IDM closes 5 min before the actual delivery.

Following closure of the markets, the actual supply or load of electricity may deviate from planned programs of responsible parties. Tennet employs balancing products and services to guarantee that the supply and demand are in balance. Balancing services include balancing energy and balancing capacity where the former refers to flexible generation or consumption, and the latter refers to a contracted option to dispatch balancing energy on call [69]. The main balancing services are primary control reserve (PCR)¹, secondary control reserve (SCR)², and tertiary control reserve (TCR)³. PCR, activates within few seconds following any deviation in system frequency [70] and stabilizes the system's frequency, but it does not bring the system frequency back to the reference value [71]. Following the primary control, fast reserves such as SCR and TCR restore the system frequency to the reference value.

PCR is procured through weekly auctions and the price is based only on the capacity. For SCR and TCR, Tennet put capacity contracts out to tender every year which oblige the contracted parties to bid for balancing for each 15 minutes. In addition to contracted parties, other market participants can bid for upward and downward balancing power. The remuneration for contracted parties is based on their bids, and the remuneration for other participants is based on marginal pricing [68].

The term “ancillary services” is also used for services which help TSOs to guarantee system security. In addition to control reserves, ancillary services include reactive power, and black start capability as well [72] where the reactive power helps to maintain the voltage of the grid [73] and black start capability provides the ability to restart the

grid following a blackout [74]. Tennet procures reactive power through yearly bilateral contracts with generation units, and the contracts may have fixed fees or variable hourly fees. Moreover, black start capability is procured via yearly contracts (or longer periods) which contain fixed fees. Providers of black start capability must be able to start generation without any support or any external energy source [73].

Participating in the wholesale markets comes with some challenges for ESS. There are a number of market barriers for implementation of ESS, among worldwide market barriers reviewed by [6,39–41], we found three barriers which are relevant for the Netherlands:

- **Minimum Capacity:** One of the market rules which limits the chance of ESS in the current markets is the minimum capacity required for entering those markets. For example, the capacity of many current battery systems are less than 1 MW, but the minimum bid in PCR, SCR, and TCR markets are 1 MW, 4 MW, and 20 MW, respectively [73], which prevents those ESSs from participating in such markets.
- **Availability requirements:** Participating in some markets reduces the chance of the ESS to benefit from other markets. For example, in the PCR market, the ESS is required to keep the energy for a period of 30 minutes and wait for an alert. As this period becomes longer, the chance of ESS to sell its electricity to other customers decreases and it is against the economic feasibility of ESS.
- **Limiting the price spread:** one source of value for ESS is arbitrage. In arbitrage, when the price is low ESS buys electricity, and because it is increasing the demand in the market, the price will increase. On the other hand, when the price is high and the ESS sells its electricity, because of increase in supply, the price will decrease. Therefore, the arbitrage activities by ESSs will result in tight price spread which will reduce its profitability. So, although arbitrage can be a good incentive for development of ESS, increasing the number of ESS in the market can be a threat for arbitrage itself.

Some market barriers such as a minimum capacity barrier are related to the design of the market, and some are related to market mechanisms and resource allocation of an ESS itself. Market design can gradually change, but dealing with resource allocation needs smarter planning and scheduling by the ESS operator.

4.3.2. Retail Market

The small and medium end-consumers may own ESS, however do not participate in the wholesale market and they receive their energy from energy suppliers (or retailers). The retail market (or tariff market) is therefore market of bilateral contracts between the suppliers and end-consumers. In the bilateral contracts, end-consumers may select many products such as green energy with specified source (such as wind) or

¹ Also called Frequency Containment Reserve (FCR)

² Also called Frequency Restoration Reserve (FRR)

³ Also called Replacement Reserve (RR)

Fig. 4. Organization of Dutch electricity market – adapted from [68] and [67].

unspecified source, or just gray energy (other mixture). These products are offered by the suppliers in the form of various types of contracts including “fixed-price”, “variable price”, “partially fixed”, etc. [75] The type of retail contract and its tariffs influences the costs, revenues, and uncertainties of behind-the-meter ESS business models.

4.3.3. Service market

ESS may be implemented via Energy Performance Contracting (EPC) which influences the structure of costs and revenues of ESS. In addition to markets which aim to deliver energy to the end-consumer, there is also an emerging market in the Netherlands for EPC [76]. Directive 2012/27/EU defines EPC as “a contractual arrangement between the beneficiary and the provider of an energy efficiency improvement measure, verified and monitored during the whole term of the contract, where investments (work, supply or service) in that measure are paid for in relation to a contractually agreed level of energy efficiency improvement or other agreed energy performance criterion, such as financial saving”. Therefore, energy service companies (ESCOs) may sign bilateral contracts with end-consumers to invest in ESS solutions and benefit from improved energy efficiency and cost savings.

4.4. Revenue streams

To be economically feasible, ESS needs to generate cash or savings. Osterwalder & Pigneur [59] enumerate generic ways of generating revenue streams such as asset sale, usage fee, subscription fees, lending/renting/leasing, licensing, and brokerage fees. In ESS business, asset sale involves transferring ownership of physical products such as

energy (e.g. selling stored electricity in day-ahead or intraday market) or the technology (by ESS developers). A usage fee is paid to use of a specific service provided by the ESS (e.g. revenue from reserve capacity). Subscription fees are paid to obtain access to services of ESS (e.g. end-consumer pays money to use behind-the-meter ESS which is owned by an ESCo). Revenue from lending/renting/leasing is generated when a company (e.g. an ESS manufacturer or an ESCo) grants exclusive right for using its ESS to another party. Brokerage fees are paid for intermediation of services of ESS (e.g. shared savings arrangements between ESCo and end-consumers).

Currently, because of lack of sufficient experience and uncertainties about consumer savings, revenue streams of a considerable number of distributed ESS have relied on asset sales or financing [77]. For larger-scale ESS, asset sales (energy markets), usage fees (for ancillary services) and their combination are obtaining more attention (see examples of cases with single- and multiple revenue streams in [78]).

4.5. Resources and energy storage technologies (ES)

Resources for a business can have different types such as physical, financial, intellectual, and human resources [59]. The focus of this paper is on the physical resources, which is dominated by the energy storage technology (ES).

There are many energy storage technologies, and they have many differences or similarities in their inputs, outputs, and other technical characteristics. The differences can make the technologies suitable for different applications, and the similarities can cause competition among them for certain applications. Therefore, classification of technologies has been interesting in the energy storage literature. Table 2

Table 2
Classifications of Energy Storage Technologies based on stored energy.

Levels of ES technology classification in the scientific Literature				Example Technology
4 classes [82] - [83]	5 classes [14], [15], [80], [81]	6 classes [2]	8 Classes [79]	
Mechanical	Mechanical	Mechanical	Potential	Pumped Hydro Compressed Air
			Kinetic	Flywheel
Electrical	Electrical	Electrical	Electrical	Super capacitors
			Magnetic	Superconducting magnetic storage
Chemical	Electrochemical	Electrochemical	Electrochemical	Batteries
				Flow cell Batteries
	Chemical	Chemical	Chemical	Hydrogen Systems
				Ammonia Dissociation-Recombination
Thermal	Thermal	Thermal	Thermochemical	Methane Dissociation-Recombination
				Sensible heat Systems
				Latent Heat System

Table 3

Range of values for technical characteristics of energy storage technologies in [2,5,11,17,81,82,84–90] | abbreviations: ms = milliseconds, S = seconds, Min = minutes, H = hours | no data found for cells with (-) | PHS = Pumped Hydro Storage, CAES = Compressed Air Energy Storage, CES = Cryogenic Energy Storage, FES = Flywheel Energy Storage, NaS = Sodium-Sulfur Battery, VRB = Vanadium Redox Battery, ZnBr = Zinc-Bromine Battery, NiCd = Nickel Cadmium Battery, Li-ion = Lithium-ion battery, SMES = Superconducting Magnetic Energy Storage, SCES = Super Capacitor Energy Storage, CS = Capacitor Storage | The color of each row illustrate class of ESS according to Table 2.

Technology	Power rating (MW)	Energy rating (MWh)	Charge duration	Discharge duration	Response time	Technological maturity
PHS	100-5000	0.15-14000	Min-H	1-100 H	S-Min	Demonstration-Matured
CAES	1-1000	1-2700	Min-H	1-100 H	1-15 Min	Demonstration-Commercial
CES	0.1–300	10–1000	H	1–24+ H	5–10 Min	Demonstration-Precommercial
FES	0-20	0.001-10	0-15 Min	ms-1 H	ms-S	Demonstration-Matured
NaS	0.5–50	0.1-600	H	S– 6 H	ms	Commercial
VRB	0.01–50	0.01-250	Min- 8 H	S–10 H	ms-10 Min	Demonstration-Commercial
ZnBr	0.025–2	0.05–4	3-4 H	S–10 H	ms	Demonstration-Commercial
NiCd	0–46	0-6.75	H	S-H	ms	Commercial – Matured
Lead–acid	1–100	0-50	–	S– 4 H	ms-S	Demonstration-Commercial
Li-ion	0-100	0-100	Min-H	Min-H	ms-S	Demonstration-Commercial
Fuel cells	0-58.8	0.312-39	H	S–24+ H	S-Min	R&D-Demonstration
SMES	0.1–10	0-3	S-H	ms–H	≤10 ms	Demonstration-Commercial
SCES	0-10	0-0.5	S-Min	ms-H	ms-S	Developing-Commercial
CS	0–0.05	–	S	ms-H	ms	Commercialized

illustrates various levels of classification for energy storage technologies. Twelve examples of energy storage technologies are presented in the right-hand side. Cho et al. [79] classifies these technologies into eight classes which are presented in the second column (from right). Similarly, Luo et al. [2] classifies the technologies into six classes by combining potential and kinetic energy classes under mechanical energy class, and by combining electrical and magnetic energy classes into a single electrical energy class. In the literature, we also observe that sometimes thermochemical energy storage is considered as part of chemical energy storage class which results in five classes [14,15,80,81] (the fourth column from the right). Evans et al. [82] classifies energy storage technologies into four classes of mechanical, electrical, chemical, and thermal technologies. In addition to these four classes, Dincer & Rosen [83] considers biological energy storage as a separate class. Power-to-power ESS is mostly based on mechanical, electrical, and electrochemical technologies.

There is considerable variety in technical characteristics of ESS. One way to illustrate this variety is through the range of reported values (the difference between the maximum and minimum values) in the literature. Main characteristics of energy storage technologies are listed in Table 3 which illustrates the range of values reported in the studied literature for the technical characteristics of various storage technologies. A wide range of values in the recent literature illustrates 1) diversity and 2) fast developments in some characteristics. The wide ranges can also be a result of the diversity of solutions within each group of technologies. For example, in the group of compressed air energy storage (CAES), there are different versions of CAES such as Diabatic CAES, Adiabatic CAES, Isothermal CAES, and underwater CAES [5] where some CAES versions can offer higher power ratings and some offer lower power ratings.

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Variety in the energy storage technologies makes them suitable for different applications and locations in the grid. Technologies with a higher power rating are better for power applications and technologies with (relatively) higher energy rating are better for energy applications. Power applications are those applications which need high amount of power in short periods and energy applications are those applications which need provision of power for longer periods [85]. Moreover, some ESS services such as area and frequency control need to be provided within a certain time and need to be maintained for certain periods. Therefore, characteristics such as response time and discharge duration can determine whether a technology can provide such services or not. Maturity of technology is another important characteristic which indicates how well they can be implemented and what role they will play in the market. Table 3 provides a big picture about current capabilities of ES technologies. Some versions of PHS and CAES have the highest power rating, energy rating, charge duration, discharge duration, response time, and level of maturity among other technologies, whereas capacitor storage (CS) has the lowest values in those characteristics. In addition, Lithium-Ion and Lead Acid have better capabilities than other electrochemical ES technologies.

4.6. Costs

Costs and the cost structure are crucial factors for viability of a business model. There are many solutions for providing flexibility in the electricity market, and for many of them the price of products and services is set in the market. Therefore, market participants do not have much freedom to increase their revenues, but what makes their solution

Table 4

Range of economic and environmental characteristics of energy storage technologies in [2,5,11,17,81,82,84–90] | PHS = Pumped Hydro Storage, CAES = Compressed Air Energy Storage, CES = Cryogenic Energy Storage, FES = Flywheel Energy Storage, NaS = Sodium-Sulfur Battery, VRB = Vanadium Redox Battery, ZnBr = Zinc-Bromine Battery, NiCd = Nickel Cadmium Battery, Li-ion = Lithium-ion battery, SMES = Superconducting Magnetic Energy Storage, SCES = Super Capacitor Energy Storage, CS = Capacitor Storage | The color of each row illustrate class of ESS according to Table 2 | Cells with single values imply that either only one source in the studied literature reported the value, or that multiple sources reported the same value.

Technology	Capital Cost \$/kW	Capital Cost \$/kWh	Operation & maintenance cost	Roundtrip efficiency (%)	Lifetime (cycles)	Lifetime (years)	Self-discharge %/day
PHS	152–4300	5–250	0.004 \$/kWh, 3 \$/kW/year	65–87	5×10^2 – 5×10^4 +	25–100	0.005–0.02
CAES	400–2000	2–200	0.003 \$/kWh, 6–25 \$/kW/year	40–95	8×10^3 – 3×10^4 +	20–100	0.003–1
CES	300–2000	3–530		40–85	$>1.3 \times 10^4$	20–40	0.5–1
FES	250–10000	1000–14000	0.004 \$/kWh, 18–20 \$/kW/year	75–99	10^4 – 10^7	15–20	20–100
NaS	150–3000	125–534	14–80 \$/kW/year	70–90	2×10^3 – 4×10^4	10–20	0.05–20
VRB	175–3200	150–1000	28 \$/kW	60–90	1.5×10^3 – 1.5×10^4	5–20	0–10
ZnBr	175–2500	150–1000	26 \$/kW/year	60–85	10^3 – 10^4	5–10	0–1
Ni–Cd	500–1500	800–1500	15–20 \$/kW/year	60–83	1.5×10^3 – 3×10^3	5–20	0.2–0.6
Lead–acid	50–800	50–500	10–50 \$/kW/year	60–95	2.5×10^2 – 2×10^3	3–20	0.1–0.3
Li-ion	150–4000	500–3800	10 \$/kW	65–~100	6×10^2 – 2×10^4	5–100	0.1–5
Fuel cells	500–10000+	2.2–20	0.0019–0.0153 \$/kW	20–70	10^3 – 2×10^4 +	5–30	~0
SMES	200–13000	500–72000	0.001 \$/kW h, 10–18.5 \$/kW/year	75–99	10^4 – 10^5	5–40	10–15
SCES	100–2500	300–30000	0.005 \$/kWh, 6–13 \$/kW-year	75–98	10^4 – 5×10^5	5–40	2–40
CS	400–1000	200–1000	<0.05 \$/kWh, 13 \$/kW/year	60–90	5×10^3 – 5×10^4	1–10	40–50

competitive with others is the lower cost.

The cost structure includes fixed and variable costs [59]. The ESS fixed costs include technology capital costs (in terms of annual debt payment) and fixed operation and maintenance (O&M) costs (\$/kW installed) while variable costs mainly include charging costs and variable O&M (\$/kWh discharged) [91]. In addition, the cost of ESS is composed of 1) storage costs, 2) power conversion system costs, and 3) balance of plant costs. The storage costs depend on energy storage capacity (\$/kWh – see storage unit in Fig. 1), power conversion system costs depend on power capacity of the storage unit (\$/kW – see power conversion system in Fig. 1), and balance of plant costs relates to facilities and control systems [88]. In the literature, balance of plant costs is typically included in the energy storage unit costs [92]. Therefore, the capital cost of an ESS can be calculated as (See [93] for a numerical example):

$$\text{ESS Capital Cost} = \text{ESS energy rating} * \text{Capital Cost } \$/\text{kWh} + \text{ESS Power Rating} * \text{Capital Cost } \$/\text{kW}$$

There is high diversity in the reported values for economic characteristics of ESS technologies. Table 4 provides range (difference between maximum and minimum) of values for costs and other economic factors of ES technologies reported in the studied literature. Similarly in Table 3 we observe high variation and diversity in the economic characteristics of ES technologies. Capital costs per unit of stored energy capacity (\$/kWh) for batteries is relatively high while capital cost per discharge capacity (\$/kW) for batteries is relatively lower compared to more mature technologies such as PHS. In addition, operations and maintenance cost for NaS, Lead Acid, ZnBr, and Ni–Cd can be too high. We also observe, that most ES technologies have versions with relatively high roundtrip efficiency, however the high-efficiency versions have not necessarily matured yet. The lifetime of ES can be explained in terms of cycles and years. In terms of cycles, flywheel (FES) has the longest life time, whereas in terms of years PHS and CAES have longer lifetimes. Self-discharge is a source of economic loss for ES technologies, and FES, CS, and SMES are the most vulnerable

technologies to such losses.

4.7. Locations for ESS

In addition to the technology, the location of ESS in the grid is also an important consideration because the location imposes technical constraints on the ESS services. Fig. 5 illustrates the locations of the physical activities in the electricity sector, and the possible locations for energy storage systems.

The transmission grid is one location where ESS can connect to. In the Netherlands, the transmission grid consists of extra-high-voltage grid (voltage ≥ 220 kV) and high-voltage grid ($35 \text{ kV} \leq \text{voltage} < 220 \text{ kV}$). The electricity which is imported to the Netherlands enters the transmission grid as well. Similarly, the exported electricity leaves the same grid. ESS can also be connected to the distribution grid. The distribution grid in the Netherlands consists of the medium-voltage grid ($1 \text{ kV} < \text{voltage} < 35 \text{ kV}$) and the low-voltage grid (voltage $\leq 1 \text{ kV}$) [94]. There are various voltage levels across the electricity system, and the voltage difference among the transmission grid, the distribution grid, generation sites, and consumption sites is solved by transformers which step up or step down the voltage. The transformers (substations) are shown by rhombuses in Fig. 5. Generation activities can be done in three forms: 1) centralized generation is connected to transmission grid, 2) distributed generation (such as wind farms) can be connected to transmission or distribution grids based on its size, and 3) distributed micro-generation is done behind the meters at consumers' sites. In the first and the second forms, there are transformers between generation facilities and grids to step up the voltage. Furthermore, there are various forms of consumption. Heavy industries can be connected directly to the transmission grid, while light industries, commercial consumers, and residential consumers are connected to various parts of distribution grid. Possible locations for ESS are shown by circles in Fig. 5. Storage can be done at centralized or distributed generation sites (locations 1,2,3). It is also possible to have

Fig. 5. Possible Locations for Energy Storage in the Dutch Electricity Sector | Red Circles = potential storage locations, Yellow Rectangles with M = metering points, Green Rhombuses = substations | Arrows illustrate flows of electricity | intensity of colors illustrate the size of generation or consumption (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

energy storage systems that are directly connected to transmission or distribution substations (locations 4,5). Community energy storage is also possible near consumer sites on the distribution grid side (location 6). Location 1–6 can be called front-of-meter locations. In addition, energy storage can be installed behind-the-meter at consumers' sites for various applications (locations 7,8,9,10). One special type of behind-the-meter storage is for consumers who generate electricity as well (location 11).

ESS location imposes constraints on provision of services and accommodation of technologies. This, in addition to the constraints of technologies for provision of services, makes a complex nexus of relevance among ESS locations, applications, and technologies. We used the data from ES-Select™ [95] in order to illustrate degree of relevance among technology, application, and location. ES-Select™ is a tool created by DNV-KEMA in collaboration with Sandia National Laboratories. In this tool, five locations are defined as follows: “central or bulk storage”, “substation”, “container or community energy storage fleet”, “commercial or industrial”, and “residential or small commercial”. These locations can be translated to locations ‘1,2,3’, ‘4,5’, ‘6’, ‘7,8,9,11’, and ‘9,10,11’ in Fig. 5, respectively.

For each location, ES-Select™ calculates a feasibility score for providing applications by a specific technology. This feasibility score is a value between 0 and 1 and it depends on installed costs in kWh,

maturity of technology, appropriateness for locations, and capability to meet application requirements (for more details about feasibility scores, see [96]). We collected all the feasibility scores for each technology for provision of individual applications at a certain location, and calculated the average of all available feasibility scores between each pairs of variables which is illustrated in Table 5. For example, the degree of relevance between “Wholesale Arbitrage” application and “PHS” technology is equal to average of feasibility scores of providing wholesale arbitrage by PHS at five locations, or the degree of relevance between “Wholesale Arbitrage” and “Substation” location (location 6) is equal to average of feasibility scores of providing wholesale arbitrage at substation by ten technologies. The calculation steps are elaborated in Appendix A. Some technologies from Table 3 are not included in Table 5 because there was no data for them in ES-Select™. In addition, among the ESS applications, ‘increasing self-consumption’ is included in ‘end-consumer arbitrage’ application.

In Table 5, the intensity of colors shows the magnitude of relevance between pair of variables (the average feasibility scores with the same pair of variables). The table has two parts: in the upper part, the relevance of ESS applications with technologies (at the right side) and with locations (at the left side) is illustrated. In the lower part of the table, the relevance between locations and technologies is illustrated. In Table 5, we observe that technologies such as PHS, NaS, Li-ion, and FES

Table 5

Average ESS feasibility scores for location, applications, and technologies- calculated based on the outputs of ES-Select™ [95].

Application ~ Location					Application ~ Technology										
Location in Figure 5					↓ Application ↓	Technology									
1 2 3	4 5	6	7 8 9 11	10 11		PHS	CAES	FES	NaS	VRB	ZnBr	Ni-Cd	Lead-acid	Li-ion	SCES
0.48	0.51	0.48	0.53	0.52	Area & Frequency Regulation	0.61	0.42	0.62	0.57	0.43	0.43	0.44	0.46	0.56	0.41
			0.55	0.52	End-Consumer Arbitrage		0.44		0.70	0.48	0.45	0.46	0.60	0.60	
			0.50	0.48	End-Consumer Power Quality		0.32	0.52	0.63	0.36	0.34	0.44	0.68	0.56	0.47
			0.53	0.50	End-Consumer Power Reliability		0.43		0.66	0.48	0.45	0.46	0.62	0.57	
0.53	0.54	0.49	0.55	0.52	Load Following	0.79	0.53		0.63	0.48	0.48	0.46	0.52	0.56	
0.53	0.54	0.49	0.55	0.52	RET Arbitrage	0.79	0.53		0.63	0.48	0.48	0.46	0.52	0.56	
0.53	0.54	0.49	0.55	0.52	Wholesale Arbitrage	0.79	0.53		0.63	0.48	0.48	0.46	0.52	0.56	
0.46	0.50	0.47	0.53	0.52	Reserve Capacity	0.54	0.35	0.62	0.57	0.40	0.40	0.44	0.44	0.58	0.41
0.50	0.53	0.48			T&D Investment Deferral	0.68	0.49		0.57	0.48	0.51	0.46	0.50	0.52	
0.53	0.54	0.49	0.53	0.49	RET Firming	0.79	0.53		0.63	0.48	0.48	0.46	0.52	0.56	
0.46	0.50	0.47	0.51	0.49	RET Smoothing	0.54	0.35	0.62	0.57	0.40	0.40	0.44	0.44	0.58	0.41
0.50	0.53				Black Start	0.68	0.57		0.65	0.50	0.53	0.45	0.46	0.49	
	0.50	0.47			Support of Voltage Regulation		0.32	0.63	0.53	0.41	0.42	0.44	0.45	0.62	0.41
					↓ Location ~ Technology →	PHS	CAES	FES	NaS	VRB	ZnBr	Ni-Cd	Lead-acid	Li-ion	SCES
					Residential & Small Commercial			0.51			0.36	0.45	0.58	0.57	
					Industrial & Commercial		0.39	0.60	0.67	0.44	0.47	0.45	0.58	0.59	0.48
					Container / Community Energy Storage		0.32	0.50	0.44	0.43	0.44	0.45	0.52	0.61	0.39
					Substation		0.47	0.73	0.66	0.47	0.50	0.44	0.51	0.57	0.43
					Central & Bulk	0.69	0.67	0.71	0.65				0.35	0.47	0.33

have better scores to provide the services at the level of generation, transmission, and distribution, and technologies such as NaS, Lead-acid, and Li-ion have a good score for applications at the level of end-consumers. We also observe that some applications such as black start can only be provided at the location of bulk generation or substations, and some applications such as end-consumer application are necessarily done at the location of end-consumers. In the lower part of Table 5, we observe that some technologies such as PHS are location-specific and can be implemented at certain locations while some other technologies can be implemented at all locations. If we compare Tables 3 and 5, we can also conclude that the level of maturity is correlated with the feasibility scores.

5. Synthesis of ESS business models design space in the Netherlands

There are many alternatives for the components of business model frameworks such as customer, value proposition, channel, revenue model, resources, and costs structure. The design of a business model involves selecting and matching the options which are compatible with each other and that together make a profitable business. In general, a business model can have one or more value propositions for one or more types of customers.

5.1. Overview of single-application business models

If a business model for ESS has only one value proposition, we call it a single-application business model of ESS. Table 6 maps single-application business models of ESS. In Table 6, each application has only one customer, while the owner of the system is not unique. For example, the application/service ‘end-consumer arbitrage’ has only one customer which is the end-consumer, but the owner of the system can be either

an end-consumer himself or an energy company. Here, the markets are the channels through which an owner of an ESS can reach the customer and offer its products and services. As we observe in the table, some markets are not existing in the Netherlands yet. For example, the customer for the application ‘T&D investment deferral’ is a grid operator, but there is still no market in the Netherlands where a grid operator can buy this service from the energy companies. If auctions for congestion management or peak shaving services emerge in the future, they will be the channels for the business model of the investment deferral application. In addition, the profit formula is defined by combining the revenue model and the cost structure, and it varies according to the type of application and the owner. For example, there is a difference in the profit formula for end-consumer arbitrage when the owner of an ESS is the end-consumer and when the owner is an energy company.

Energy companies can offer all ESS services to energy companies (including themselves), grid operators, and end consumers. The services an energy company can offer to an energy company include load following, wholesale arbitrage, RET arbitrage, RET Firming, and RET Smoothing.

- For load following in which ESS deals with demand variations while the generating unit produce electricity in the in the optimal level, an energy company can invest in ESS and the profit will be generated based on the savings from higher efficiency. If an energy company offers a load following service to another company, the profit will be dependent on service fees and the ESS costs. There is no structured market in the Netherlands for load following and the companies need to reach each other through various sorts of communications.
- For wholesale arbitrage, the energy company sells the stored electricity to another energy company through energy markets such as the long-term, day-ahead, and intra-day markets. The profit is dependent on the difference between peak and off-peak prices, and the

Table 6

Map of ESS single-application business models for the Netherlands.

Locations								
1	4	6	7	Owner	Customer	Application	Market	Profit Formula
2	5		8					
3			9					
			10					
			11					
				Energy Company	Energy Company	Load Following	Bilateral Contracts – None	Service Revenue / Saving on additional efficiency - ESS Costs
						Wholesale Arbitrage	LT/DAM/IDM	Wholesale price spread - ESS Costs
						RET Arbitrage	LT/DAM/IDM	Wholesale price spread + (saving on additional efficiency) - ESS Costs
						RET Firming	Bilateral Contracts – None	Service fee / Saving on reduced RET investment - ESS Costs
						RET Smoothing	Bilateral Contracts – None	Service fee / Reduce power quality deviation costs - ESS Costs
					TSO/DSO	Area & Frequency Regulation	Weekly Auctions	Service Revenue - Electricity Cost - ESS Costs
						Reserve Capacity	Yearly capacity Auctions and daily energy auctions	Service Revenue - Electricity Cost - ESS Costs
						Support of Voltage Regulation	Auction for Bilateral Contracts	Service Revenue - Electricity Cost - ESS Costs
						Black Start	Auction for bilateral contract	Service Revenue - Electricity Cost - ESS Costs
						T&D Investment Deferral	None	Service Revenue - Electricity Cost - ESS Costs
					End-Consumer	End-consumer Arbitrage	Bilateral Contracts	% Consumer energy bill savings - ESS Costs
						Increase of Self-consumption	Bilateral Contracts	% Consumer energy bill savings - ESS Costs
						End-consumer Power Reliability	Bilateral Contracts	Service Revenue - ESS Costs
						End-Consumer Power Quality	Bilateral Contracts	Service Revenue - ESS Costs
				End-Consumer	End-Consumer	End-consumer Arbitrage	None	Consumer energy bill savings - ESS Costs
						Increase of Self-consumption	None	Consumer energy bill savings - ESS Costs
						End-consumer Power Reliability	None	Power Interruption Costs - ESS Costs
						End-Consumer Power Quality	None	Low Power Quality Costs - ESS Costs

ESS costs.

- For RET arbitrage, the energy company sells the stored electricity generated by RET to another energy company through energy markets such as the long-term, day-ahead, and intra-day markets. The profit is dependent on the difference between peak and off-peak prices, and on the ESS costs. If ESS helps to avoid curtailment of renewables, the benefits from higher efficiency will be included in the profit as well.
- RET firming is valuable because it levels the output of a RET unit and it can reduce the investment in RET capacity. Like load following, energy companies can communicate with each other in various ways and there is no formal market. If an energy company offers the service to itself, the profit from RET firming is dependent on savings from reduced investment in generation capacity and the ESS costs. If an energy company offers this service to another company, the profit will depend on the service fees and the ESS costs.
- The benefit of RET smoothing comes from avoiding penalties for quality deviation. Energy companies can communicate with each other in many ways and there is no formal market. If an energy company offers the service to itself, the profit is dependent on avoiding penalties and the ESS costs. If an energy company offers

this service to another company, the profit will be based on the service fees and ESS costs.

The services an energy company can offer to grid operators generally include ancillary services and T&D investment deferral.

- For area and frequency regulation, energy companies can reach the TSO through weekly auctions as discussed in Section 4.3. The profit depends on the service revenue which is based on the auction price, the charging electricity price, and on the ESS costs.
- For reserve capacity, energy companies can participate in the yearly capacity and daily energy auctions, and the profit depends on the service price, the charging electricity price, and the ESS costs.
- For support of voltage regulation, energy companies can participate in yearly auctions. The profit is based on the service fee (fixed yearly, or variable hourly), the charging electricity price, and the ESS costs.
- For black start, energy companies can participate in auctions for yearly (or longer) contracts. The profit depends on the fixed service revenue, the charging electricity price, and ESS costs.
- For T&D investment deferral, no market is defined for energy companies to offer services such as peak shaving which results in T&

D investment deferral. However, if such a market emerges in the future, the profit will be dependent on the service price determined in the market, the charging electricity price, and the ESS costs.

Both energy companies and end-consumers can provide ESS services at the end-consumer level. These services include arbitrage, power quality, power reliability and increase of self-consumption. If energy companies offer the services to the end consumers, they should reach the end-consumers through traditional sale activities or modern methods such as their websites to sign bilateral contracts, and there is no formal and regulated market to offer these services.

- For end-consumer arbitrage, if the end-consumer owns the ESS, the profit is based on the saving from the time-shift of consumption and the ESS costs. If an energy company offer this service, the revenue of company will be percentage of the savings while the ESS costs remain almost the same.
- An increase in self-consumption, as mentioned in Section 4.7, has the same nature as end-consumer arbitrage. The only difference is the presence of generation units in this segment of end-consumers. Therefore, the profit calculation is the same as end-consumer arbitrage.
- For end-consumer power reliability, if the end-consumer owns the ESS, the profit is based on avoiding costs of power interruption and the ESS costs. If the service is offered by an energy company, its profit will depend on a determined service fee and the ESS costs.
- For end-consumer power quality, if the end-consumer (e.g. high-tech industry) owns the ESS, the profit is based on avoiding costs of low power quality and the ESS costs. If the service is provided by an energy company, the profit of the company will be determined by the service fees and the ESS costs.

Single-application business models can be viable if the ESS can be efficiently used, and there is enough revenue, and the ESS costs drops. However, there are considerable doubts whether all these conditions can be met at the same time for front-of-meter single-application business models.

5.2. Stacking benefits

If an ESS can allocate its capacity to multiple applications, new economic opportunities arise. Bundling a number of ESS applications by a single technology is considered as a key to help profitability and competitiveness of the ESS [15,19,97]. The capability for providing multiple services by ESS is called ‘benefits-stacking’ [20]. Furthermore, Lombardi & Schwabe [98] presented the ‘sharing economy’ as a business model for ESS and argued that motivations behind the sharing principle are generation of higher revenues and sharing of investment costs.

In addition, although bundling ESS applications can increase the profitability of ESS business, the increase in profitability depends on a synergy and lack of conflicts among bundled applications. For example, T&D investment deferral has a synergy with most other applications, as length of ESS use by this application is relatively low and the ESS capacity can be used for other applications. In addition, load following has a synergy with many other applications because ESS can provide load following while it is charging [99], or reserve capacity can have synergy with RET arbitrage [100]. In addition, some applications can have both synergies and conflicts with other applications according to differences in the supply and demand conditions [101].

Therefore, success in finding viable business models for ESS lie in making a portfolio of applications with synergies, and planning and scheduling applications to achieve better revenue.

5.3. Uncertainties

Many uncertainties can influence viability of ESS in the Netherlands. In general, revenue of ESS depend on the difference of prices in the different markets. Therefore, market price is one of the uncertainties for ESS. Market price is dependent of quantity of generation and demand. Generation depends on the fuel prices, CO₂ certificate prices, availability of wind and sun, and the uncertainty surrounding all these factors. In addition, the demand is not precisely predictable and depends on many uncertain factors including the weather. Keles [102] argues that among various uncertainties, the electricity market price and renewable generation are the most influential in determining the short-term dispatch of power generating units.

In addition to the operational uncertainties in the market, there are some uncertainties at the regulatory level worldwide and in the Netherlands. The fact that market actors cannot predict the developments of the regulatory framework causes uncertainty in their decision making which is an important barrier for investment in ESS [6].

All the uncertainties can be translated to risks of ESS business models, and the risks can be translated to both opportunities and threats. Therefore, the way of exploiting the opportunities and dealing with threats can influence the viability of ESS business.

6. Conclusion

The objective of this paper was to provide a conceptual framework and a design space for electricity storage systems (ESS) in the Netherlands. This paper described scope and applications of ESS, and explained that the need for energy storage has not yet been sensed in the Netherlands. We also reviewed the institutional structure of the Dutch electricity sector and the regulatory barriers for implementation of ESS in the Netherlands. We explained the role of business models to overcome business problems, analyzed the main components of a business model for ESS in the context of the Netherlands, and highlighted the relationship among energy storage technologies, applications, and possible locations. The main contributions of this paper are the map of single-application business models which constitute the elements of a service portfolio that an ESS needs to have to make a profit and be sustainable, and Table 5 which highlighted the nexus of constraints among location, applications, and technologies.

Despite the low level of ESS implementation in the Netherlands, because of diminishing national gas reserves and because of CO₂ targets of the Energy Agenda, we expect more and more variable renewable generation which can be translated to need for more sources of flexibility and energy storage.

There is considerable variety in the technical and economic characteristics of energy storage systems. By reduction in costs, and by focusing on revenues which can be increased by better management of ESS service portfolios and their internal synergies, and by exploiting the opportunities from market uncertainties, there might be opportunities for economic activity of ESS in the Netherlands.

In addition, for some ESS single-application business models such as T&D investment deferral, the channels to reach customers is not clear. It seems that grid operators are cautious about engaging in such transactions due to regulatory uncertainty.

Our paper has several limitations. First, we assumed that changes at the regulatory level are not expected and we concentrated only on business models. Furthermore, we acknowledge the opinion of Burger & Luke [77] that in addition to business models other factors such as managerial skills play an important role in the success of the ESS business. However, the scope of our research is limited to identifying generic and widely implementable ideas for ESS business in the Netherlands.

Finally, the business models need to be tested and evaluated. Our future research will be to model and explore the evolution of ESS in the

Netherlands under various uncertainties. In addition, because of nature of a design problem, our study was limited to the Netherlands as we needed to make the institutional constraints as clear as possible. However, because of high similarity in the institutional structure of European countries, this research can be a base for similar research in other European countries.

Appendix A

A method to determine the degree of relevance among technology, application, and location

In ES Select, for each location we selected a single application, and calculated the feasibility scores for the ES technologies ($S_{i,j,k}$, where i is location, j is application, and k is technology). Then, we collected the collected feasibility scores in a spreadsheet table and calculated average feasibility scores as an indicator for degree of relevance between pairs of locations, applications, and technologies as follows (There are 5 location, 13 application, and 10 technologies):

$$\text{Degree of Relevance of Application } j \text{ and Technology } k = \frac{1}{5} \sum_{i=1}^5 S_{i,j,k}$$

$$\text{Degree of Relevance of Location } i \text{ and Technology } k = \frac{1}{13} \sum_{j=1}^{13} S_{i,j,k}$$

$$\text{Degree of Relevance of Location } i \text{ and Application } j = \frac{1}{10} \sum_{k=1}^{10} S_{i,j,k}$$

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