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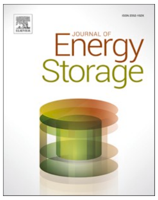

Research papers

Investigating the participation of battery energy storage systems in the Nordic ancillary services markets from a business perspective

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A B S T R A C T

Battery energy storage systems (BESSs) are gaining potential recognition in renewable-based power systems. To maintain the stability of such systems, BESSs units are being deployed for the provision of ancillary services (ASs). For BESS owners, it is vital to assess the business value of providing ASs to engage in a profitable trade. However, studies so far have mainly focused on the operational control of BESS units in ancillary services markets (ASMs) while ignoring investigations from a business viewpoint. Therefore, in this paper, we analyse the BESS-based provision of Nordic ASs from a BESS-business perspective. To this aim, we identify the profitable bidding hours for the BESS units by investigating hourly patterns in the market prices of the past six years. We also analyse the monthly and yearly trends in historic price datasets of ASs to help BESS owners develop long-term business plans. Moreover, for the BESS owners to choose between different markets, we investigate the revenue streams associated with each ASs and determine the yearly income from their availability and capacity payments. Our findings imply that BESS business viability in the Nordic ASMs can be increased by stacking ASs based on their availability payments, energy content, and activation requirements.

1. Introduction

Rising environmental concerns and higher climate change awareness are increasing reliance on renewable energy sources (RES) in the electricity sector [1]. However, the higher integration of RES-based plants into the grid creates challenges in maintaining a balance between electricity demand and supply. It also replaces traditional sources of synchronous inertia, thereby adversely affecting the grid stability [2,3]. Consequently, to ensure power system stability and reliability of operation, ancillary services (ASs) are becoming more important [4]. These services are procured by transmission system operators (TSOs) through short-term competitive markets called ancillary services markets (ASMs). Nowadays, in modern power systems, new players such as battery energy storage systems (BESSs) and electric vehicles (EVs) are entering the ASMs [5]. It is thus becoming crucial to investigate the behaviour of ASMs from the BESS business perspective as it has been recognised that a higher input from investors and financiers can boost BESS integration in power systems [6].

So far, frequency containment reserves (FCR) have been recognised as one of the greatest value applications that can be driven from the BESSs [7–12]. This is mainly due to the fast response capability of the BESS technologies, which is the primary requirement of the FCR service. Additionally, remunerations provided by the grid operators and the possibility of the flexible modification of its control curves make FCR a service of choice for the EV and BESS owners [13,14]. Moreover, market prices for regulation and reserves often exceed the coincident prices for energy, thereby proving to be well suited for BESSs due to their low operation cost when idle [15]. However, unlike conventional power plants, a fixed BESS capacity cannot be reserved for participating in ASMs due to their limited energy reservoir. Therefore, for business entities with BESSs assets to play a strategic role in ASMs, it is vital to investigate the price behaviour of ASs to ensure market bidding during profitable hours. However, since the market participation of small-scale resource owners in ASMs is a relatively new concept, there is a lack of analysis of their historical price behaviours from a business viewpoint. Understanding the trends and patterns in the historical market data and investigating its implications on long- and short-term business plans is crucial to integrate more BESS technologies in ASMs.

To date, most of the studies conducted in this direction have focused on investigating the price behaviours of North American ASMs. In [16], the price behaviour of ancillary services in day-ahead markets of the Midcontinent Independent System Operator (MISO) – in the US – was

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assessed for 49 months. Similarly, in [17,18], hourly prices of regulation services in the Electricity Reliability Council of Texas (ERCOT) were explored for seven years. However, studies considering the historic price behaviours of the European markets are relatively scarce. Such investigation in the European context is vital because the business viability of integrating BESSs units in the ASMs depends on their pricing mechanisms, which depending on market structures, national requirements, participating entities, environmental policies, and operational conditions differ from country to country [19]. Therefore, even though a few days of the market price data was analysed by the authors of [9,20] for the Nordic ASMs, and the authors of [21] for the Italian ASMs; however, such short-term investigations are not well-suited for the BESS owners for making viable business decisions. Moreover, in addition to these short term investigations, some studies on European ASMs have focused on their rules, requirements and structures, while other studies have focused on developing control strategies for BESS operation. [22,23] developed BESS control strategies for the Nordic ASMs, and [24–28] proposed distributed control, coordinated control, and droop control with state-of-charge (SoC) feedback for providing ASs using multiple BESSs. Similarly, [29–33] modeled BESS frequency control for islanded and micro grids.

The common aspect in the above-mentioned studies is that first, none of these studies have investigated the pricing trends of ASs in the European ASMs, despite the fact that FCR has been identified as one of the most feasible BESS services in the European region, and second, these studies do not investigate the BESS integration in the power system from a business viewpoint. Instead, by developing BESS control strategies, they mainly look at BESS participation in ASMs from technical and operational viewpoints. Even though such considerations help system operators regulate grid frequency, reduce electricity bills, and maintain grid stability, they, however, do not ensure business feasibility for large-scale BESS owners. For a BESS owner bidding in the ASMs, it is essential to identify the profitable bidding hours of the day by investigating hourly patterns in the market prices. It is also crucial to analyse monthly and yearly price patterns to develop business plans and to assess price differences between various services to choose between different market services. Additionally, based on the historic datasets, determining the revenue from different payment streams associated with each BESS service is vital for the BESS owners to assess the business potential of bidding in the ASMs. It can help them in performing business-friendly BESS service stacking while accounting for the differences in prices, energy content requirements, activation instants, revenue streams, etc. of different ASs. However, to date, neither has any study investigated the behaviour of ASMs while considering the viability of BESS business nor have the historical prices of the Nordic ASMs has been analysed in particular for this purpose.

For the above-recognised reasons, this paper investigates the historic price behaviours of the Nordic ASMs from BESS business viewpoint. The Nordic electricity system is considered because it is a well-interconnected market and can thus serve as an example in the energy market design for the other European countries [34]. Moreover, its energy mix is dominated by renewables, thus giving it a hint of the desired future European power system [35–38]. For the Nordic ASMs, the identified gaps are addressed in the following ways. Firstly, the system requirements of different ASs for the Nordic countries are discussed and their market requirements including response time, activation duration, droop requirements, and payment types are investigated. Secondly, the historical prices of the ASs with viable BESS business potential are analysed. This is achieved by investigating hourly data for the past six years, i.e., 2015–2020. In the analysis, the yearly probability distribution curves of each service are compared based on which the similarities and differences in the yearly price behaviour are assessed. Moreover, profitable bidding intervals for BESS owners are examined based on the monthly, and hourly patterns in historic market data. Furthermore, the market behaviour of ASs is compared, and the influence of the differences in their prices, energy content, and activation requirements on the business viability of BESS in ASMs is explored. Finally, the revenue streams associated with each service is calculated based on different payment types, and the business implications of bidding in ASMs on the BESS projects are discussed. The value of BESS service stacking in ASMs is also explored and the business prescriptions on BESS service stacking are addressed. The analysis presented in this paper is vital for investors, financiers, policymakers, and researchers to investigate the viability of BESSs participation in ASMs from business perspective.

This paper has six sections. Section 2 overviews the BESS services of the Nordic ASMs. Section 3 proposes the method to assess BESS participation in Nordic ASMs, while Section 4 applied the proposed method on FCR-N, FCR-D, and FFR markets. Section 5 addresses the business implications of BESS participation and the paper ends with concluding remarks in Section 6.

2. BESSs in the Nordic ASMs – Services overview

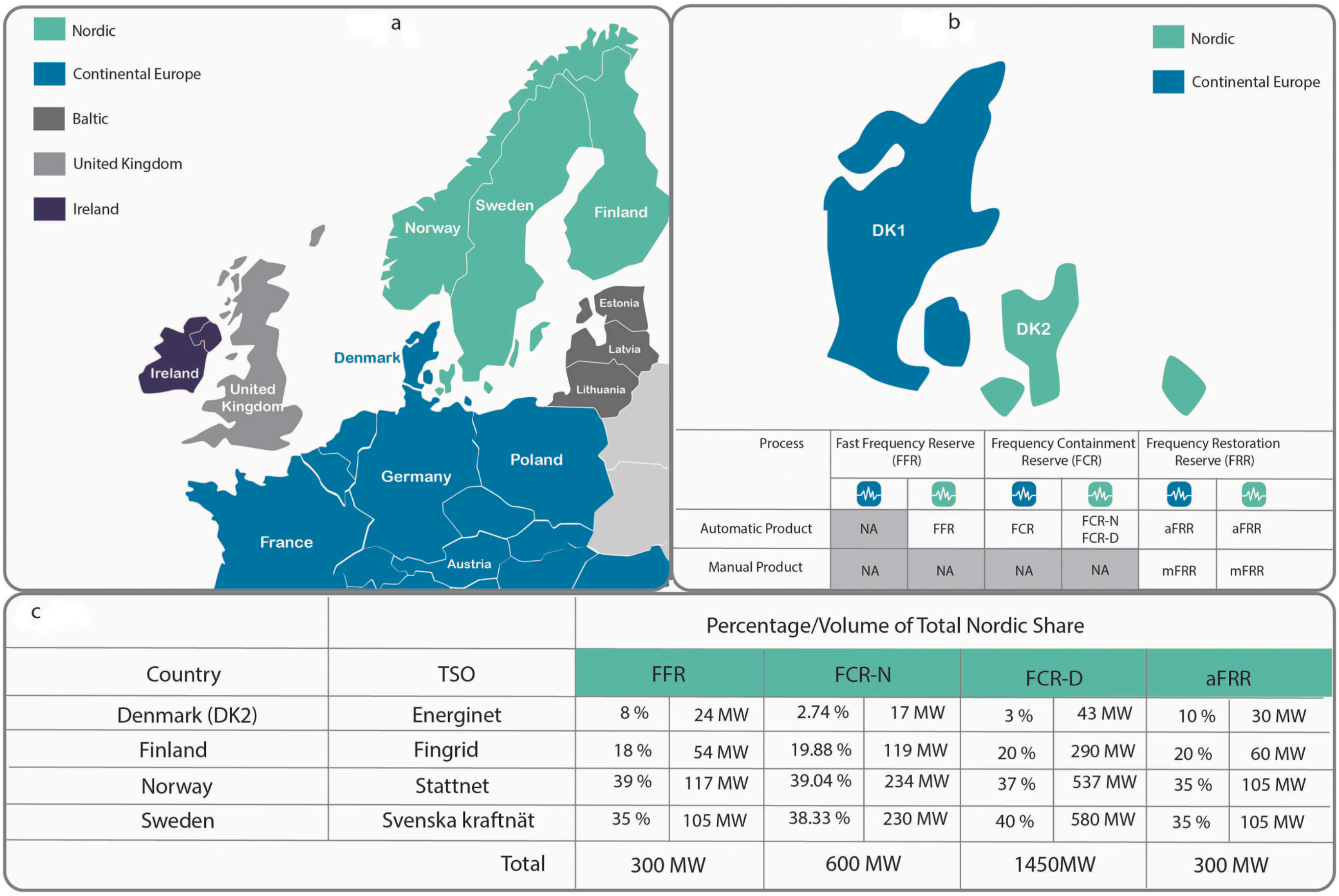
The ASMs consist of different types of ASs. This includes frequency regulation services (FRSs), voltage control services, and system restart and recovery services. ASs can be procured in three ways. First, via a mandatory response which is required as a condition of being connected to the power network. Second, via a long-term bilateral contract between the TSO and the ancillary service provider, and third, via a market-based procurement mechanism on the basis of invited bids [39]. Since BESSs have a limited energy reservoir, BESS owners can provide ASs to earn revenues mainly by participating in market-based procurement mechanisms. In Nordic ASMs, voltage control is compulsory for all large-scale units directly connected to the grid and system restart and recovery services are procured as long-term contracts from specific suppliers. Consequently, FRSs are the main ASs in the Nordics that allow a business possibility for BESSs via market-based procurement mechanisms. FRSs deal with deviations in a power system by containing or restoring frequency to its nominal value. Depending on the system needs, BESS units can increase or decrease their electric power to supply FRSs. The market requirements including response time, response duration and droop control of FRSs are the same for all countries of Nordic synchronous areas (SA). The SAs are a group of power systems that operate under the same frequency. Since this study is conducted under the BOSS project, which is the largest grid-connected BESS project in Denmark. Therefore, a particular focus of this paper is on the provision of BESS-based services in the Danish ASMs. However, due to the interconnected nature of the Nordic SA, similar conclusions can be drawn for the other Nordic and European countries.

2.1. Market requirements

2.1.1. Service procurement

Denmark is split into two SAs, called DK1 and DK2. In DK1 – connected to Continental Europe SA – frequency containment reserves (FCR), and frequency restoration reserves (FRR) are available. FRR reserves are further subdivided into automatic (aFRR), and manual (mFRR) reserves. In DK2 – connected to the Nordic SA – two types of FCR are available. They are called frequency-controlled normal operation reserve (FCR-N) and frequency-controlled disturbance reserve (FCR-D). Moreover, recently a new regulation service called the fast frequency reserve (FFR) has become available in the DK2. Similar to DK1, mFRR, and aFRR reserves are also available in DK2. Fig. 1a illustrates the countries connected to the Nordic SA and other surrounding SAs. Fig. 1b illustrates DK1 and DK2 regions of Denmark along with their relevant FRSs. Additionally, Fig. 1c shows the level of system requirement per service per country for the Nordic SA according to the recent statistics of 2022 [40,41]. The second column of Fig. 1c lists the TSO's of each country. Energinet is the Danish TSO, responsible for procuring 8 %, 2.74 %, 3 %, and 10 % of the total Nordic need for FFR, FCR-N, FCR-D, and aFRR reserves respectively.

For DK2, Energinet procures FCR-N and FCR-D reserves from a



Process	Fast Frequency Reserve (FFR)		Frequency Containment Reserve (FCR)		Frequency Restoration Reserve (FRR)	
	Continental Europe	Nordic	Continental Europe	Nordic	Continental Europe	Nordic
Automatic Product	NA	FFR	FCR	FCR-N FCR-D	aFRR	aFRR
Manual Product	NA	NA	NA	NA	mFRR	mFRR

		Percentage/Volume of Total Nordic Share							
Country	TSO	FFR		FCR-N		FCR-D		aFRR	
Denmark (DK2)	Energinet	8 %	24 MW	2.74 %	17 MW	3 %	43 MW	10 %	30 MW
Finland	Fingrid	18 %	54 MW	19.88 %	119 MW	20 %	290 MW	20 %	60 MW
Norway	Stattnet	39 %	117 MW	39.04 %	234 MW	37 %	537 MW	35 %	105 MW
Sweden	Svenska kraftnät	35 %	105 MW	38.33 %	230 MW	40 %	580 MW	35 %	105 MW
	Total	300 MW		600 MW		1450MW		300 MW	

Fig. 1. a) Synchronous areas (SA) map b) Denmark DK1 and DK2 on SA map c) volume requirements per service per country for Nordic SA.

common Danish-Swedish hourly day-ahead market which allows both Danish and Swedish bidders to provide reserves to the fulfill the needs of the two countries. FFR reserves on the other hand are procured on hourly basis solely from the Danish market while aFRR reserves for DK2 are bought from DK1 via HVDC interconnector. mFRR reserves are supplied in DK2 via long-term contracts with Danish providers. Since only day-ahead market exists for FCR reserves in DK2 – unlike Finland where yearly market also exists – the procured volume remains unchanged per hour per year, i.e. 17 MW for FCR-N and 43 MW for FCR-D. However, FFR reserves are procured based on day-ahead forecasted volumes, their hourly procured volumes thus vary. Moreover, since hourly market-based procurement – suitable for BESS participation – mainly exists for FCR-N, FCR-D and FFR, the remainder of this paper mainly focuses on these three reserves.

2.1.2. *Service provision*

FCR-N reserves keep the frequency close to 50 Hz in the event of frequency deviations [42]. At frequency deviations between 0 and 100 mHz, FCR-N reserves must be supplied linearly by the BESS units. At frequencies equal to or above 50.1 Hz, 100 % of FCR-N downward capacity must be activated by recharging the BESS units. While at frequencies equal to or below 49.9 Hz, 100 % of FCR-N upward capacity must be activated by discharging of BESS units. The activation must be supplied within 2.5 min [42–46].

On the other hand, FCR-D reserve is divided into two separate products. FCR-D-upwards and FCR-D-downwards for sudden frequencies under 49.9 Hz, and higher than 50.1 Hz respectively. BESS units must be discharged to provide FCR-D upwards and recharged to provide FCR-D-downwards. However, while supplying FCR-D upwards, if the frequency has remained above 49.9 Hz for 60 s BESS units can initiate recovery by recharging if their energy reservoir has run out. Similarly, while supplying FCR-D downwards reserves if the frequency has remained below 50.1 Hz for 60 s BESS units can initiate recovery by discharging if their energy reservoir has reached its maximum limit. BESS units must restore their full capacity within 120 min of initiating recovery and maintain the regulation for at least 15 min [42–45].

Fast frequency reserves (FFR) are used to regulate the system frequency when there is a major system disturbance in low inertia situations. FFR then becomes necessary as FCR-D cannot maintain frequency above the specified values by itself [47]. There are three possible timeframes for FFR activation. It can be activated at frequency dips below 49.7, 49.6, or 49.5 Hz. The maximum time for full activation is 1.3 s, 1.0 s, and 0.70 s respectively. So far, only BESSs units have the capability to fulfill the fast response requirements of FFR. The activation durations of FFR can either be long or short, which are 30 s, and 5 s respectively. The BESS unit must stay active as long as the frequency is below 49.8 Hz [47,48]. Fig. 2a shows the response time for all FRS products of DK2. The fastest response time is for FFR of 1.3 s, followed by FCR-D of 5–30 s, and FCR-N of 2.5 min. Fig. 2b shows the activation frequency range of FCR-N, FCR-D, and FFR reserves, while Fig. 2c shows their droop control signals.

2.2. *Business requirements*

Nordic BESS owners can participate in the FRSs market by submitting bids two days (D-2) or one day (D-1) before the day of operation (D). These bids are submitted by a specific time called the gate closure (GC). All the bids submitted before the GC are sorted according to their price per MW and are either accepted or rejected. For FCR-N, and FCR-D, GC is 15:00 for D-1, and 18:00 for D-2. All accepted bids for FCR-N and FCR-D

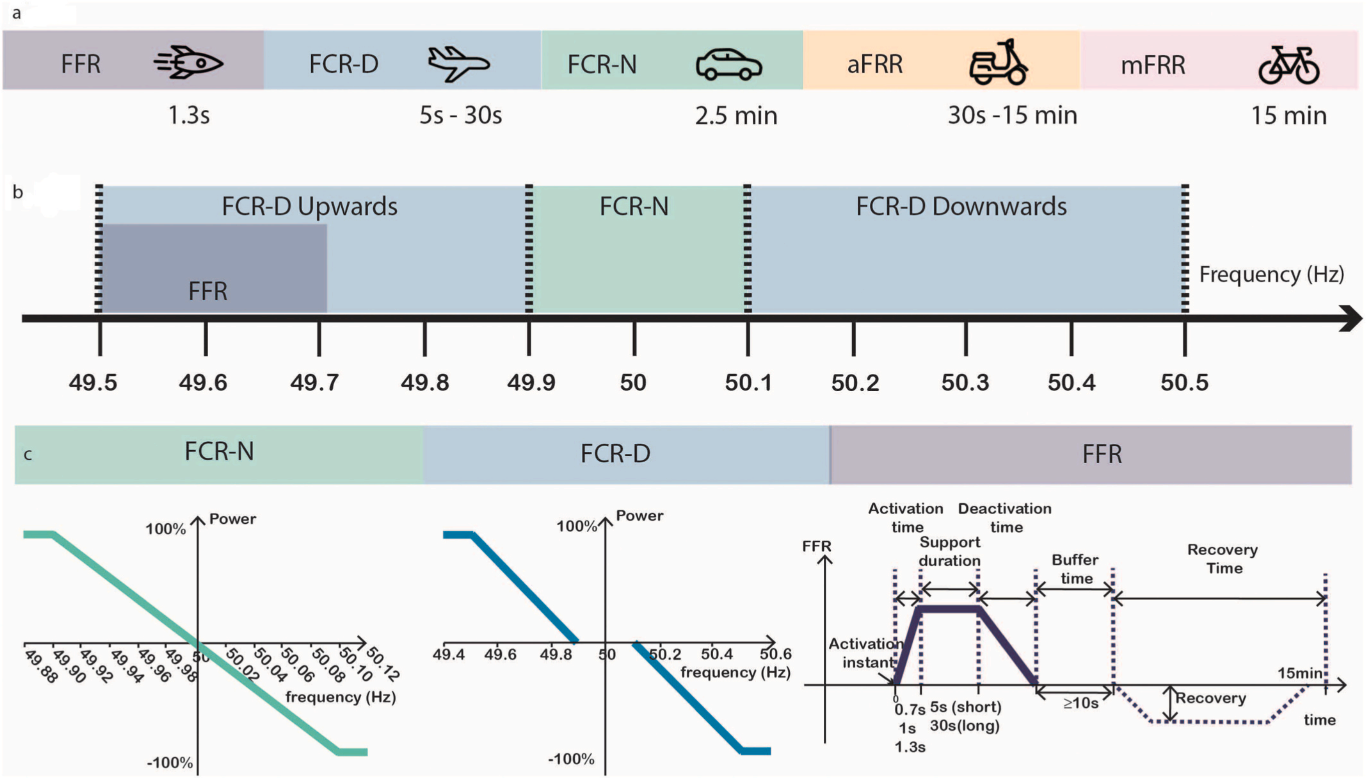


Fig. 2. a) Response time of the Nordic FRSs b) frequency activation range for FCR-N, FCR-D, and FFR c) droop control for FCR-N, FCR-D, FFR.

receive offered price as availability payments – also known as pay-as-bid price. For FFR, bids can only be submitted for D-1 until 15:00 and they receive the market clearing price – also known as marginal price – as availability payment [47]. The GCs and bid submission for D-2 and D-1 are illustrated in Fig. 3a.

Depending on the type of the service, the Nordic BESS owners may also receive energy payments corresponding to the MWh of energy provided or absorbed in response to the system frequency deviations. This is true for the case of FCR-N markets. Contrarily, for FCR-D and FFR reserves no calculation is made for supplied energy volumes. An illustration of the revenue streams for BESS owners from different ASs is shown in Fig. 3b. The figure shows both availability and energy payments for FCR-N while only availability payments for FCR-D and FFR. Furthermore, Table 1 shows the number of purchase hours, average

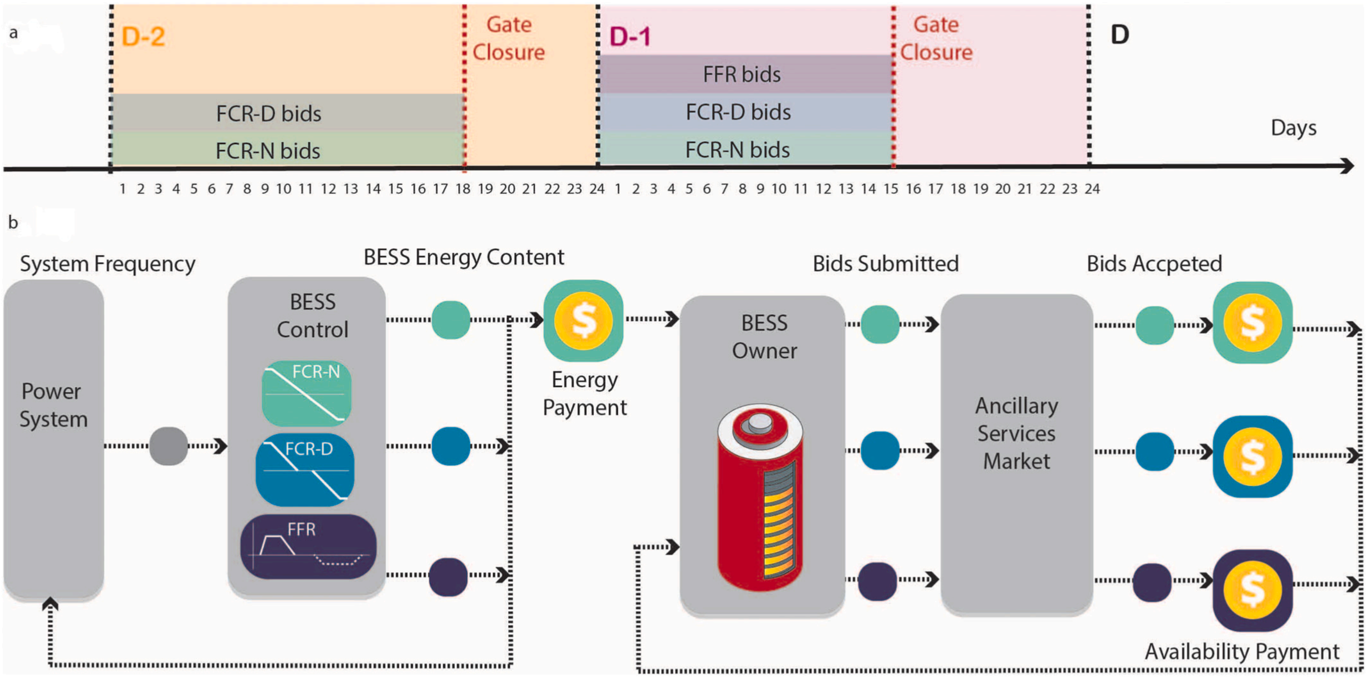


Fig. 3. a) Gate closure times for bid submission by BESS owners b) BESS participation mechanism in Nordic ancillary services markets.

Table 1
2021 statistics of ASs in DK2.

Year	Service	No. of purchase hours	Procured quantity (MW)	Average price (DKK/MWh)	Annual payment (million DKK/MW)
2021	FCR-N	8760	10	281	2.461
2021	FCR-D	8760	30	335	2.934
2021	FFR	1555	7	2725	4.237

purchased quantity, and average price of 2021 for DK2 based on Energinet's statistics [49].

Here, the third column refers to total number of procurement hours in 2021 and the fourth column refers to the average amount of reserves supplied by the Danish providers in each hour. Both FCR-N, and FCR-D, were procured in every hour of the year, and 10 MW out of 17 MW of FCR-N and 30 MW out of 43 MW of FCR-D were supplied by the Danish bidders – rest were supplied by the Swedish bidders since it is a common Denmark-Sweden market. The table also shows the average 2021 price in DKK/MWh, which when multiplied by the number of purchase hours gives the annual payment in DKK/MW as shown in the last column. The column thus shows the average revenue that can be earned by a 1 MW unit bidding in FCR-N, FCR-D or FFR markets for all required hours of 2021. It is worth noticing that even though total purchase hours of FFR are less as compared to the other services, however, due to its high average price, its annual payment is 30 % and 41 % more than FCR-D and FCR-N. Therefore, it is crucial for the BESS owners to investigate historical prices of different services.

In addition to the payment streams from different ASs, factors such as installation location, connection charges, and service aggregation potential may also impact the BESS business and must be considered. BESS allocation at different voltage levels influences the installation charges and electricity tariffs charged to the BESS owner [50]. Generally, BESSs at lower voltage levels have higher installation charges due to more transformers, substations, and electrical facilities being used [51]. For cases when MW/MWh capacity of a BESS is high, its connection to the grid may also have an impact on various network components. Therefore, technical constraints like line rating limits and their current-carrying capabilities become important [52]. In such cases, considering the dynamic thermal rating of power lines, cables, and transformers, in addition to their static ratings may be useful as the latter underutilizes their available potential [53–55]. Similarly, considering service aggregation potential at the installation location increases payment streams available for BESS units and prevents them from sitting idle when one particular service is not profitable or desirable.

3. BESSs participation in the Nordic ASMs – Investigation method

The main focus of this paper is to conduct an empirical analysis to investigate the business potential of BESSs in the ASMs of the Nordic region. It is important to note that the empirical studies rely on the actual historical data to identify the behavioral impact of different factors on the parameter of interest. In our case, we investigate the historical availability and energy payments data of FCR-N, FCR-D, and FFR to identify the impact of their behavioral patterns on the BESS business. Contrarily, simulation-based studies rely on reconstructing the environment and simulating changes that may impact the variables of interest. For example, one may model a market environment to simulate changes in the availability payment pricing mechanism to account for the impact it may have on the BESS business. Empirical studies are thus focused on analysing the historical data to investigate the status quo while simulation studies are essentially focused on predicting changes in the status quo. Authors of [56,57] have also addressed such differences between empirical and simulation-based approaches and emphasized on the importance of the former. Therefore, the main focus of this paper is to conduct an empirical investigation on the historical availability payments data of FCR-N, FCR-D, and FFR. The energy payments data that form a part of FCR-N revenue streams are also investigated.

3.1. BESSs' availability payment analysis

We consider six years of hourly availability prices, i.e., from January 2015 to December 2020 for FCR-N and FCR-D from [58]. The prices are measured in the Danish Kroners per megawatt hour (DKK/MWh). On the other hand, six months of hourly prices are considered for FFR, i.e., from 01/05/2021, to 30/10/2021 from [59] due to the unavailability of its price data in previous years since it is a new service in the Nordic FRMs.

An insight into the yearly price distribution curves is achieved by kernel density estimation (KDE). KDE draws a continuous curve – the kernel – at each historic hourly price value ‘p_i'’ – the data point. To make a density estimation, all the curves are added. The contribution of each data point is smoothed over its local neighborhood. The contribution of data point p_i to the KDE at a point p depends on how far apart p_i and p are. Depending on the shape of the kernel function and the bandwidth accorded to it, the extent of the contribution of p_i to the KDE may vary [60]. If we denote the kernel function as K and its bandwidth by h, the estimated density at any point p is given by

$$f(p) = n^{-1}h^{-1}\sum_{i=1}^{n} K[(p-p_i)/h] \tag{1}$$

By integrating the area between any two points on the KDE curve, the probability of the availability price falling in the corresponding price range can be estimated. Analysing the KDE of each year thus allows a probabilistic comparison between prices of different years.

Moreover, to investigate yearly patterns in the availability prices, heatmap data visualisation is used. Heatmaps are applied in a tabular format to reveal patterns and detect similarities in the six years of the price data. However, to prevent the outliers from significantly affecting the heatmap colors, only the prices that fulfill the following criteria are displayed:

$$FCR-N_{price} \leq \mu_{FCR-N} + 2\sigma_{FCR-N} \tag{2}$$

$$FCR-D_{price} \leq \mu_{FCR-D} + 2\sigma_{FCR-D} \tag{3}$$

In the above equations, μ_{FCR-N} and μ_{FCR-D} stand for the average price of FCR-N and FCR-D, respectively. Whereas σ_{FCR-N} and σ_{FCR-D} respectively stand for their standard deviation.

Additionally, the similarity between prices of different years is assessed by calculating Euclidean distance (ED) between their timeseries. ED compares temporal sequences by calculating the distance between each data point. To estimate ED between availability prices of two years, hourly prices are resampled to a daily average. Thus, after resampling, the time sequence of each year contains 365 data points instead of 8760. The additional day in the leap years of 2016 and 2020 is ignored. The resampled timeseries are represented as follows:

$$FCR_{2015} = \left[p_{d1}^{2015}, p_{d2}^{2015} \ldots p_{d365}^{2015}\right] \tag{4}$$

$$FCR_{2016} = \left[p_{d1}^{2016}, p_{d2}^{2016} \ldots p_{d365}^{2016}\right] \tag{5}$$

$$\mathrm{FCR}_{2017} = \left[\mathrm{p}_{d1}^{2015}, \mathrm{p}_{d2}^{2015} \ldots \mathrm{p}_{d365}^{2015}\right] \tag{6}$$

$$FCR_{2018} = \left[p_{d1}^{2016}, p_{d2}^{2016} \ldots p_{d365}^{2016}\right] \tag{7}$$

$$FCR_{2019} = \left[p_{d1}^{2015}, p_{d2}^{2015} \ldots p_{d365}^{2015}\right] \tag{8}$$

$$FCR_{2020} = \left[p_{d1}^{2016}, p_{d2}^{2016} \ldots p_{d365}^{2016}\right] \tag{9}$$

In the above equations, p represents the mean price of the day. The year number is shown as a superscript. For example, p_1^{2015} stands for mean price for the first day of 2015. Similarly, while p_2^{2015}, stands for mean price of the second day of 2015, p_{365}^{2015} stands for the last day. For the resampled timeseries, the ED is calculated using the following formula:

$$\mathrm{d}(FCR_{2015}, FCR_{2016}) = \sqrt{\sum_{i=1}^{365} \left(p_{di}^{2016} - p_{di}^{2015}\right)^2} \tag{10}$$

The above equation shows the ED estimate between availability prices of the year 2015 and 2016. For the sake of simplicity and for better visualisation, the ED values are normalised by subtracting the minimum ED value from each entry and dividing it by the difference of the maximum and minimum ED value. The normalised values are then subtracted from one and referred as $\mathrm{ED_n}$, as shown in the following matrix:

$$\begin{bmatrix} 1-\mathrm{d}(\mathrm{FCR}_{2015}, \mathrm{FCR}_{2015})_{\mathrm{n}} & \cdots & 1-\mathrm{d}(\mathrm{FCR}_{2015}, \mathrm{FCR}_{2020})_{\mathrm{n}} \\ \vdots & \ddots & \vdots \\ 1-\mathrm{d}(\mathrm{FCR}_{2020}, \mathrm{FCR}_{2015})_{\mathrm{n}} & \cdots & 1-\mathrm{d}(\mathrm{FCR}_{2020}, \mathrm{FCR}_{2020})_{\mathrm{n}} \end{bmatrix} \tag{11}$$

In the above equation the normalization is done as follows:

$$\mathrm{d}\left(FCR_{y1}, FCR_{y2}\right)_n = \mathrm{d}\left(FCR_{y1}, FCR_{y2}\right) - ED_{min} \Big/ ED_{max} - ED_{min} \tag{12}$$

here y1 and y2 are the two years between which ED is computed.

3.2. BESSs' energy payment analysis

To calculate the revenues from the energy payments, a BESS unit of 1 MW/MWh is considered. The BESS unit is considered to be participating separately in only one market at each hour. The calculations for FCR-N, FCR-D, and FFR in this section are thus independent of each other and are done mainly to quantify the differences in energy content requirements, activation requirements, and possible yearly revenues from a BESS unit in each market.

The megawatt-power (MW-power) to be delivered by the BESS unit is computed by applying droop control signals – as shown in Fig. 2c – to the power system frequency data. Since the per second frequency data of 2015–2020 from [61] is used, the power is calculated in MW/s. The droop control equations of FCR-N, FCR-D, and FFR are shown in Eqs. (13), (14), and (15):

$$P_i = \begin{cases} -P_{\max} & f_i > 50.1 \\ \dfrac{-2\,(f_i - 49.9) + 1}{0.2} & 49.9 \le f_i \le 50.1 \\ +P_{\max} & f_i < 49.9 \end{cases} \tag{13}$$

$$P_i = \begin{cases} -P_{\max} & f_i > 50.5 \\ \dfrac{-1\,(f_i - 50.1) + 1}{0.4} & 50.1 \le f_i \le 50.5 \\ +P_{\max} & f_i < 49.5 \\ \dfrac{-1\,(f_i - 49.5) + 1}{0.4} & 49.5 \le f_i \le 49.9 \\ 0 & 49.9 < f_i < 50.1 \end{cases} \tag{14}$$

Table 2
Summary statistics of availability payments and regulation prices.

Data	Count	Mean	STD	Max	Skew	Kurtosis
FCR-N AP_h	52,608	182.9	136.5	1948.29	2.73	14.89
FCR-D AP_h	52,608	89.72	88.16	2121.77	5.21	63.16
FFR AP_h	4392	108.3	204.3	1368.00	2.60	6.816
p_h^{reg-up}	52,608	282.0	207.2	14,910.5	11.57	533.83
p_h^{reg-dn}	52,608	219.1	123.1	1898.9	0.83	6.93

$$P_i = \begin{cases} P_{\max} & f_i \le 49.6 \\ 0 & f_i > 49.6 \end{cases} \tag{15}$$

In these equations, f_i is the power system frequency at ith second of the day. And P_i is the MW-power of the BESS unit at the ith second calculated according to the droop equations. $+P_{\max}$ is 1 MW, while $-P_{\max}$ is −1 MW. Based on P_i the per second energy content that must be supplied or absorbed by the BESS unit (E_i) and per-hour energy content (E_h) of the BESS unit is computed. E_h when multiplied by hourly regulation-up (p^{reg-up}) or regulation-down (p^{reg-dn}) prices gives hourly energy payment (EP_h) for 1 MW/1 MWh BESS. p^{reg-up} and p^{reg-dn} are measured in DKK/MWh and published by Energinet on [62]. For the hour h, EP_h is given by Eq. (16) when E_h is positive and Eq. (17) when E_h is negative:

$$EP_h = E_h \times p_h^{reg-up} \tag{16}$$

$$EP_h = -E_h \times p_h^{reg-dn} \tag{17}$$

3.3. BESSs' revenue stream analysis

When estimating FCR-N, FCR-D and FFR revenues for the BESS unit, it is assumed that bids are submitted for each hour of the year and all submitted bids are accepted. Consequently, the calculations correspond to the maximum possible revenue that can be earned by the BESS units.

For FCR-N, P_i for each second of each year is calculated from Eq. (13), which gives us 1.89×10^8 values. Since FCR-N is a symmetrical product – both up and down regulation must possible – it is assumed that the initial energy content (E_{bat}) is 0.5 MWh. At each second, there is an increment or decrement in the energy-content of the BESS ($E_{bat} \pm E_i$). This results in continuous charging and discharging of the BESS unit. Here, E_i is calculated per second by dividing P_i by 3600 and it is ensured that $E_{bat} \pm E_i$ is maintained for the BESS unit to remain within its operational range, such that:

$$E_{max} \le E_{bat} \pm E_i \le E_{min} \tag{18}$$

Here, $E_{min} = 0$ and $E_{max} = 1$. P_i values are summed for each hour and divided by 3600 to calculate E_h for the hour h:

$$E_h = \sum_{i=h}^{i=h+3600} \frac{P_i}{3600} \tag{19}$$

EP_h is then calculated using Eqs. (16) and (17) and total hourly FCR-N revenue $FCRN_h$ from Eq. (20):

$$FCRN_h = \sum_{i=h0}^{i=H} AP_h^{fcrn} + \sum_{i=h0}^{i=H} EP_h^{fcrn} \tag{20}$$

Here, AP_h is the hourly availability payment. $h0$ is the first hour of BESS operation, and H is the total number of hours of BESS operation. On the other hand, for the BESS unit is participation in FCR-D or FFR market, E_h is calculated only for the sake of comparison with FCR-N E_h. However, no EP_h calculations are made in their case, thus total hourly FCR-D revenue $FCRD_h$ and total hourly FFR revenue FFR_h are given by:

$$FCRD_h = \sum_{i=h0}^{i=H} AP_h^{fcrd} \tag{21}$$

$$FFR_h = \sum_{i=h0}^{i=H} AP_h^{ffr} \tag{22}$$

In the above calculations, the 1 MW/1 MWh BESS unit is considered to be participating separately in FCR-N, FCR-D, and FFR market. BESS participation in multiple markets is also considered and is called BESS service stacking. In BESS service stacking, combined BESS participation in FCR-N, FCR-D, and FFR markets is considered, however, it occurs at

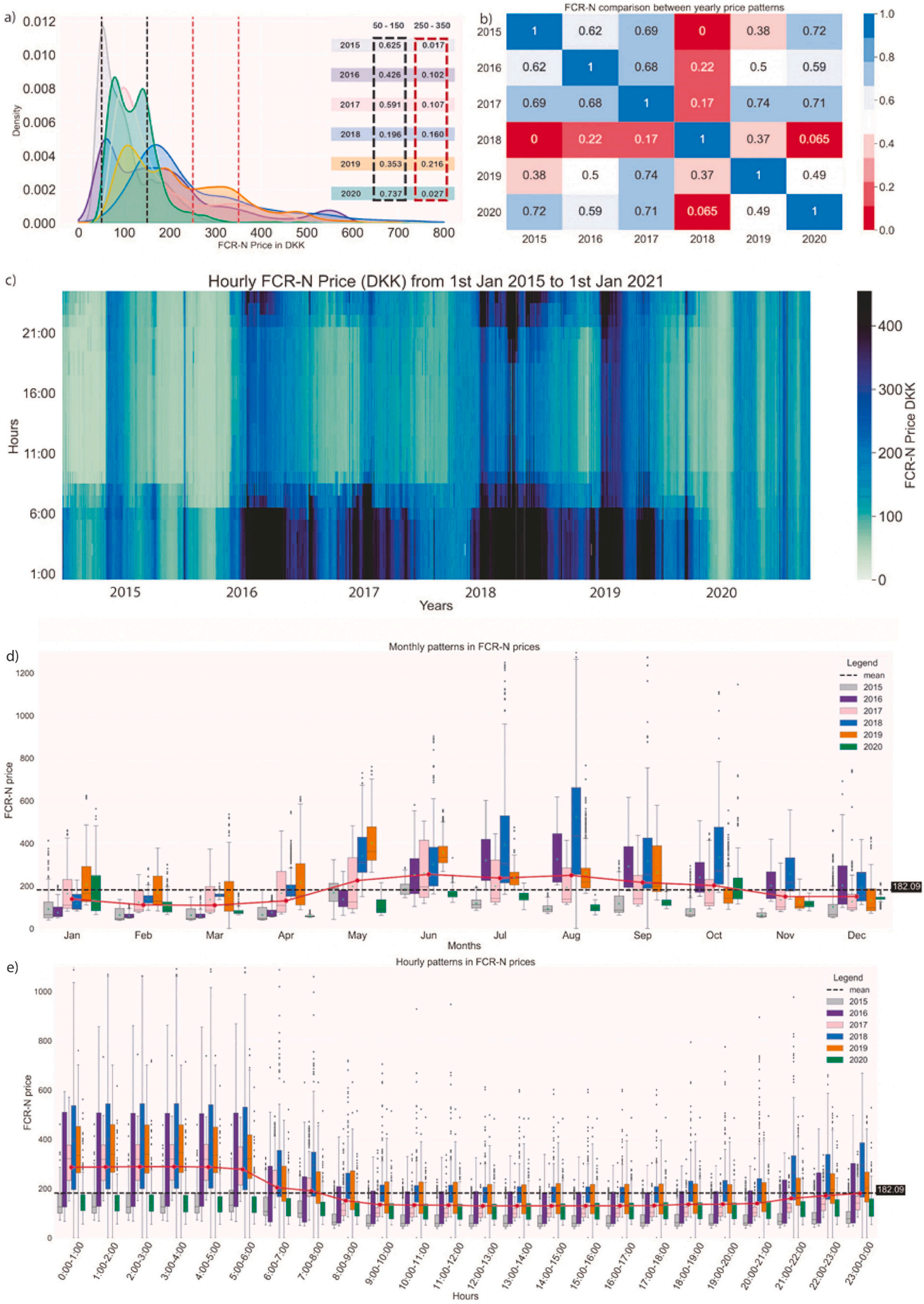


Fig. 4. a) Probability distribution plots of FCR-N AP_h b) ED between different years of FCR-N AP_h, c) heatmap illustration of FCR-N AP_h d) monthly pattern sin FCR-N AP_h e) hourly patterns in FCR-N AP_h.

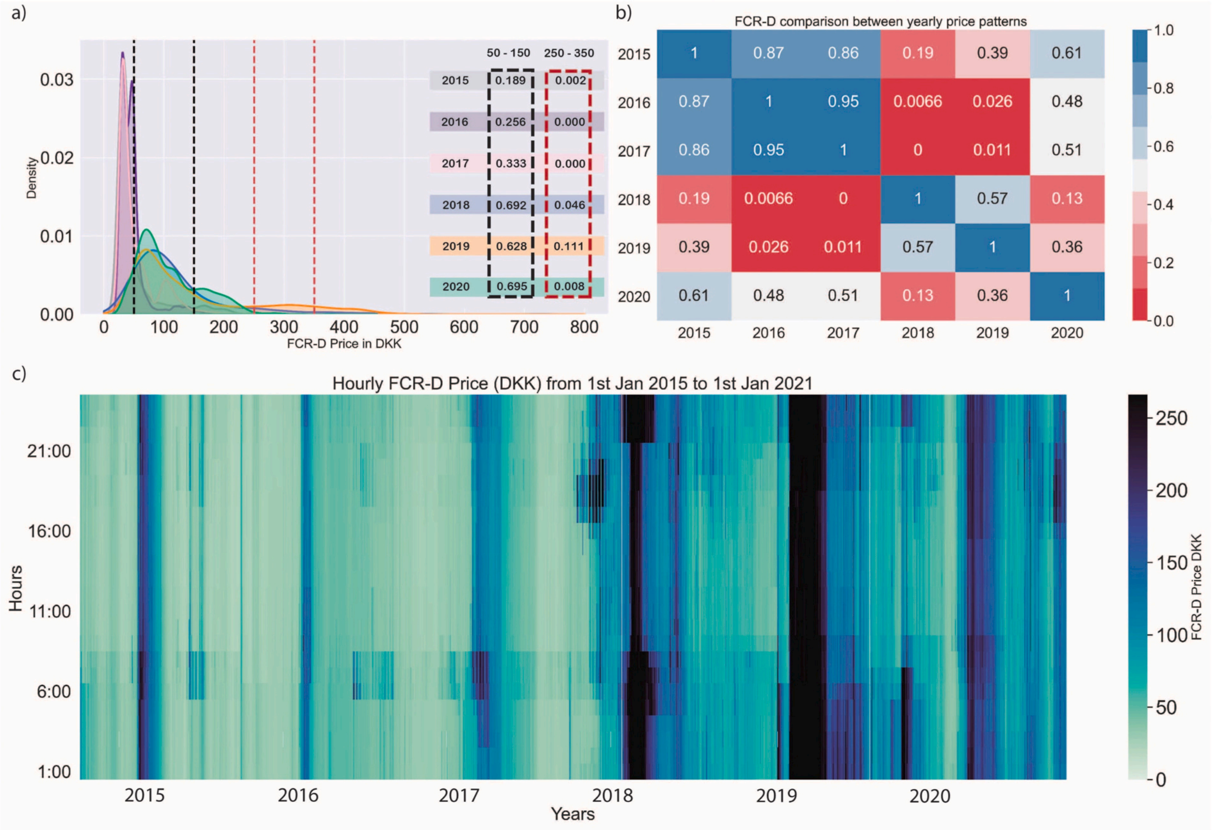


Fig. 5. a) Probability distribution plots of FCR-DAP_h, b) ED between different years of FCR-AP_h, c) heatmap illustration of FCR-D AP_h.

different hours of the day. Therefore, at a specific hour the entire 1 MWh energy is available in one market only. The yearly BESS stacked revenue is thus calculated as:

$$BESS_{stacked} = FCRN_{hN} + FCRD_{hD} + FFR_{hR} \tag{23}$$

Here, hN, hD and hR are respectively hours of the year in which BESS is participating in the FCR-N, FCR-D, and FFR market which is chosen by comparing their hourly availability payments.

4. BESSs participation in the Nordic ASMs – Business assessment

This section investigates the hourly availability payments (AP_h) of 6 years in DKK/MWh for FCR-N and FCR-D which amount to 52,608 data points. Six months of FFR prices are also investigated. Table 2 shows their summary statistics. p^{reg-up} and p^{reg-dn} statistics are also included.

4.1. BESSs participation in FCR-N markets

For FCR-N AP_h the skewness of 2.73 shows the distribution's right tail is longer than the left tail, thus indicating a significant number of data points in the lower price range. Similarly, a high kurtosis of 14.89 shows that the distribution has many outlier values far from the central value – mean and median. Moreover, the KDA plot in Fig. 4a illustrates the probability of FCR-N prices falling in different price ranges. The probability values in the range 50–150 DKK/MWh are 0.625, 0.426, 0.591, 0.195, 0.353, and 0.737, respectively for 2015–2020, thus showing that FCR-N AP_h were lower than average in 2020, which was not the case in 2018. Moreover, the probability values in the range of 250–350 DKK/MWh are 0.017, 0.102, 0.107, 0.160, 0.216, 0.027 respectively for 2015–2020, being relatively lower than 50–150 DKK/MWh range. Fig. 4c illustrates the heatmap of yearly FCR-N AP_h following Eq. (2). Days of the years are represented on the x-axes, while hours of the days are represented on the y-axes. The darker colors indicate higher values. AP_h are observed to be higher from midnight to early morning – off peak hours.

However, the off-peak hours of the 2016–2019 show higher values than 2020, thereby indicating a difference in the 2020 AP_h behaviour from previous years. This is further elaborated in the heatmap of Fig. 4b based on Eq. (11). The six years are represented on both the x-axes and the y-axes, and the colors show the similarity between AP_h of the corresponding years based on Eqs. (4)–(10). Values higher than 0.5 are illustrated in blue and lower than 0.5 are illustrated in red. As evident from the Fig. 4b the FCR-N AP_h of 2015 show higher similarity of 0.62, 0.69, and 0.72 with 2016, 2017, and 2020, and lower similarity of 0.0 and 0.38 with 2018 and 2019. Similar patterns are observed for the AP_h of 2016.

Fig. 4d illustrates a boxplot for the monthly price trends of six years. The months of the years are shown on the x-axes, while the FCR-N AP_h are shown on the y-axes. The colors of the boxplots show the corresponding years. The mean value for the boxplots of each month is shown by a red circle connected together with a red line indicating the monthly trend. The overall mean of FCR-N AP_h is shown by a dashed black line. Fig. 4d shows that the mean FCR-N AP_h are lower for January–April and start to increase in May–August. These trends start decreasing after August and become low again in November and December. In 2015–2019, the prices trends were relatively higher in the summer months, while in 2020, October and January showed higher prices – with the highest outlier values appearing in October. Also, the monthly average prices are higher than the total average in the mid-year months of May–October and lower for the rest.

Fig. 4e illustrates a boxplot of the hourly price trends of six years. The hours of the day are shown on the x-axes, while the FCR-N AP_h values are shown on the y-axes. The mean value for the boxplots of each hour is represented by a red circle connected together with a red line indicating the hourly trend. The hourly price trend shows higher values from 0:00 to 6:00, after which it begins to fall until 10:00. It then remains almost

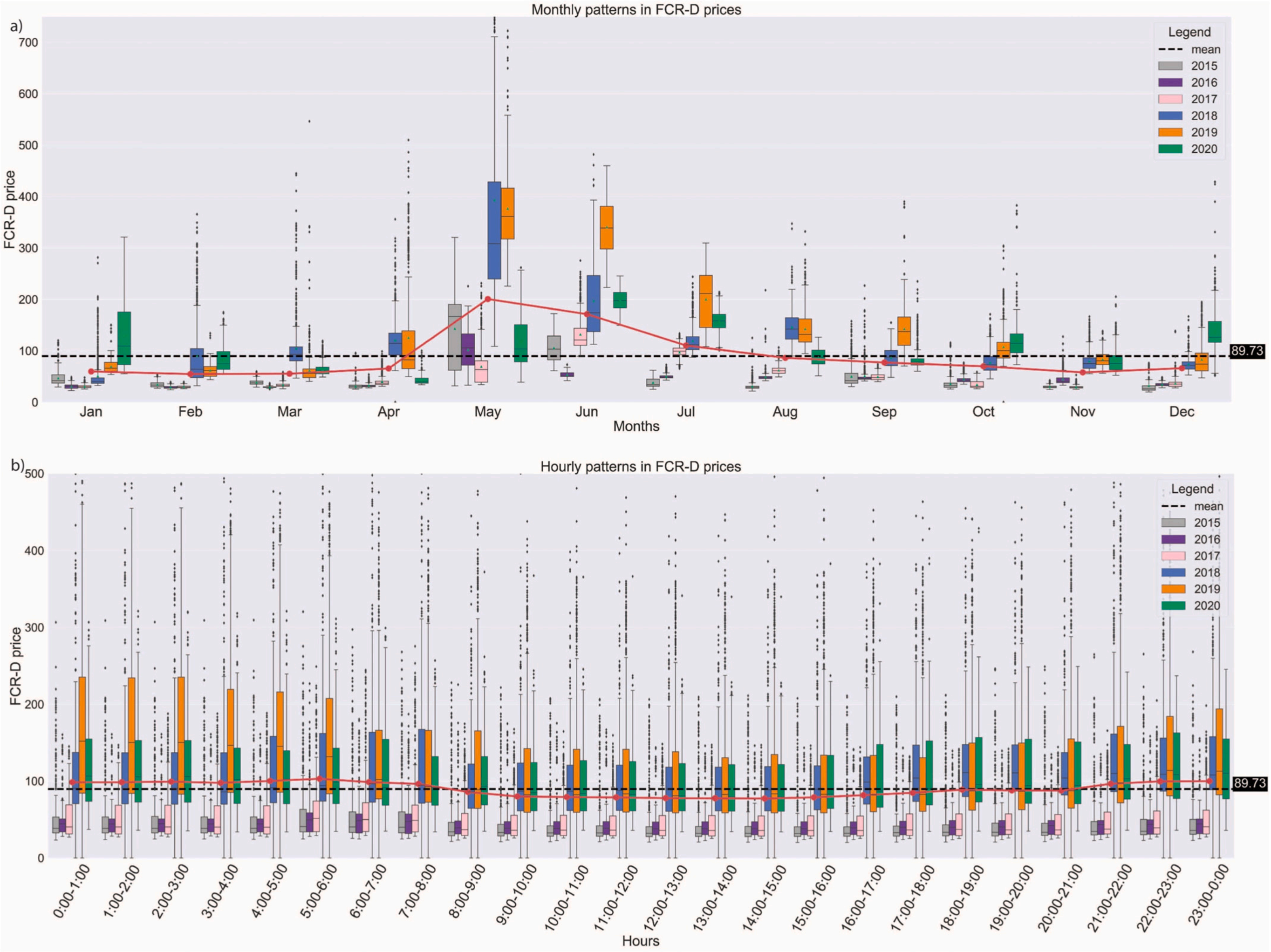


Fig. 6. a) Monthly patterns in FCR-D AP_h b) hourly patterns in FCR-D AP_h.

the same until 21:00, after which it begins to increase again. This holds true for 2015–2019, whereas, in 2020 the relative difference between the hourly prices was not as significant as the previous years. For example, in 2019, the average hourly prices fell from 350 DKK/MWh at 12:00 to 150 DKK/MWh at midnight. However, in 2020, it fell from 150 to 115 DKK/MWh during the same hours. Moreover, the hourly mean values are higher than the total average for 0:00–8:00 and lower for the rest of the hours.

The analysis indicates that FCR-N AP_h is not essentially similar to the prices of the preceding years. However, some generalizations can be made in this regard. The business potential of BESS units can be enhanced by participating in FCR-N market from midnight to early morning. Similarly, the business potential can be enhanced by participating in mid-year months from May–October.

4.2. BESS participation in FCR-D markets

Similar to the FCR-N AP_h, the FCR-D AP_h are investigated for six years The skewness and kurtosis of FCR-D AP_h distribution are 5.21 and 63.16, respectively, which are higher than that of FCR-N, thus indicating a longer right tail – a greater number of low-price values – and a more heavily tailed distribution. Fig. 5a illustrates a KDE plot for the FCR-D AP_h of each year. The probability of FCR-D AP_h falling in the range of 50–150 DKK/MWh is 0.189, 0.256, 0.333, 0.692, 0.628, and 0.695, respectively for 2015–2020. However, these probability values are quite low for the range of 250–350 DKK/MWh as compared to both the former range of FCR-D AP_h and similar range of FCR-N AP_h. Furthermore, Fig. 5c illustrates the heatmap of yearly FCR-D AP_h prices based on Eq. (3). Unlike FCR-N AP_h, FCR-D AP_h do not show significant price variation throughout the day. The similarities in the yearly FCR-D AP_h patterns are further elaborated in the heatmap of Fig. 5b based on the Eq. (11). The FCR-D AP_h of 2015, 2016, and 2017 show the highest similarity with each other as indicated by the $\mathrm{ED_n}$ values. Contrarily, the years 2018, and 2019, show the lowest values of $\mathrm{ED_n}$ with the rest of the years. They, however, show a higher value of 0.57 with each other. Moreover, the $\mathrm{ED_n}$ of FCR-D AP_h of 2020 shows similarity with 2015–2016 as opposed to the immediate prior years.

In addition to the yearly patterns in FCR-D AP_h, the monthly patterns

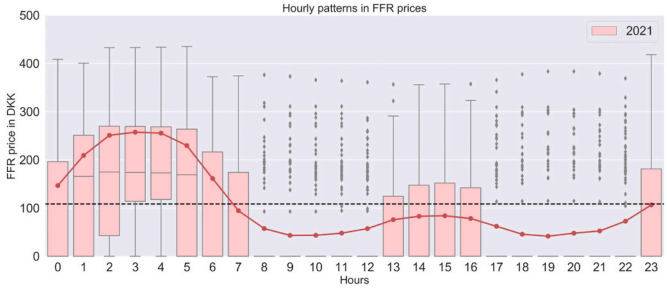


Fig. 7. Hourly patterns in FFR AP_h.

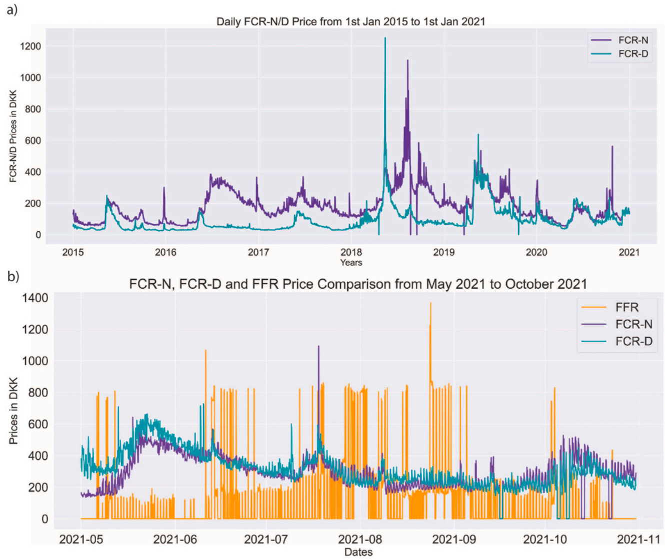


Fig. 8. a) 6-year comparison between hourly FCR-N and FCR-D prices b) 6-months comparison between hourly FCR-N, FCR-D and FFR prices.

are also investigated. Fig. 6a illustrates boxplot for the monthly FCR-D AP_h of all six years. The months of the years are shown on the x-axes, while the FCR-D AP_h is shown on the y-axes. The colors of the boxplots show the corresponding years. The mean values for each month are connected with a red line indicating the monthly price trend. Additionally, the overall FCR-D mean price of 89.73 DKK/MWh is also shown with a dashed black line. Fig. 7a shows that the monthly mean FCR-D prices are lower for January to April and start to increase in May. They however decrease again after May until the end of the year. However, the year 2020, shows dissimilarity in this monthly FCR-D price trend, as it has high prices in January and December as opposed to the other years. Moreover, Fig. 6a also shows the FCR-D monthly price averages with respect to the overall mean line of 89.73. These values lie above the mean line for May, June, and July only.

Moreover, the hourly trends in FCR-D AP_h are shown in Fig. 6b. The hours of the day are shown on the x-axes, while the FCR-D $AP_h$are shown on the y-axes. The dashed-red trend line of hourly mean does not show much variations. The trend is slightly higher from 0:00 to 8:00, however, the price difference is quite low. The years 2015–2017, show similar hourly price behaviour, with relatively low prices as compared to the years 2018–2020. The categorical mean of the later years is similar to the total mean of 89.73, whereas it is lower for the former years. Moreover, many outlier prices exist for the years 2015–2019, whereas they are quite less for the year 2020.

4.3. BESS participation in FFR markets

Since FFR is a relatively new service in the Nordic SA, analysing its yearly and monthly prices patterns is not possible. Therefore, in Fig. 7 hourly patterns in the FFR AP_h for six months are investigated. The black dashed line in Fig. 7 shows the mean FFR price, 108.36 DKK/MWh for these six months. It is also evident from Fig. 7 that the FFR prices have a mean of around 150 DKK/MWh at 0:00; however, the mean FFR price increases to 250 DKK/MWh, from 0:00–3:00, and then starts to decrease again until 7:00. After that, FFR prices are generally 0, except for a few hours in the afternoon, i.e., from 13:00–16:00. During the hours with 0 mean hourly prices, there were certain hours in 2021 when prices reached as high as 400 DKK/MWh.

5. BESSs' participation in the Nordic ASMs – Business implications

5.1. BESSs' participation in multiple markets

Comparison of historical market prices can help BESS owners decide whether it would be more profitable to bid in the FCR-N, FCR-D or FFR market. Fig. 8a.illustrates a six-year comparison between FCR-N and FCR-D AP_h. FCR-N AP_hwere mainly higher as compared to FCR-D AP_h, except for the end of 2020. In addition to FCR availability prices, Fig. 8b, illustrates a comparison of FCR-N, FCR-D, and FFR AP_h. For the six months of 2021, FFR AP_h were less volatile as compared to FCR-N and FCR-D AP_h. Also, FCR-N, and FCR-D AP_h of 2021, were comparable. Additionally, at times, FFR AP_h are 25 %–75 % higher than FCR-N or FCR-D AP_h. The latter is within the range of 200 DKK/MWh to 600 DKK/MWh, whereas the former goes either as high as 800/MWh – 1000/MWh DKK.

BESS owners bidding in the Nordic FRMs can earn revenue from the AP_h of FCR-N, FCR-D, and FFR, by merely being present in the market, irrespective of whether their units were activated or not. Even though AP_h of FCR-N are generally higher as compared to FCR-D, however this may not necessarily imply bidding primarily in the FCR-N market would ensure a profitable business for BESS owners. This is because of three main reasons. Firstly, the frequency fluctuations of the power system are generally within the range of 49.9–50.1 Hz, which requires activation of FCR-N reserves. The events of grid-frequency falling below 49.9 Hz or rising above 50.1 Hz – thus requiring FCR-D activation – are less frequent. For the years 2015–2020, the grid-frequency of respective years was in the latter-mentioned range for 2.0 %, 2.6 %, 2.2 %, 2.2 %, 2.5 %, and 1.8 % of the times as compared to the former-mentioned range. This implies that the actual activation of reserves is less probable in FCR-D market as compared to FCR-N. Secondly, the per hour energy content requirement E_h of FCR-D is significantly lower than FCR-N. Fig. 9a illustrates the comparison between first 1000 h E_h of FCR-N, FCR-D and FFR for the six months of 2021. In this case even though the prices of FCR-N and FCR-D are comparable (as seen in Fig. 8b), their E_h differs significantly. It varies between −0.8 MWh–0.6 MWh for FCR-N, and −0.04–0.02 for FCR-D. Thirdly, charging and discharging of BESS (activation requirement) occurs almost continuously for FCR-N, it however occurs only at certain instants for FCR-D. As illustrated in Fig. 9b, for the 60,000 s, BESS is continuously being charged and discharged following the changes in grid-frequency for FCR-N, however, for FCR-D it is activated only at certain instants. Frequent activations cause BESSs to undergo higher number of charge discharge cycles, thereby causing higher cell degradation, and consequently shorter BESS lifespan. Therefore, for the last few months of the year 2020, and the 6 months of the year 2021, when FCR-N and FCR-D are comparable, participation in FCR-D market can help BESS owners earn similar revenue as FCR-N market, but with lesser impact on state-of-health (SoH) of their BESS units. However, for the hours of the year when FCR-N AP_h are significantly higher, even if participation in FCR-D market is less deteriorating for the battery's SoH, bidding in FCR-N markets is a more profitable trade decision.

5.2. BESSs' revenue streams in multiple markets

While considering BESS participation in multiple markets, in addition to their availability payment it is also important to look into their energy payments. Depending on the frequency of the power system, the BESS owners deploy droop control signals to supply or consume the required energy content to and from the grid. Based on the equations discussed in the Sections 3.2, and 3.3 the comparison of energy payments for FCR-N, and FCR-D with their availability payments is illustrated in Fig. 10. For 1 MW/1 MWh BESS; the FCR-N energy payments of the years 2015–2020 are 5.1 %, 2.7 %, 3.2 %, 2.4 %, 3.1 %, and 8.8 % of the availability payments. Moreover, the energy payments of FCR-D are

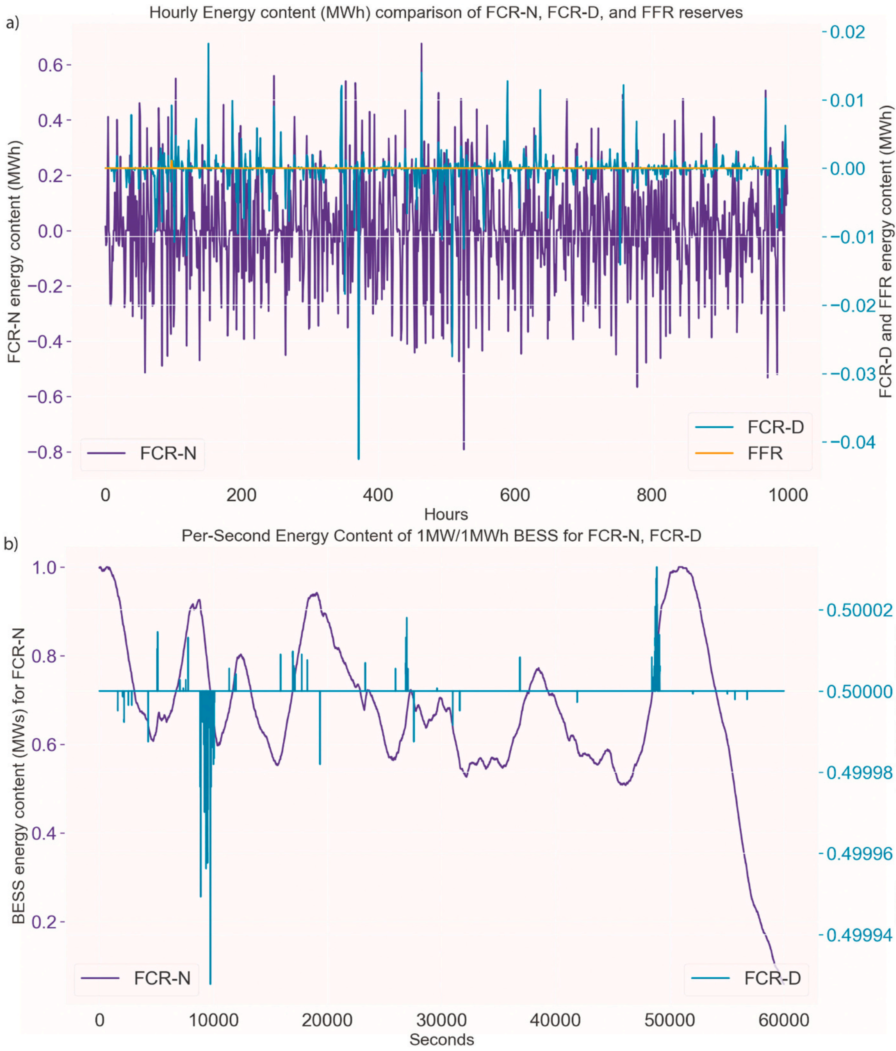


Fig. 9. a) Hourly energy content comparison for FCR-N, FCR-D and FFR b) per-second energy content comparison for FCR-N and FCR-D FFR.

even lower – approximately 0.05 % of the FCR-D availability payments. However, since in the Nordics, FCR-D ‘energy payments’ are not ‘paid’ to the market participants and are therefore neglected. Therefore, Fig. 11 illustrates the total revenue from availability and energy payments for FCR-N, and only availability payment for FCR-D calculated using Eqs. (20) and (21). The results adequately conclude that the main source of revenue for the BESS owners in ASMs are the availability payments since energy payments constitute only a fraction of their total revenue. It is worth highlighting that in DK2, the pricing mechanism of FFR is different from FCR-N and FCR-D. The latter two markets operate on pay-as-bid mechanism while the former operates on pay-as-clear. In pay-as-bid, participants with accepted bids are paid the amount of their bids, while in pay-as-clear all participants are paid the price of the highest bid. It is thus riskier to submit very high bids in pay-as-bid markets. Therefore, government bodies must look into the implications of different pricing mechanisms on the trends of availability payments and develop policies that can ensure higher BESS participation.

It is important to note that Figs. 10 and 11 show the maximum possible revenues a BESS owner can earn. Depending on the SoH of the BESS units, power losses in the system, system efficiency, and accepted bids, these values would vary. Other factors such as BESS allocation location, DTR of transmission lines, and RES availability at installation site, would also impact the overall business potential of BESS projects. For example, as addressed in [51] BESS units connected to the low-voltage grid level in DK2 are charged a monthly electricity tariff of 97.47 øre/kWh when charged at the peak load hours which is higher than the electricity tariff at medium voltage grid-level of 26.18 øre/kWh. However, depending on the unique requirements of their BESS projects, these considerations may vary and must be accounted for on case-by-case basis.

5.3. BESS service stacking

For the BESS units signed up for both FCR-N and FCR-D, service stacking can be a possible business solution. Service stacking allows BESS owners to participate in the FCR-N market, for the hours of the day when FCR-N prices are higher, and FCR-D market for rest of the hours. As discussed in the paper, off-peak hours of the day generally showed higher AP_h for all 6 years as compared to the on-peak hours. This can be explained by the disconnection of the large-scale generation units from the grid during the off-peak hours which results in a higher need for FCR-N. The possible revenues from BESS service stacking for FCR are calculated based on Eq. (23) – FFR_{hR} is excluded – and are illustrated in the Fig. 11. In the equation hN are the hours when FCR-N AP_h is higher, while and hD are the hours when FCR-D AP_h is higher. As evident from the figure, for 2015–2020, revenue from stacked BESS services is 19.36 %, 9.99 %, 11.18 %, 17.09 %, 19.04 %, and 22.57 % higher than using the BESS unit only for FCR-N service. Similarly, for these years, the stacked revenue is 19.36 %, 9.99 %, 11.18 %, 17.09 %, 19.04 %, and 22.57 % % higher than using the BESS unit for FCR-D service alone. An

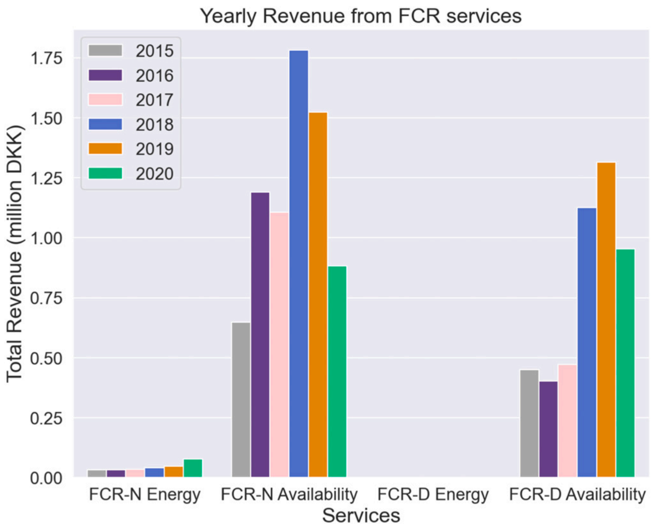


Fig. 10. Comparison between energy and availability payment revenue.

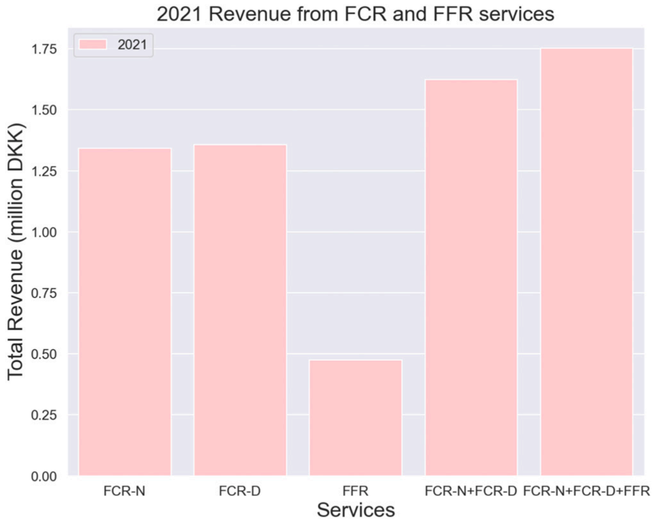


Fig. 12. Comparison between revenue from FCR-N, FCR-D, FCRN + FCR-D, and FCR-N + FCR-D + FFR in 2021.

important consideration while performing BESS service stacking is the response time required to switch between different services. In DK2, BESSs units must be able to switch from FCR-N to FCR-D without intentional delay when frequency crosses 49.9 Hz or 50.1 Hz. However, for switching back from FCR-D to FCR-N, there can be a delay of 30 s. Moreover, the BESS units must pass the prequalification tests set by Energinet for both services to perform BESS service stacking.

In addition to FCR service stacking, FCR + FFR service stacking may also ensure potential business as shown in Fig. 12 for the year 2021. The revenues from providing FCR-N and FCD-D service in the year 2021 are similar. Additional revenues can be earned by bidding into FFR market from midnight to early morning when the availability payments are significantly high. From Fig. 12, the revenue from FCR + FFR service stacking in the year 2021 is 23.3 % higher than using the BESS for FCR-N service alone. Moreover, it is 22.5 % higher than using the BESS for FCR-D service alone, 72.8 % higher than using it for FFR alone, and 7.74 % higher than using it for FCR-N and FCR-D stacked services.

Since a high variance in FFR AP_h exists at different hours of the day developing a forecast model may help BESS owners compare the AP_h of different ASs to engage in business-friendly service stacking. To develop such forecast model statistical techniques, artificial intelligence (AI) based techniques or econometrics may be used. In the former two, the BESS unit must rely on historical data to predict future prices and perform service stacking to maximize revenues. Whereas in the latter, the key determinants of AS prices must be identified to enable BESS owners choose between markets by predicting their future behaviour patterns. However, since ASMs are relatively new as compared to day-ahead spot markets, their forecast literature is scarce. AI-based models have been extensively used to forecast prices of various other markets in the electricity sector such as day-ahead market and balancing markets [63–65], however, ASMs have not been targeted. Moreover, since ASs products in different regions of the world are diverse and ASMs have unique market requirements in contrast to the energy markets, econometrics research in this direction is also scarce. Therefore, it is a potential future direction of this work to a) develop an AI-based forecast to perform business-friendly BESS service stacking, b) to develop an econometric model to identify the factors – if any – deriving the prices of ASs products in the Nordics, and c) to analyse the behaviour of ASs products of different regions of the world and compare the business potential of integrating BESS in those regions with the Nordics.

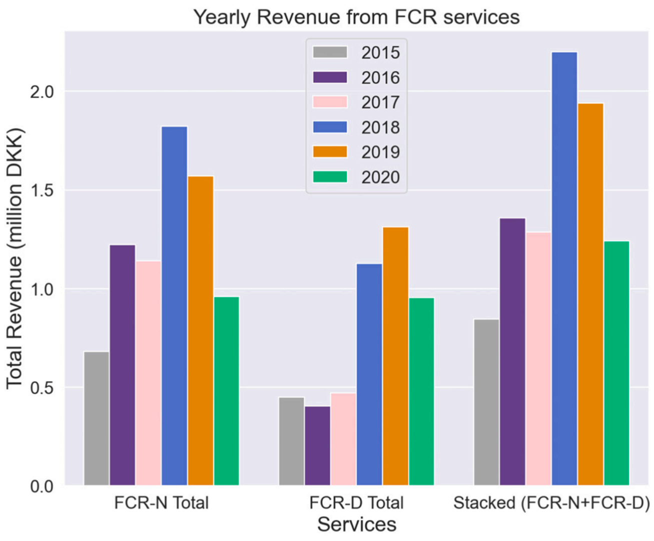


Fig. 11. Comparison between revenue from FCR-N and FCR-D and stacked revenue from FCR-N + FCR-D.

6. Conclusion

This paper investigated the historic price behaviours of the Nordic FRMs while considering business viability of BESSs. It explored yearly, monthly, and hourly patterns in price behaviours of the FCR services by analysing price data for the past six years. In the paper, we found a higher percentage of FCR-N prices lied within the range of 50–150 DKK/MWh, thus indicating high availability prices. For BESS owners participating in FCR-N markets, we found the profitable bidding time was during the off-peak hours. We also found the mid-year availability prices of FCR-N to be higher, especially from May to August. On the other hand, we found the percentage of FCR-D prices within the range of 50–150 DKK/MWh were relatively low, thus indicating lower availability prices. We also found FCR-D prices were similar during different hours of the day as contrast to FCR-N prices. We concluded that FCR-D availability prices are generally lower as compared to FCR-N prices for all six years. Moreover, we also investigated the price behaviour of the FFR service and found its prices to be less volatile as compared to the FCR-N and FCR-D.

Based on historical data, we also estimated the revenue that can be earned from different regulation services. We found that for FCR-N, revenue from the availability payment was approximately 90 % higher than the revenue from its energy payments. We also found the FCR-N availability payment revenue was higher than FCR-D's for all 6 years. We concluded that while making business decisions, in addition to the availability payment revenue, it is important to consider the activation requirements of FCR-N, and FCR-D to avoid SoH degradation of BESS. We also concluded that stacking FCR-N, and FCR-D based on their hourly and monthly price trends can increase the revenue by 2 %–8 %. We further concluded that considering FFR provision in addition to FCR can result in further increase in the total revenue owing to the high availability prices of FFR at certain hours of the day. We also concluded that developing forecast models to predict availability prices of FRMs can ensure business-friendly BESS service stacking. Hence, our analysis and empirics thus obtained should be seen as a reasonable first step in understanding the price behaviour of Nordic frequency regulation products from BESS business viewpoint.

CRediT authorship contribution statement

The authors confirm contribution to the paper as follows: Conceptualization: Zeenat Hameed, Seyedmostafa Hashemi; Methodology, Investigation, Writing initial draft, Visualisation, Resources and Editing: Zeenat Hameed; Review: Seyedmostafa Hashemi, Chresten Træholt, Supervision, Project Administration and Funding Acquisition: Seyedmostafa Hashemi, Chresten Træholt. All authors reviewed the results and approved the final version of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

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