The Aggregator as a Storage Provider

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***Abstract*—The energy transition from fossil resources to integration of more renewables such as solar and wind has become the focus in the energy strategies of many countries. The time difference between solar energy production and power demand peak hours in the grid can be significant, bringing the role of electricity storage, especially battery systems, to center stage. Based on this fact with data from the solar energy output at Oslo and Nord Pool electricity prices, the revenue potential for storage is calculable. For the prosumers acting as both energy users and producers, storage is installed mainly for self-consumption. In comparison, storage with aggregators may achieve profit out of the outrage of the market price fluctuation.**

***Keywords*—electricity storage, batteries, prosumer, aggregator, business model, Smart-MLA**

I. Introduction

The construction of a green, low-carbon, and clean energy system with renewable energy sources has become the first choice for most countries to develop their energy strategy. Despite the COVID-19 pandemic, more than 260GW of renewable energy capacity was added globally in 2020, exceeding expansion in 2019 by close to 50% [1]. The growth of solar energy was 127 GW, while wind grew by 111 GW [1]. Consumers can produce energy with small-scale home solar panels, and new technologies like smart meters allow this energy to be sold back to the grid. The term prosumer is used for these new combined producers and consumers. The prosumers sell surplus energy to the grid through a Distribution System Operator (DSO) or an aggregator.

The prosumer has a smart meter installed that tracks the energy transferred from and to the grid. The smart meter communicates with the aggregator through a network connection, as shown in Fig. 1.

An aggregator is an entity that organizes several prosumers and handles both internal and external energy sales. The aggregator can also play an essential role as a flexibility provider. The prosumers can delegate control of parts of their consumption to the aggregator, optimizing the power consumption to reduce peak loads.

The Smart-MLA project [2] is an ERA-Net Smart Grid Plus research project with academic and industrial partners from Denmark, Norway, Romania, Sweden, and Turkey. The project aims to develop and demonstrate a cloud-based multi-layer aggregator solution to facilitate optimum demand response and grid flexibility for energy systems to utilize up to 100% renewable energy. One specific goal is to investigate emerging business models for aggregators and prosumers. This paper addresses the provision of electric storage within smart grids in the context of emerging business models.

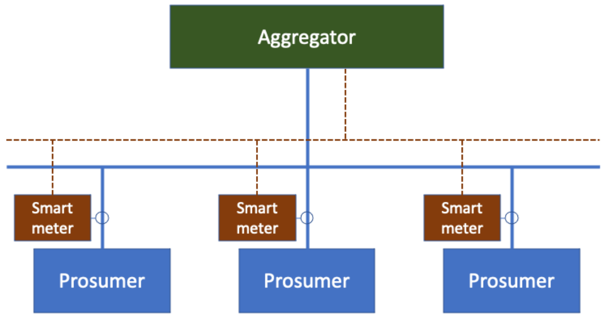

Fig. 1. The aggregator and the prosumers

The electricity demand varies throughout the day. The production peaks from renewable energy are not correlated with the peaks in consumption. To address this mismatch between peak production and demand, Roy et al. [3] have demonstrated that utility-scale solar energy combined with battery storage can replace fossil-fuel power plants at a lower cost of operation. For household prosumers, an interesting similar approach is to use the battery of an electric vehicle as temporary storage. But an aggregator may also offer storage, perhaps at a lower cost. This paper aims to discuss the location of storage. Should it be with the prosumer or with the aggregator?

The paper is organized as follows: The following section contains a short literature review on storage technology, including storage costs and capacity for batteries. Section III discusses revenue potential based on data of solar panels production and price from the Norwegian electricity market. Section IV presents the prosumer storage model and aggregator storage model, and the last section contains the conclusion and ideas for further research.

II. Energy Storage Technologies

Energy storage technologies convert electrical energy to another form that can be stored and converted to electricity when needed [4]. According to Luo and co-authors [5], EES can have multiple attractive value propositions (functions) to power network operation and load balancing, such as:

- helping in meeting peak electrical load demands
- providing time-varying energy management
- alleviating the intermittence of renewable source power generation

- improving power quality/reliability
- meeting remote and vehicle load needs,
- supporting the realization of smart grids
- helping with the management of distributed/standby power generation,
- reducing electrical energy import during peak demand periods.

Commonly used storage technologies can be categorized as mechanical, thermal, electrical, or chemical. Table 1 lists the storage categories and technologies [6]. The most used technology and systems are Pumped Hydro Storage (PHS), Compressed Air Energy Storage (CAES), Electricity to Gas (E2G), and High Energy Batteries (HEB).

A. Pumped Hydro Storage (PHS)

Pumped hydro is one of the energy storage technologies deployed on a gigawatt scale. In addition to the power stations generally built in the current power grid regulated as daily pumped storage, pumps are installed in the annual regulated hydropower stations to achieve Seasonal Pumped Storage (SPS). Compared with the existing daily pumped storage power station, seasonal energy storage capacity is more extensive, and the water height requirement is generally higher than 200 meters. Seasonal pumped storage has a longer life span of up to 50 years. Its conversion efficiency is high too, which can reach 70%~95% [7]. However, large-scale seasonal pumped storage is limited by the requirements of suitable sites, and its location selection is challenging. The actual engineering application requires a preliminary investigation of the geological environment conditions.

TABLE I. CLASSIFICATION OF ENERGY STORAGE TECHNOLOGIES

	Categories	**Technologies**
Energy storage technologies	Mechanical	Gravity - Pumped Hydro Storage
		Kinetic - Flywheels
	Thermodynamic	Pressure - Compressed Air Energy Storage
		Heat - Thermoelectric
	Electromagnetic	Electric - Capacitors
		Magnetic - SMES
	Electrochemical	Hydrogen - Electricity to Gas
		Batteries - Chemistry Batteries, Flow Batteries.

B. Compressed Air Energy Storage (CAES)

Compressed air energy storage refers to the energy stored as high pressure compressed air and consumed in a different form of energy converted from the compressed air. In supporting power network operation, compressed air energy storage works by compressing air to high pressure using compressors during low electric energy demand. Then the stored compressed air is released to drive an expander for electricity generation to meet increased load demand during the peak periods. Compressed air energy storage is another electric energy storage system that can realize large-capacity and long-term electric energy storage. Compared with other energy storage technologies, Compressed air energy storage is proven to be clean and sustainable energy storage with the unique features of high capacity and long-term storage. Its scale and cost are similar to pumped hydroelectric storage (PHS).

Compressed air energy storage has attracted much attention in recent years, while further development for pumped hydro storage is restricted by the availability of suitable geological locations [8].

C. Electricity to Gas (E2G)

Electricity-to-gas uses electricity to produce hydrogen and hydrogen methanation to obtain hydrogen as a raw material for chemical production and methane, the main component of natural gas, and store it. The current industrial applications of electricity-to-gas products are mainly divided into two categories. (1) The stored natural gas/hydrogen energy is converted into electricity through energy conversion devices (fuel cells, gas turbines, etc.) to supply end users with electrical loads. (2)The stored natural gas/hydrogen energy is directly supplied to the terminal load (such as industrial gas, hydrogen energy vehicles, etc.) without conversion of energy form to meet the user's side gas demand/hydrogen demand [9]. Current hydrogen storage technologies mainly include gas hydrogen (GH2), liquid hydrogen (LH2), and liquid organic hydrogen carriers (LOHC).

D. High Energy Batteries (HEB)

For many batteries, there is considerable overlap between energy management and shorter-term applications. Furthermore, batteries can generally provide rapid response, which means that batteries "designed" for energy management can provide services over all the applications and timescales discussed. Denholm and co-authors show that several battery technologies are deployed for energy management applications: chemistry batteries, high-temperature batteries, and liquid electrolyte flow batteries [10].

For distributed prosumers to participate in the energy market to make the arbitrage by storing the produced low-priced off-peak energy and selling it during periods of high prices in the short term from several hours to several days. Today, batteries are still expensive for storing electric energy. Some initiatives have been launched, e.g., the Tesla Powerwall[11], a battery storage unit charged from solar panels, and where the power can be used at some later time.

Another approach is to use the batteries of electric vehicles as household power storage when the vehicle is parked. This approach, Vehicle-2-Grid (V2G), requires special technology to facilitate two-way power transfer. However, it can provide mid or long-term energy storage from several days to several months. Battery technology is improving rapidly partly due to the thriving of the electric cars market. The capacity of batteries is improving, and the cost is decreasing. BloombergNEF expects average prices for Lithium-ion battery packs to be close to $100/kWh by 2023. The report also points to more cost-effective solutions like lithium iron phosphate (LFP), with cell prices already at $80/kWh [12].

Electricity storage in the household or by the aggregator does not have the high requirements of the auto industry. The packaging will be more straightforward, and the batteries do not need the same degree of compactness. Battery weight is neither significant in this context. Estimation made by the U.S Energy Information Agency shows that utility-scale battery storage costs decreased nearly 70% between 2015 and 2018 [13], and it is expected that the price will decrease as the battery-storage technology improves in the years to come.

Of the different storage technologies surveyed here, batteries are perhaps currently the most viable option. Apart from hydrogen, the other energy storage technologies are still under development. Generating hydrogen through electrolysis (so-called green hydrogen) is expensive and requires large amounts of electricity, which means low efficiency [14]. Batteries, of course also have a production cost, but once made, batteries can be charged and discharged for several thousand cycles. Additionally, there is a lot of research into making better, more long-lasting batteries that use fewer rare earth metals [15], and there is currently much research on the application and optimization of utility-scale battery systems for grid optimization, which is expected to become cheaper over the next three decades [16] [17].

III. Revenue Potential

Considering the time difference of renewable energy production and the power peaks and off-peaks in the grids, we use the Oslo area (Norway) to analyze the solar energy production and storage to get a better understanding of the revenue potential for prosumers and aggregators.

A. Solar energy output

The European Union's PhotoVoltaic Geographical Information System (PVGIS) [18] allows calculating the output of solar panels in Europe, Africa, and several American and Asian countries. In Norway, the solar input varies from 700 kWh/m2 in the far north to 1100 kWh/m2 in the country's southern parts. This means that one standard solar panel can generate between 500 and 700 kWh of energy each year, given a loss of 25%, which is the standard loss in the PVGIS tool. The actual output will, of course, vary with weather and season. In northern Norway, on a sunny summer day, the midnight sun means the solar panel generates electricity 24 hours a day. In contrast, the same solar panel in the polar winter night will generate nothing.

The Norwegian capital, Oslo (Latitude 59.962, Longitude 10.716), is used to simulate output from photovoltaic panels. The input data for the simulation is that the photovoltaic system is installed at a 35° fixed angle, with the azimuth at 0°. The current price of solar panels is approximately 100 euros per square meter. The capital interest is 4%. The lifespan of the solar panels is set to 30 years.

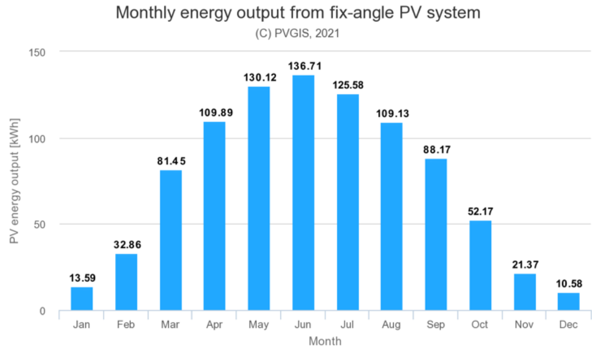

Fig. 2. Simulation of photovoltaic output

The simulation results show that the monthly energy output from the 35° fixed installed photovoltaic system varies according to the changes of sunshine, as shown in Fig. 2. If the angles of photovoltaic panels are adjustable, more output of energy can be achieved. Fig. 3. gives the information of the outline of the horizon in Oslo.

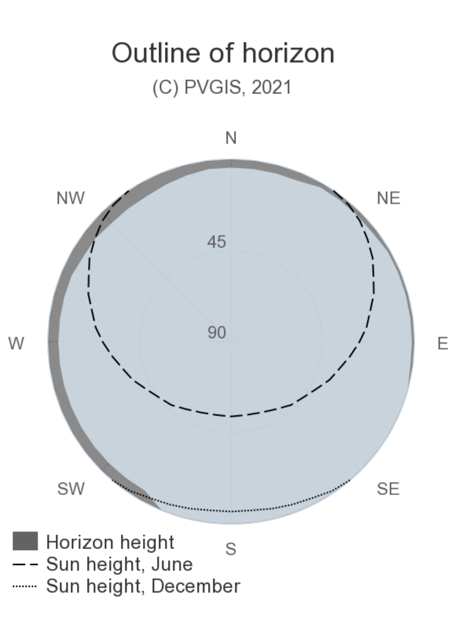

Fig. 3. Horizon heigth and sun height, Oslo, Norway

B. Market price and revenue potential

In Scandinavia, electricity is traded on Nord Pool with day-ahead and intraday markets. The day-ahead market is the main arena for trading power, and the intraday market supplements the day-ahead market and helps secure a balance between supply and demand [19]. The day-ahead and intraday price varies throughout the day and the year, with high variations decided by demand and supply. To better understand the market, data from 36 days (5^{th} ,15^{th} ,25^{th} of each month) in the last year were analyzed. With data from Nord Pool [19], we examined market price variation to investigate the profit margin for the photovoltaic prosumers in Oslo.

The data from June 2020 to July 2021 shows high price differences. The price for 1MWh varies from 0,34 euros (July 5th, 2020) to 200,02 euros (February 5th, 2021). The average minimum price for 1 MWh was 21,84 Euro, and the average maximum price was 42,96 Euro, as shown in Fig. 4.

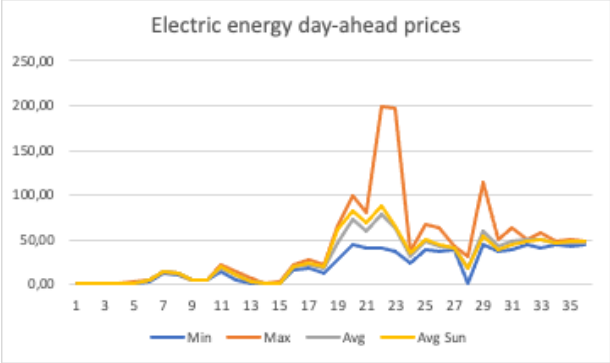

Fig. 4. Electricity prices for 36 days from June 2020 to July 2021.

On an hourly basis, the most common peaks with higher prices occur from 08:00 to 09:00 am. and from 5:00 to 7:00 pm., as shown in Fig. 5. In comparison, the photovoltaic panels produce mainly from 10 am to 3 pm during the day. Therefore, it is also advisable to store the photovoltaic energy during the production peak at noon and sell it in the evening or the following morning.

On a smart grid level, it could be an advantage to store the electricity for later consumption. This would make the smart grid more stable and also more resilient.

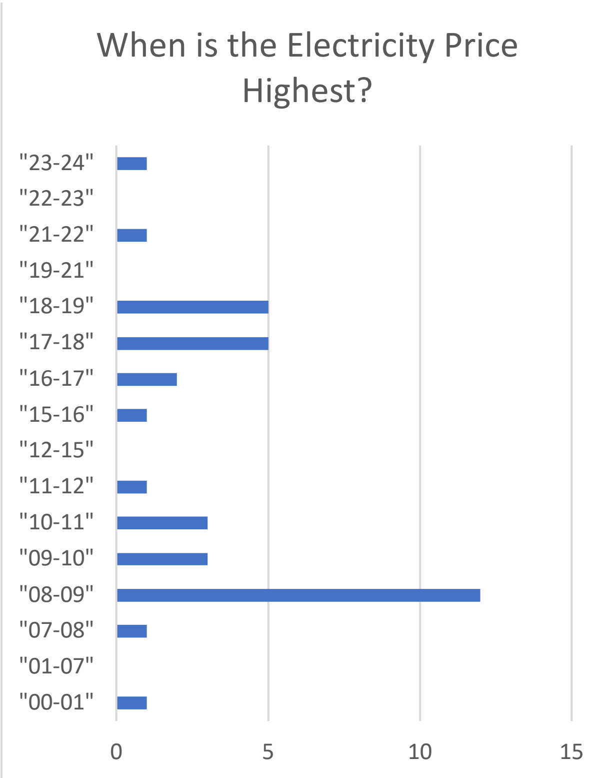

Fig. 5. Distribution of peaks througout the day

IV. Prosumer Storage and Aggregator Storage

The intermittent and random output of renewable energy has brought significant challenges to the balance of power demand and supply and grid stability. For the individual prosumers, in most cases, storage is installed for self-consumption. At the same time, it may be more advantageous for an aggregator to store energy on behalf of the prosumers.

A. *Storage by prosumers*

Storage by the prosumer seems to be well established. The prosumers install batteries primarily for self-consumption. Sha et al. [20] show that by adopting storage systems, one can significantly reduce the energy costs of prosumers and reduce the maximum load of the distribution network. Zheng et al. [21] have pointed out that prosumer-based energy management and sharing in smart grids are critical elements for the transition towards carbon neutrality. The prosumer will consider how the cost of storing energy influences energy storage systems' performance, in turn serving as a decision basis to assess whether a storage system is economically convenient for their specific case. The prosumer storage model is shown in Fig. 6. below.

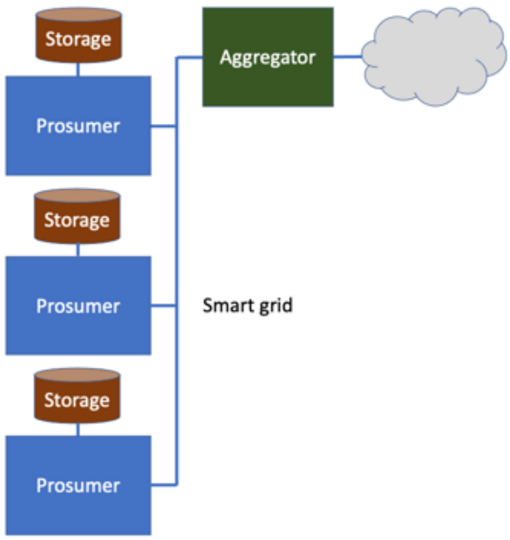

Fig. 6. Storage by prosumers

In the self-consumption model, prosumers charge their batteries during the daytime at off-peak and reduce the need for buying energy during peak periods to reduce their electricity cost. However, the batteries need additional control technology and packaging. Also, the installation costs are another factor contributing to to the total costs.

With the wide adoption of electric vehicles (EV), prosumers may have the option to use batteries of their electric vehicles for their energy storage solutions.

B. *Storage by the aggregator*

Prosumers participate in storage services mainly for self-consumption. They may get some revenues from selling their stored energy at peak time, but they would be better of by using the energy themselves. However, individual decisions by prosumers could be inefficient from a broader power system perspective.

An aggregator brings new opportunities. By enlisting many prosumers, the aggregator could handle larger amounts of energy and sell large scale flexibility.

Gissey et al. [22] show that aggregators could reduce the disparity between private and system value by financially incentivizing consumers to give up control of their storage resource to use it more efficiently for the benefit of the wider electricity system. Scale effect works with aggregation of many prosumers than respectively. If an aggregator establishes storage, the aggregator can buy surplus during the daytime and sell back or sell on the market when the price is high, as shown in Fig. 7.

The aggregator gets the advantage of larger scale. The packaging and control technology together with installation costs will be much lower for one centralized storage than storage spread out with the prosumers. The prosumers do not need to install their own storage, but can subscribe to or buy capacity from the aggregator.

According to Revankar [23] aaggregators storing electricity is also a key mechanism for supplying electricity reliably, increasing security and economic value, and decreasing carbon dioxide emissions. Aggregator storage can also play a significant role in keeping a balance between supply and demand, avoiding electric fluctuations, and contributing to the low voltage distribution system operator grid's stability and making the distribution system operator grid system more efficient, especially for the weak low voltage grid in Norway.

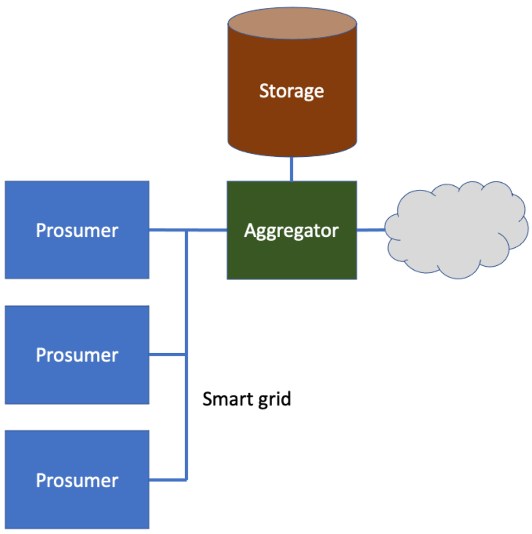

Fig. 7. Storage by the aggregator

V. Conclusion, Limitations, and Future Work

Based on our research on aggregator and prosumer business models, we find very little research on the discussion of aggregators providing storage as a revenue model. The aggregator has at least three different revenue opportunities:

1) To buy energy from prosumers at market price when production is available and sell it later at a higher price. The aggregator is making its revenues from the fluctuations in electricity prices throughout the day.

2) To offer storage as a service to prosumers. The aggregator would provide Energy Storage as a Service (ESaaS). This would be like a Dropbox™ for electric energy. The prosumers can then choose to sell it to the market or use it for its own purposes. In this case, the aggregator gets revenues from either renting out storage or charging a subscription fee, or both.

3) Bundling EaaS (energy as a service) and ESaaS. The aggregator in companions with other companies could provide a complete package of services and utilities based on specific customer demands. Examples could be business models that offer electric care, energy providers (solar panels), storage and control/monitoring (Google Nest) target different consumer segments (households, manufacturing industry, property management, etc.).

The primary assumption is that large-scale storage is cheaper than small-scale storage. For prosumers, it is the cost of batteries and the additional hardware to handle the charging and discharging of the batteries and the installation cost that need to be considered when investing in battery storage. Space may also be an issue. A prosumer would probably focus on compactness, which brings additional costs. An aggregator could use a larger facility and not be overly concerned about the compactness of the installation.

A. *Limitations*

This research is limited to one specific case, which is a Norwegian electricity market. Therefore, the potential revenues may differ in other parts of the world. The literature review on storage costs and developments in photovoltaic energy describes the interchanges generally. In contrast, an overview on a more detailed level might reinforce the stated point even further. The discussion about prosumer storage and aggregator storage is also general.

B. *Future Work*

We assume that large-scale storage is cheaper than small-scale storage for analyzing the prosumer and aggregator storage models. Further work will investigate prosumer sentiments towards the aggregator as a storage provider. What would be the barriers towards adoption, and what is the best approach for aggregators to get prosumers to adopt one of the "aggregator as storage" business models?

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