SOLELFORSKNINGS CENTRUM SVERIGE

Theme 3-6

How do large solar parks and battery storages contribute to Swedish frequency regulation market?

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UPPSALA UNIVERSITET

1. Introduction
2. Aims and case studies
3. Method
4. Results
5. Conclusion and future work

Delayed investments in the grid

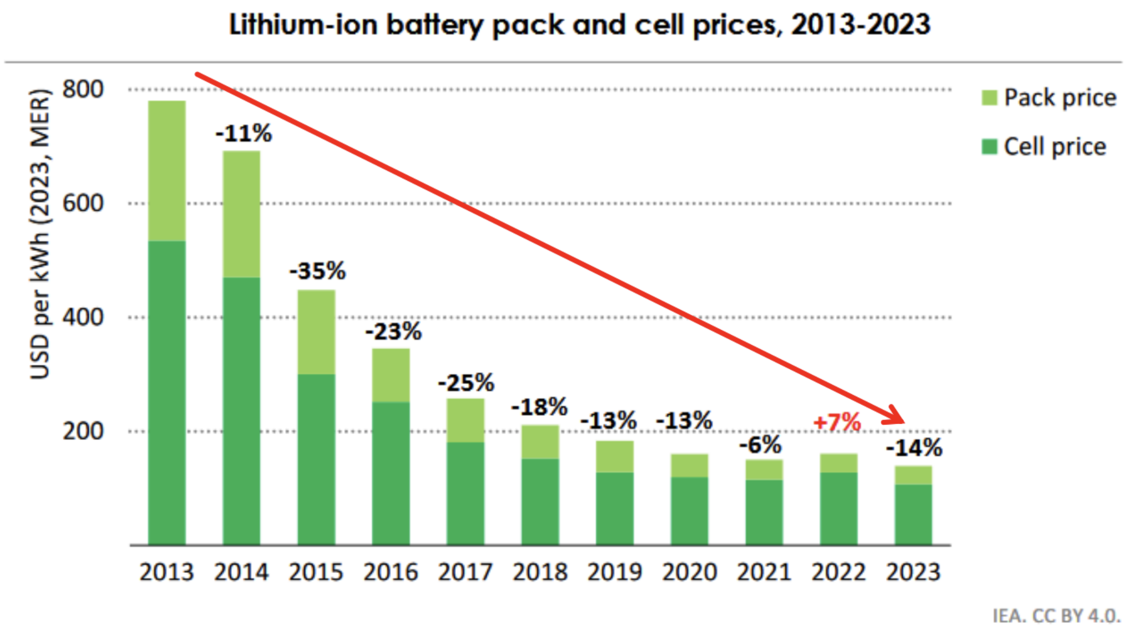
Intermittent power productions need more flexibility

Balancing of the power system

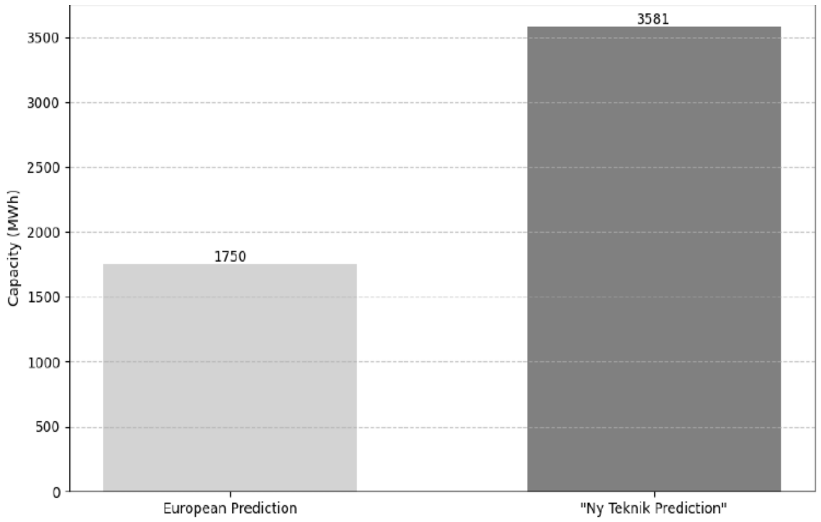
“If you want more renewables on the grid, you need more batteries. It’s not going to work otherwise.”

Andrés Gluski, the CEO of AES Corporation

Battery storage capacity and prices

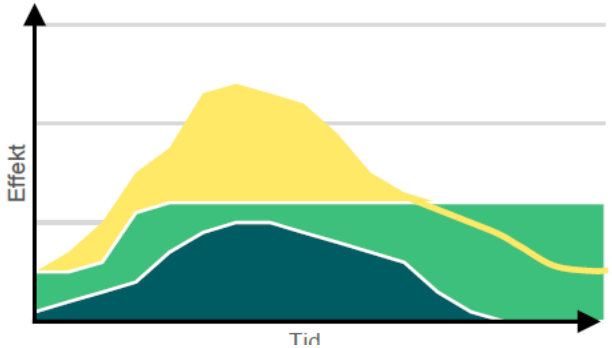


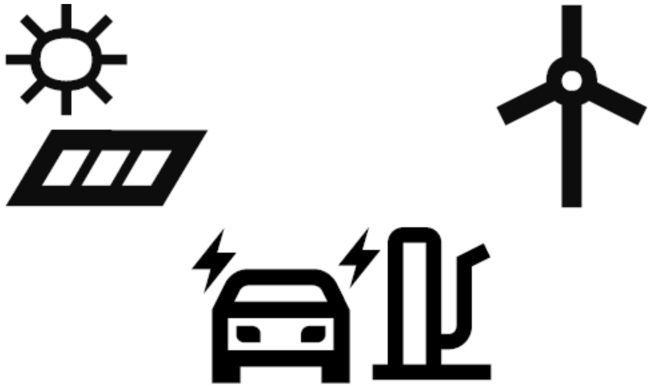
Prices for lithium-ion batteries steadily declined over the last decade with a spike in 2022, but dropping again in 2023

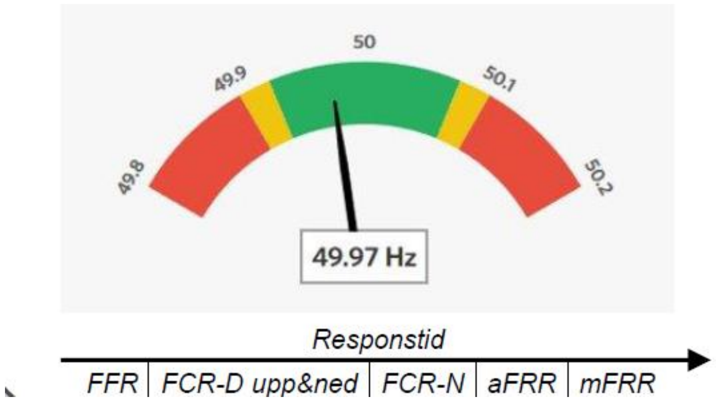


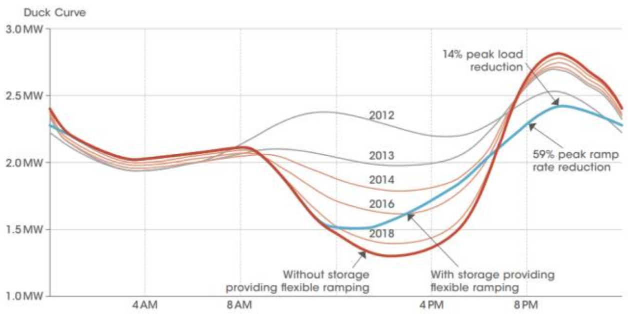
150%-300% increase in 2030 in Sweden

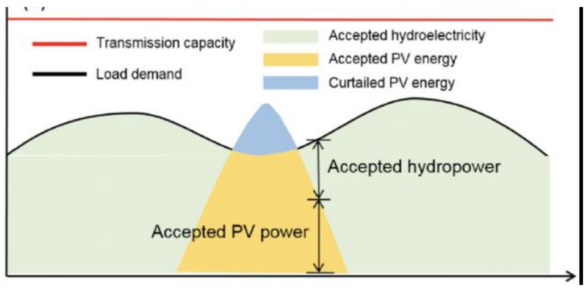
Solar and battery combination











Creating a techno-economical framework for solar parks combined with battery storage operating on Frequency market and day ahead market

Case study

Fyrislund, Uppsala PV park

VASAKRONAN

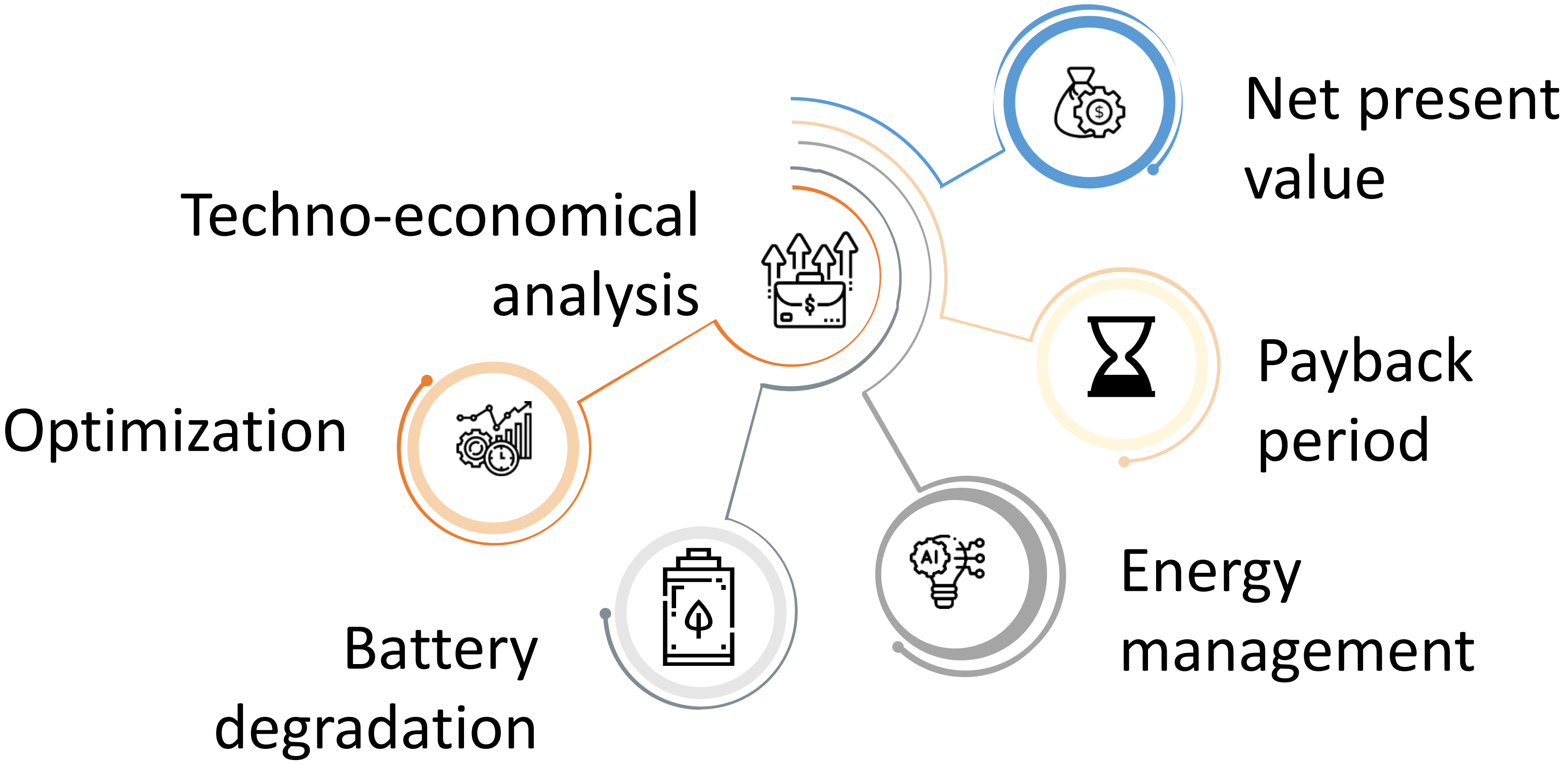
Investigating the economic benefits of using stationary battery storage for peak shaving in a church powered by a PV system. **Stacking:**

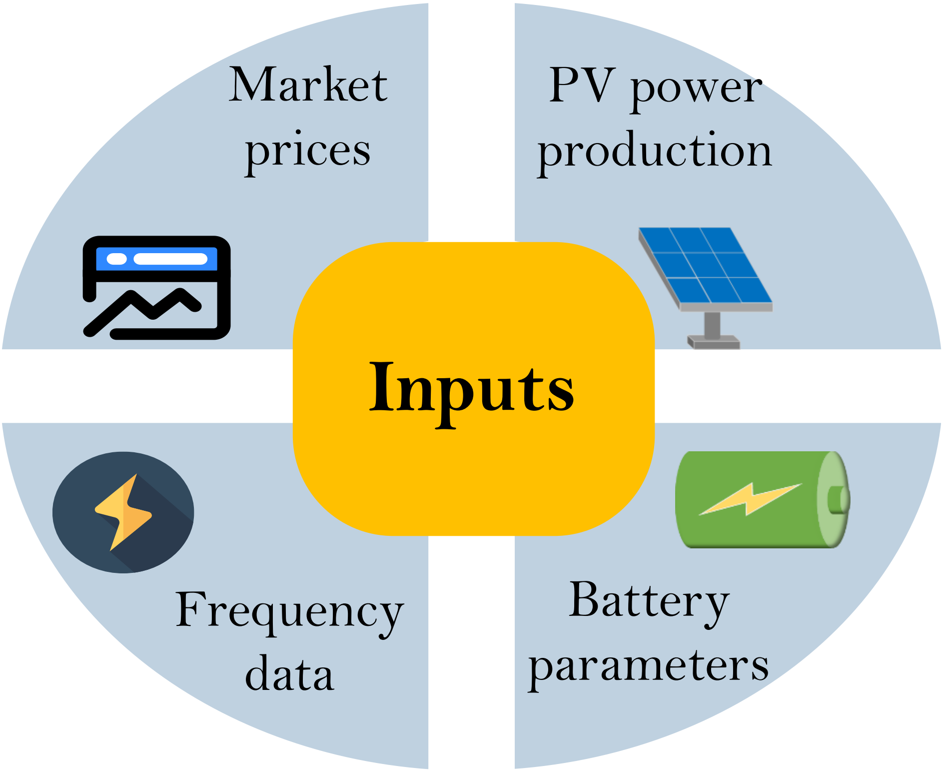
- Participating in local energy market
- Maximizing Self consumption
- Arbitrage optimization
- Frequency market

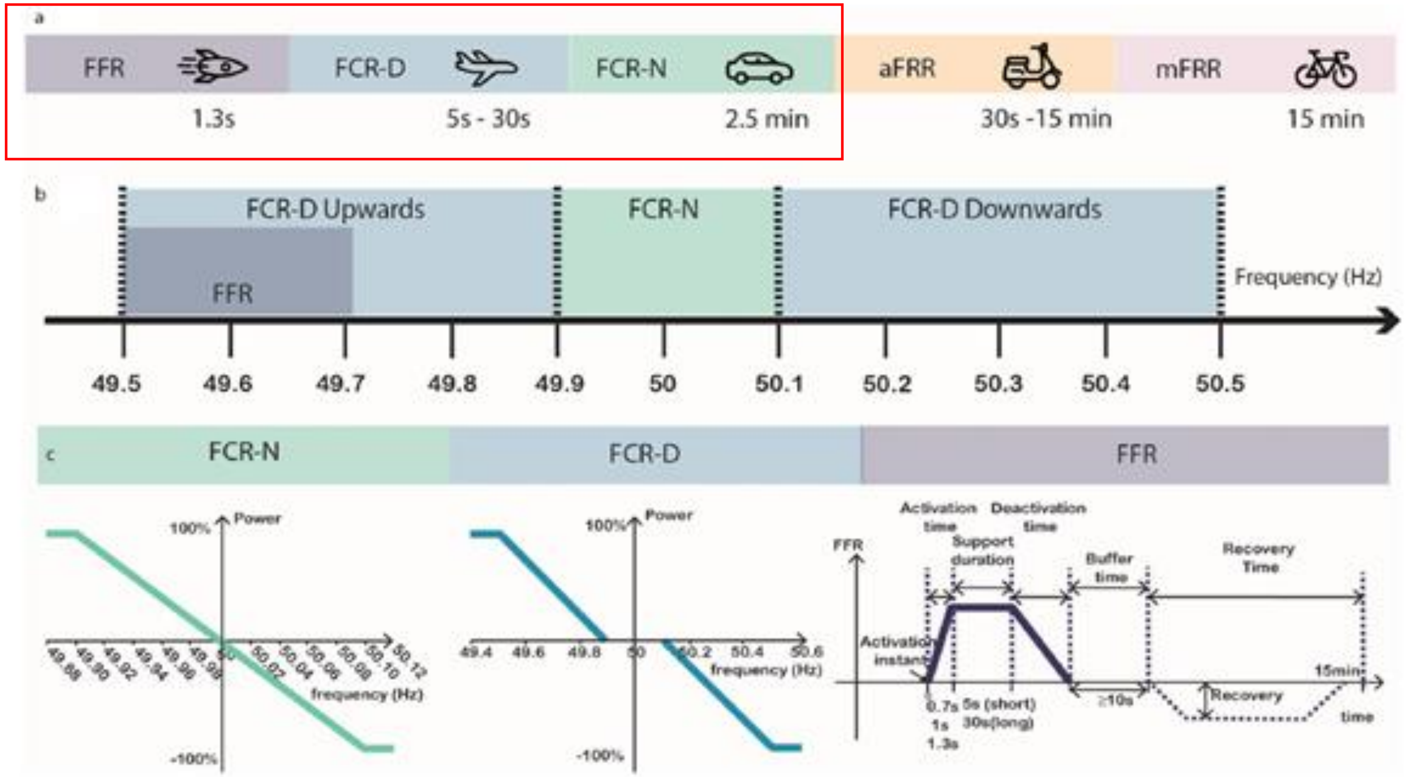
Case study

Karlstad, Kila Kyrka

Svenska kyrkan


Techno-economical analysis
Net present value
Payback period
Energy management
Battery degradation
Optimization

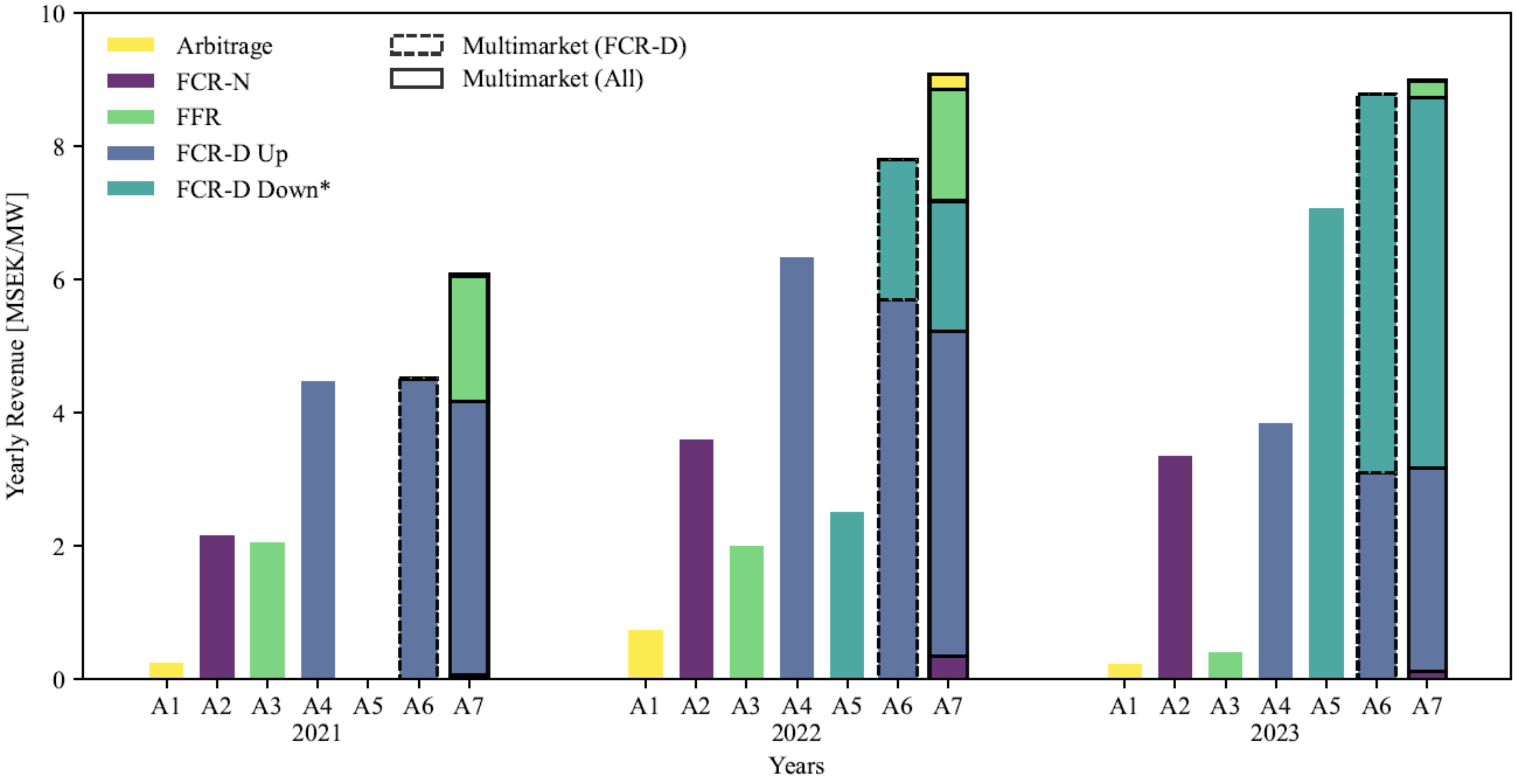

Market prices
PV power production
Inputs
Frequency data
Battery parameters



Response time

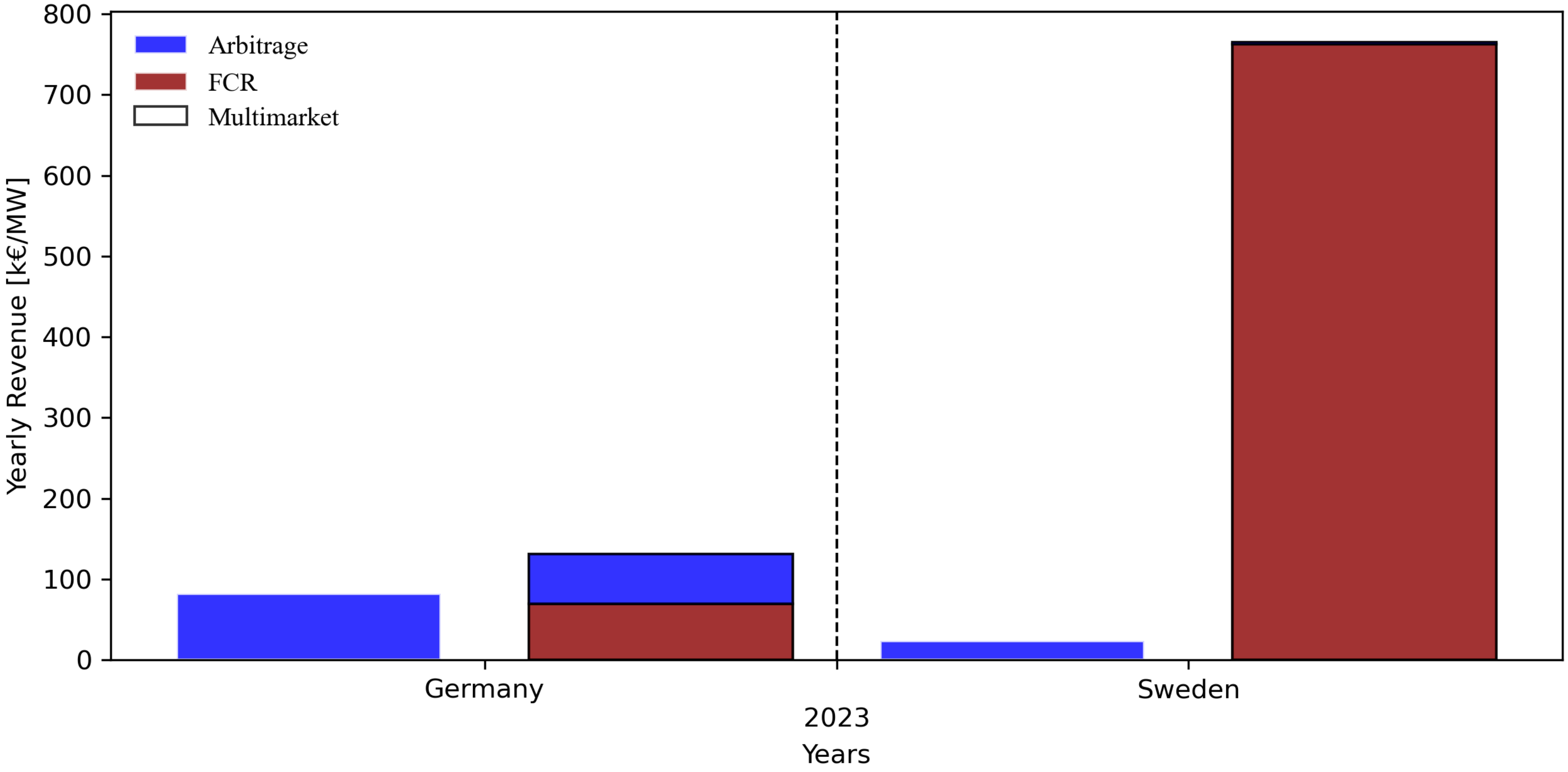
operation range

Activation rate



The economical value of battery storage in 2022 or in 2023 is around **8 MSEK/MWh**

FCR: Frequency containment reserve



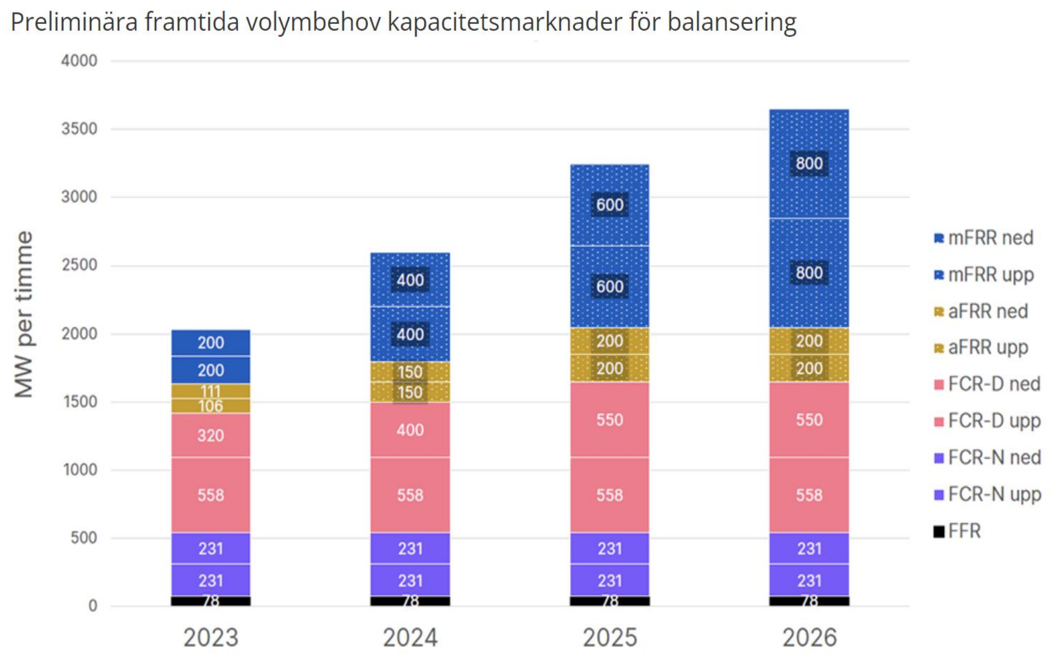
The economical value of battery storage in Sweden is **4 times** higher than Germany

- Data from Kila Church shows that installing battery is not economically feasible if it is not participating in the frequency regulation market.
- A 120 kWh / 60 kW battery has a 1.6-year payback operating in peak shaving and multimarket (FCR-D).

- The Economical value of Battery in Sweden is due to Ancillary services
- Low synergy when combining PV parks with Battery storage (FCR)
- The degradation is low when operating on Ancillary services
- Battery storage benefits churches economically, environmentally, and socially.

Future outlooks:

- Including other ancillary services
- Include electric vehicles in the system



SOLVE

Recently work

22nd Wind & Solar Integration Workshop (WIW 2023) Copenhagen, Denmark 26-28 September 2023

ECONOMIC ESTIMATIONS OF A PV PARK COMBINED WITH STATIONARY BATTERY STORAGE OPERATION ON DAY-AHEAD AND FREQUENCY REGULATION MARKETS

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Keywords: HYBRID PARK, STATIONARY BATTERY STORAGE, FREQUENCY REGULATION MARKETS, ANCILLARY SERVICES, ECONOMIC ANALYSIS

Abstract

As interest in deploying Battery Storage systems (BSSs) grows, a significant challenge is to determine the specific services that the BSS should provide to maximize profits. This study aims to determine the most profitable strategy and size of integrated grid-connected BSS with and without PV park for participating in Day-Ahead Market (DAM) and Frequency Regulation Market (FRM). The Frequency control services activate in response to changes in the electricity grid frequency, with BSS supporting during frequency fluctuations. The focus of this study is on the primary regulation within FRM. In this study, a BSS operation algorithm is evaluated in economic terms. The algorithm imports inputs like market prices, fees, tariffs, PV production, and chosen BSS service. Economic metrics include Net Present Value (NPV) and Internal Rate of Return (IRR). Real-world data from a Swedish PV park was used for case studies across three categories: BSS stand-alone, PV park alone, and PV-BSS combination. Results highlight that stand-alone BSS scenarios are superior to PV-BSS combination cases, showing a 73% Internal Rate of Return (IRR) for a 1000 kWh/400 kW BSS configuration. PV park alone participation in FRM and DAM shows marginal benefits compared to only acting on the spot market. The sensitivity analysis examining changes in prices for both DAM and FRM relative to 2022 reveals a significant negative change in revenue in 2020, which is explained by the higher and more fluctuating electricity prices. Lastly, the sensitivity analysis explores changes in the acceptance rate of bids in the future relative to 2022, as FCR products will be procured at a marginal price. These analyses indicate potential negative changes that may occur as the acceptance rate may decrease.

1 Introduction

According to the International Energy Agency (IEA), utility-scale solar PV and onshore wind are considered the most cost-effective options for new electricity generation in most countries [1]. In 2022, the growth rate of solar PV generation has increased by 26%, aligning with the projected levels from 2023 to 2030 in the Net Zero Emission by 2050 scenario [2]. Additionally, the volatile electricity prices due to foreign gas dependencies are driving the transition to a more renewable energy combination.

Sweden aims to achieve completely renewable electricity production by 2040 [3]. As a consequence, wind and solar power capacity have increased in Sweden in recent years [4]. However, these energy production technologies are weather dependent, which creates challenges to efficiently integrating them into the electric grid and ensuring power system stability.

The power system functions as an interconnected network that requires continuous regulation to maintain balance. In the Nordic network, a grid frequency of 50 Hz indicates a balanced system. Deviations in frequency activate standby capacity assets managed by Svenska kraftnät (SvK), Sweden's transmission system operator (TSO), to address imbalances. Frequency regulation (FR) ancillary services, which encompass actions to maintain power system stability, are procured and overseen by SvK [5]. SvK classifies FR services into four types: Fast Frequency Reserve (FFR), Frequency Containment Reserve (FCR), automatic Frequency Restoration Reserve (aFRR), and manual Frequency Restoration Reserve (mFRR) [5]. The three FCR services are: FCR-Normal (FCR-N), FCR-Disturbance upwards (FCR-D up), and FCR-Disturbance downwards (FCR-D down)[6]. Historically, FR services were entirely met by hydropower [5]. Recently, SvK has predicted that the ancillary services market will reach a value of 3 billion SEK in 2023, a 50 percent increase from 2021 [7]. Thus, integrating different actors into the ancillary service FR markets becomes an attractive option.

According to the International Renewable Energy Agency (IRENA), the most important services which Battery Storage Systems (BSSs) can provide to the system operator are: frequency regulation, flexible ramping, and black start services [8]. However, revenues from these services are mostly difficult

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Techno-Economic Analysis of a Stationary Battery Storage Operating on Frequency Regulation Markets in a Church Powered with PV System

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Abstract

In Sweden, Svenska Kyrkan (the Church of Sweden) has over 3300 churches. A majority of the churches are electrically heated. Usage patterns of electrically heated buildings such as church buildings, creating problems for the grid and the church organization through increased grid fees. Simultaneously, interest in deploying Battery Energy Storage Systems (BESSs) is growing. A significant challenge is determining the specific services the BESS should provide to maximize profits for the owner. For church load profiles, with the help of a battery, the church consumption peaks can be shaved. Additionally, when the Battery Energy Storage System (BESS) is not used for this purpose, it can instead be employed to support the grid through participation in the frequency regulation market. Frequency control services are activated in response to changes in the electricity grid frequency, with the BESS providing support during frequency fluctuations. The objective of this study is to investigate the economic value of installing BESS in a church powered by a PV system. Various frequency regulation services, with a focus on primary reserve, are explored. The model operates on other energy markets, which are local flexibility and day-ahead markets. The inputs include selected services, feed-in and feed-out profiles, historical frequency data, and frequency regulation and energy market prices over the year 2023. The case study involves measured data from Kila Church, which has a 60 kWp solar power system and is located in mid-western Sweden. The economic metrics are net present value and payback period, whereas technical and environment metrics are the battery degradation and CO2 emission equivalents, respectively. This study indicates that the investment in BESS is profitable if the BESS operates on frequency stability services together stacked with Peak Shaving (PS). The results show a 1.6-year payback period for a 120 kWh/60 kW BESS. A sensitivity analysis explores future changes in prices of the frequency regulation market and BESS shows that FCR-D Up has more sensitivity for a drop in the prices in the future. Nevertheless, FCR-D Down has more economic potential value. Conclusively, BESS would be a beneficial investment for churches and facilities with similar load and PV power generation profiles, both from an economic and societal perspective.

Keywords: Stationary Battery Storage, Frequency Regulation Markets, Ancillary Services, Techno-economic Analysis

1. Introduction

In 2015, the United Nations launched Agenda 2030 to promote sustainable development through goals aimed at reducing poverty, addressing climate action, and ensuring affordable and reliable energy for all (Swedish UN Association, 2015). At the European level, the European Green Deal targets a 55% reduction in emissions by 2030 and aims for carbon neutrality by 2050 (European Comission, 2015). Additionally, the European Commission has implemented the REPowerEU plan in response to disruptions in fossil fuel imports, aimed at enhancing energy savings, diversifying energy supplies, and promoting clean energy (European Commission, 2022). Sweden has set a goal to achieve completely renewable electricity production by 2040 (IRENA, 2020). Consequently, wind and solar power capacities in Sweden have increased in recent years (Lindahl et al., 2022). However, these energy production technologies are weather-dependent, posing challenges for integrating them efficiently into the electric grid and ensuring power system stability. These objectives drive the growth of renewable energy production and

22nd Wind & Solar Integration Workshop (WIW 2023) Copenhagen, Denmark 26–28 September 2023

VERY SHORT-TERM SCENARIO-BASED PROBABILISTIC FORECASTING OF PV PARK POWER PRODUCTION

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Keywords: PROBABILISTIC SOLAR PV PARK POWER PRODUCTION, SCENARIO FORECASTING, MARKOV-CHAIN MIXTURE DISTRIBUTION MODEL (MCM), PERSISTENCE ENSEMBLE, CLIMATOLOGY

Abstract

Grid-connected photovoltaic (PV) parks are increasing in number and size. For local optimal battery control, electricity market participation and generally for delivering ancillary services to the grid from PV parks, it is important to be able to forecast PV park power generation. This study investigates short-term probabilistic forecasts and scenario-based forecasts on PV park clear-sky index for photovoltaics with two Markov-chain mixture distribution (MCM) models, Persistence Ensemble (PeEn) and Climatology. The models were trained on, and used to forecast, a 5 minute resolution data set of PV park power generation for two years from Vasakronan AB's PV park in Uppsala, Sweden. The study shows that the MCM models outperform the PeEn and Climatology for five minute ahead forecasts in terms of continuous ranked probability score and in terms of point forecast MAE. It is also concluded that PeEn outperforms the Climatology, which despite lack of accuracy has highest similarity in result output. In terms of scenario-forecasting, where the two MCM models are compared to outputs from the Climatology, all models have similar CDF goodness-of-fit. In terms of autocorrelation, the MCM models are superior. Based on the results, the MCM model, regardless of setting, is recommended as advanced benchmark for very short-term probabilistic PV park power production forecasts.

1 Introduction

Grid-connected photovoltaic (PV) parks, or utility scale PV, are increasing globally [1] and in Sweden [2]. When connecting PV parks to local battery storage, in particular with the intent to participate on frequency markets or other ancillary services for the electricity grid, the use of accurate forecasts of PV power production can be useful for scheduling battery charging and optimal dispatch production [3].

Forecasting can be divided into point forecasting, which makes a point prediction, and probabilistic forecasting which issues a predictive probability distribution as forecast. Probabilistic forecasts may be considered superior, as they contain more information about uncertainty of the forecast [4]. When it comes to solar forecasting research it is composed of both point and probabilistic forecasting, the latter having increased in the last decades [4–7].

Examples of probabilistic forecasting of PV park power production include using ensemble learning, based on numerical weather prediction (NWP) ensembles, with K-nearest neighbor models for several hours ahead forecasts for several locations in the GEFCom2014 dataset [3]. Another example includes using a convolutional neural network in combination with quantile regression to both produce probabilistic and point forecasts on data sets from PV parks in Belgium with 15 minute resolution [8]. In [9], Allesandrini and McCandless also used ensemble members from numerical weather prediction and analogue ensemble with Shaake shuffle to forecast both wind and PV park power generation on a Kuwait location dataset with five minute resolution data. Also, probabilistic co-located PV and wind park power production forecast models based on numerical weather prediction were developed in [10] and used to forecast 15 minute data for a co-located PV and wind park in Sweden. There is generally a lack of forecasts for sub-hour very short-term PV park power production and for using data driven models, in contrast to advanced NWP-based models. There is also a lack of benchmarks, as has been a problem in solar irradiance forecasting [7].

Metrics for performance evaluation is a crucial part of both probabilistic and point forecast evaluation. Metrics that have been used in the PV park forecasting field include autocorrelation estimate for ensemble members [9] and Continuous Ranked Probability Score (CRPS) [8–10]. Also a wide range of point forecast metrics have been used, including Mean Absolute Error (MAE) [8] and Root Mean Square Error (RMSE) [8, 9].

1.1 Contributions in this study

This study is the first to use the MCM model on forecasting PV park power production. It also appears to be the first study to

Techno-Economical Assessment of Battery Storage Combined with Large-Scale Photovoltaic Power Plants Operating on Energy and Ancillary Service Markets

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Abstract

As the interest in deploying Battery Energy Storage System (BESS) grows, a significant challenge is to determine the specific services it should provide to maximize profits. This study investigates the most profitable markets and sizes of grid-connected BESS with utility-scale solar Photovoltaics (PV) power plants using techno-economic analysis frameworks. The objective is to maximize profitability in energy and frequency markets, focusing on primary regulation and energy arbitrage for Sweden and Germany. The inputs are historical market prices, historical frequency data, and real measurement power data from a utility-scale PV system. The economic metrics are net present value and payback period, whereas technical metrics are battery degradation and equivalent cycle count. The results show that adding a BESS to an existing PV park does not result in a lower payback time than if implementing a stand-alone BESS. However, the payback period does differ between Sweden and Germany, i.e., being 1.1 and 5.8 years, respectively. This is explained by the lower frequency control prices for Germany compared to Sweden. The technical results indicate that the BESS energy capacity after 10 years of operation is approximately 83% for Germany, whereas, for Sweden, it is around 87%. Also operating the BESS on energy arbitrage together with the primary regulation market showed a 4.8-year payback period with a slight increase in loss of energy capacity (from 83 to 80%) for Germany. Connecting the BESS to various PV configurations showed a discrepancy in economic and technical metrics, resulting in a best-case of a 4.7-year payback period. In that case, it transpires that BESS has limited synergy with utility-scale PV due to favoring primary regulation operation during periods of high PV power production. A sensi-

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Thank you for your attention

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