HEDGING IN THE RENEWABLE ENERGY SECTOR

A CASE STUDY ON RISK MITIGATION FOR SOLAR FACILITIES

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Abstract:
This thesis examines the risks and implications posed by the expansion of the renewable energy sector, using the perspective of Swedish solar facilities and the renewable project developer OX2. The paper is presented as a case study, primarily based on a qualitative methodology, involving interviews with various stakeholders. Although solar energy currently accounts for a small fraction of Sweden's energy mix, the rapid expansion and spillover effects of neighboring countries are probable to intensify cannibalization and volatility. These factors are likely to impact OX2's operations negatively by reducing asset valuations and creating conflicts between investor and consumer preferences. The thesis also examines mitigation mechanisms of the identified risks and finds that operational hedges are deemed capital-intensive but can reduce the underlying risk. On the contrary, financial hedges are more assessable but do not reduce underlying risks; instead, they transfer them to the counterparty at a cost.

Keywords: Hedging, Cannibalization, Solar, Batteries, Co-location

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Lastly, we would like to express our gratitude to the interviewees who generously shared their time and experiences for this study. Their insights and contributions have been invaluable in helping us gain a deeper understanding of the research topic.

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1. Introduction

In response to the Paris Agreement, with the target of keeping global warming below 2℃ compared to pre-industrial levels, the whole energy system is undergoing a comprehensive transformation. Since the treaty was adopted in 2015, the world has started moving from high-emitting fossil fuels to clean renewable energy sources urgently (United Nations, 2016). The International Energy Agency (2023) finds that renewables will surpass coal as the largest source of electricity generation globally by 2025 and will further account for 90% of global electricity expansion in the next five years (United Nations, 2023).

Sweden has established ambitious individual targets to fulfill the Paris Agreement and is striving to have a domestic energy production completely based on renewable sources by 2040 to reach net zero greenhouse gas emissions five years later (World Economic Forum, 2018).

In 2021, over 60% of the total electricity produced in Sweden stemmed from renewable sources: 43% hydro, 17% wind, and 1% solar (Statistikmyndigheten, 2022). Increasing this amount to 100% by installing more renewables while simultaneously phasing out alternatives reshapes the power system and causes implications. The efficiency of variable renewable energy (VRE) production depends heavily on favorable weather conditions and the output is, therefore, largely non-controllable. Thus, concentrating production to certain hours with a high likelihood of a mismatch between supply and demand. Particularly for solar because of its unique generation profile; during sunny periods, usually at midday in the summertime, increased levels of electricity are generated and transmitted to the electrical grid while consumption is low. Consequently, the spot price decrease and solar facilities receive less revenue for the produced energy. This effect worsens as solar installations increase, commonly referred to as cannibalization risk (Kanellakopoulou & Trasbesinger, 2022b).

With the expansion of the VRE sector, many argue that battery storage will play an increasingly vital role in coping with cannibalization. The general dilemma with the electricity market is largely attributed to the inability to store electricity in greater quantities. However, if battery storage is added to a VRE facility in a co-location, it adds the capacity to control the timing of the output. When production is high and prices are low, electricity can be stored and eventually sold when the relationship has reversed, so-called time-shifting. Hence, improving the ability to synchronize supply and demand to boost revenues and reduce risks (Kanellakopoulou, 2022).

OX2, a leading developer of renewable energy in Europe, is currently increasing its development of solar energy projects, each of which requires substantial time and resources. The development stage may extend over several years as it involves various steps, including environmental assessments of the project area, obtaining necessary permits and applying for the electricity grid connection. Given that the activities are approved, projects are usually sold prior to construction. The progression of the energy market during the development stage becomes decisive for the finalized project's value. Thus, the protracted processes present a significant risk for OX2 because of the high uncertainty regarding the growth of cannibalization. Since competitors' expansion is expected to increase cannibalization and reduce the revenues of solar energy production, investors are likely to discount the price further as time goes by. It is, therefore, important for OX2 to start analyzing different hedging strategies that can counteract the potential value reduction in the future.

1.1 Objective & Scope

This study is conducted in collaboration with OX2 and the research method utilizes a combination of public and confidential data sources, along with interviews with employees and external stakeholders of OX2.

The central purpose of this thesis is to provide an in-depth understanding of the long-term risks associated with the increasing investments in the VRE sector, its implications for OX2 and if hedging is a viable solution to mitigate the potential value reduction of solar assets. Beyond this, the thesis is deliberately structured to form a valuable foundation for the Stockholm School of Economics Department of Finance to further develop a case study for educational purposes. Hence, the scope is adjusted to serve this objective by covering crucial empirical aspects which can be applied to analyze the new potential market entry for co-locations that OX2 is planning in real-time.

The potential field of study is vast and, therefore, in need of a clear and achievable scope that takes time and resources into account. There are multiple risks associated with renewable investments; however, this paper will focus on the risks stemming from the expansion itself. Similarly, batteries can provide various revenue streams. Although examining all revenue sources would provide a more accurate depiction of the business case, some have been excluded due to the complex technical nature; this includes providing ancillary services by having batteries stabilizing the electricity system. Moreover, the primary focus is on the batteries' risk mitigation features, which are better captured by studying time-shifting. While the attention is on the Swedish market, a discussion on the interconnected energy markets impacting prices in Sweden is included.

Furthermore, this thesis uses solar power as a synonym for the photovoltaic process where sunlight is converted to electricity, in a so-called photovoltaic effect. Batteries are used in the context of a large-scale energy storage system. The combination of solar and lithium-ion batteries is the co-located system examined.

By addressing the following questions, this thesis strives to achieve its purpose:

(i) What risks does the expansion of VRE create for Swedish solar facilities?
(ii) How do the risks in (i) impact OX2's business?
(iii) What are the advantages and disadvantages of financial and operational hedges in mitigating the risks in (i)?

This study finds numerous risks associated with the VRE expansion, with increased cannibalization and volatility being the most salient consequences. Solar power accounts for a small fraction of the Swedish energy mix today. However, cannibalization is expected to increase due to the fast-paced expansion and imported effects from European countries with a higher share of solar. Furthermore, an energy system with a higher share of renewables is characterized by higher weekly volatility. These implications may influence OX2's business negatively by complicating and reducing asset valuations as well as changing the market perception of the security of the asset class.

Various hedging strategies, such as long-term supply contracts, capital structure adjustments, battery storage and pooling assets, mitigate the risks differently. Hedging through power purchase agreements has been a common alternative. While cheaper, it does not fundamentally reduce risk; instead, it reallocates them between the counterparties. It has also proven to be inadequate during the current energy crisis. However, decreased leverage can increase the investor's resilience to such adverse events. Battery storage and pooling assets have the potential to serve as an operational hedge and reduce the underlying risk but are more costly than the financial alternatives.

1.2 Contribution

Given the dominance of wind energy as the leading technology in the Nordic region, research has mainly centered around this technology. However, this thesis shifts the focus toward solar energy, which is expected to experience significant growth in the coming years (Blume-Werry et al., 2021). Furthermore, prior studies have examined solar power in regions with abundant solar availability and a substantial part of the overall electricity system (Clò & D'Adamo, 2015; López-Prol et al.,2020). By targeting the Nordics, where different conditions for solar investments and expansion exists, a new perspective is provided in this thesis.

It is not only an interesting region to study, but the current period is equally as exciting. The European energy system is undergoing a crisis, which has changed the conditions and need for refined risk management. This has reignited the energy market's interest in hedging and participants have started to question and evaluate the efficiency of different methods. Additionally, research on the combination of solar and battery technologies has yet to be thoroughly investigated and findings have not been broadly tested or evaluated. This primarily applies to examining a co-located system's impact on risk parameters and the hedging mechanisms it provides, which is explored in this paper.

To evaluate these moderately unexplored fields, research will be based on practical applications for real projects. Hence, utilizing data from concrete initiatives and individuals actively involved in implementing these projects and managing associated risks.

The ambition of this thesis has been to raise awareness of the risks arising from the rapid ongoing shift towards renewables and to shed light on potential solutions. Oddly enough, the challenges are rarely mentioned in the media or political debates. Hence, this study will bring valuable insights to several actors like policymakers, professionals and the academic community. Ideally, the findings provide a deeper understanding of how political measures and legislation could be directed to support the renewable sector. In a professional context, the authors hope this study can help OX2 decide whether they should start developing batteries co-located with solar power assets. Lastly, the authors hope to pave the way for further research on this broad and important subject.

1.3 Outline

Section 2 provides an overview of previous literature on hedging, both in a broader context and, more specifically, on the electricity market. Section 3 explains the case methodology applied in this thesis and discusses its advantages and limitations. Section 4 serves as a background to the case by providing an overview of OX2, the European energy market and relevant technologies. The case is then presented in Section 5, describing the evolving risks of the VRE sector, its potential implications for OX2 and potential solutions in the form of different hedging strategies. A discussion and comparison of the solutions are carried out in Section 6, followed by conclusions in Section 7.

2. Literature Review

2.1 Operational and Financial Hedging

The literature on hedging is extensive. Many researchers have covered different aspects of hedging and the sectors usually studied include international manufacturing firms, agriculture, energy, foreign exchange and insurance.

Hedging refers to a business strategy of reducing or managing risk. In line with traditional finance, Modigliani and Miller (1958) argue that corporate hedging does not create additional value in a perfect market setting. However, Boyabatli and Toktay (2004) oppose this theory and argue that the reality differs from Modigliani and Miller's assumptions; instead, they argue that several imperfections make hedging a relevant risk management tool for firms. The imperfections include costs associated with bankruptcy and financial distress, taxes and external financing.

In the literature, hedging strategies are often divided into financial and operational categories. The primary purpose of hedging is to protect against losses that may occur due to unfavorable market movements. While the distinct methods utilize different approaches, they aim to fulfill the same purpose. The former relates to the process of mitigating risks by using financial instruments like derivatives or insurance and the latter involves adjusting or diversifying operations, which covers a variety of actions (Berk & DeMarzo, 2020). Operational hedging can, for instance, be achieved through geographical or product expansion, where losses in one business area may be compensated by gains in the other.

Boyabatli and Tokray (2004) discuss alternative methods for limiting the downside risk, such as delaying logistics decisions, changing supply chains and holding surplus capacity. Operational changes can improve the firm's flexibility, allowing it to respond to changes in market conditions by creating similar characteristics of an option, with the ability to exercise functions to exploit volatility. However, Berk and DeMarzo (2020) argue that hedging rarely provides complete protection from risks, especially during long periods and without high costs.

Kim et al. (2006) studied the relationship between financial and operational hedging for foreign exchange risk. They highlight that operational hedging should not be viewed as a substitute for financial hedging but rather as a complement and argue that it only provides firm value when combined with a financial hedge. Allayannis et al. (2001) examined U.S. multinational firms within the same field and came to the same conclusions. Moreover, Wolf et al. (2017) find that increased leverage in combination with hedging leads to increased firm value for most industries.

Financial hedging within the electricity market is also a widely covered topic. Harvey and Hogan (2000) discuss the benefits of forward contracting and its effect on average electricity prices. Deng and Orren (2006) examine similar topics and review various strategies with financial instruments and the pricing of these tools. They discuss how derivative contracts can be used to mitigate market risks. Bessembinder and Lemmon (2002) study forward pricing in the American energy market and the effect of the limited storing ability of electricity. Hain et al. (2018) observe that the growth of the renewable energy sector increases price and quantity risk and that unhedged portfolios are exposed to a significantly higher risk. They also conclude that forwards provide limited hedging protection but are the only liquid alternative for hedging.

Regarding operational hedging within the electricity market, previous literature has mainly discussed the technical difficulties and the cost aspect of storing electricity. Research on storage has been done on various geographical markets, storage technologies and periods. Steffen (2012) analyzed the economic feasibility of pumped-hydro storage in Germany between 2002 and 2010 and found profitability to be a major challenge. He concluded, however, that the increasing investments in renewables and the German phase-out of nuclear can make actors re-evaluate previous investment decisions. Similarly, Staffell and Rustomji (2016) found that revenues from time-shifting were insufficient to cover the investment costs of batteries in the UK. However, Wilson et al. (2018) discovered that price volatility is the major revenue driver for batteries rather than the average price. There are, thus, reasons to believe that the conditions for co-location systems have changed with the current energy crisis.

Furthermore, multiple papers examine the combination of various assets to generate a stable production pattern and create an operational hedge in volume due to their complementary production attributes. For example, Radchik et al. (2013) studied the combination of solar and gas in such an arrangement and found economic benefits for the respective asset owner. They also conclude that further research should be conducted on other combinations of assets, such as solar and battery storage.

3. Methodology

3.1 Empirical Methodology

In the field of social science research, the case study method is suitable for addressing questions in a contemporary setting where the researcher has limited control over the studied variables. A case study can help enhance the reader's understanding of corporate events, such as organizational and managerial processes, by conducting in-depth analyses of the event in its real-world context. Moreover, the analysis can be derived from quantitative or qualitative support or a combination of both (Yin, 2014). Its strength lies in the ability to handle many sources of empirical material like interviews, documents and observations. Thus, it has proven useful for describing or explaining a specific phenomenon rather than providing a definite answer based on cause and effect (Merriam, 1994).

Given the field of this study, a case study serves as a viable method for analyzing and evaluating the present circumstances of OX2. This is particularly relevant given that diverse strategic alternatives for risk mitigation are being discussed simultaneously as this thesis is written.

3.1.1 Data

The main data sources were public and undisclosed information, as well as interviews with employees and external stakeholders of OX2. Since the thesis is written in collaboration with OX2, a lot of the market data and financial models were gathered from their internal systems. Access to firm stakeholders, such as consultants, was also granted and used in the research. Interviews were held with the most relevant stakeholders and selected based on their knowledge of the field studied. Occasionally, information collected during the process was confidential and could not be fully disclosed in this thesis. Some of it has been anonymized for its inclusion in the thesis. Other information has enhanced the researchers' understanding of the crucial aspects of the case but presented in a way that ensures the non-disclosure of sensitive data. Hence, the inability to fully disclose some information has not limited the in-depth analysis of the case. The paper is also entirely a product of the researchers, implying OX2 has only provided guidance and feedback in the discussions of which information is too sensitive to publish.

The interviews conducted followed a semi-structured approach. Meaning questions have been prepared and sent out to the interviewees in advance, encouraging individual reflections (Merriam, 1994). Although the format was less rigid during the interviews, spontaneous follow-up questions were asked in response to some answers. The possibility to follow up unclarities has been available and utilized in some cases. This correspondence has mainly been conducted through email.

The interviews have been used to complement the empirical research and data provided by OX2. It is a valuable explorative method to test assumptions of the data. Therefore, emphasis is placed on not influencing the interviewees to receive answers in line with assumptions but rather their own views. This is one reason for sending out questions before the interview so the interviewees can establish their opinions without the researcher's influence. In writing the questions, weight has also been placed on avoiding leading the answers.

Table 1 summarizes the interviewees, their position, employer and date. The interviews have been held with a mixture of internal and external stakeholders. Views expressed in the interviews represent the individual's opinions, which do not necessarily pertain to the organization's general perspective. The external companies provide OX2 with different services, such as market analyses, technical and financial models. They are also established players in the industry and have long experience and expertise within the energy sector. Axpo is active in 30 countries worldwide and is one of Sweden's largest Power Purchasing Agreements (PPA) actors. They are also Switzerland's largest producer of renewable energy and a significant player internationally in energy trading of solar and wind (Axpo, 2023). Aurora Energy Research is the largest power analytics provider in Europe. They provide market forecasts and advisory services (Aurora, 2023). Pexapark is a successful software and advisory company that specializes in renewable energy. They manage risk, facilitate PPA contracts and provide various consulting services (Pexapark, 2023). Afry is a Swedish engineering company with energy, industry and infrastructure experts. Similarly, Afry also provides services within management consulting, such as market analysis (Afry, 2023).

Table 1. Overview of interviewees

Interviewee	*Role*	*Company*	*Date*
Carl Ferm	Transaction Associate	OX2	02.03.23
Michiel van Asseldonk	Technical Lead Energy Storage	OX2	09.03.23
Linnea Tjernlund	Lead Analyst Energy Storage	OX2	09.03.23
Lukas Bergman	Transaction Associate	OX2	15.03.23
Atle Beisland	Energy Market & PPA Consultant	OX2	17.03.23
Tomas Sjöberg	Managing Director in Sweden	Axpo	17.03.23
Alexander Esser	Senior Commercial Manager	Aurora	24.03.23

Brian Knowles	Director of Storage & Flexibility	Pexapark	28.03.23
Olli Hagqvist	Director of Power Markets & PPA	OX2	29.03.23
Nikita Semkin	Principal	Afry	12.04.23
Christian Fickler	Commercial & Strategy Manager	OX2	19.04.23
Sixto Garcia Barea	Solar Procurement	OX2	24.04.23

3.2Methodological Evaluation

There are several benefits to the case method but also a few drawbacks. The case's ability to generate new ideas and research areas is a significant advantage. A case in a new field can provide a valuable starting point where data and theory are limited (Siggelkow, 2007). Dubois and Gadde (2002) also emphasize that learning from a specific event is done best when combined with its environment and that cases are good at providing the context of a particular event.

The downsides are that some phenomena are too specific, hard to generalize and that findings are unstable over time. The researcher's subjectivity can also play a prominent role in the analysis and conclusions, making it a questionable scientific method (Dubois & Gadde, 2002). However, the validity can be increased by utilizing techniques such as targeting rival explanations, triangulation and logic models. Triangulation implies using multiple sources, theories and methods (Yin, 2014). This has been implemented through the collection of both public and private data as well as through conducting interviews with multiple industry experts. Additionally, various perspectives and theories have been applied to the thesis.

Another drawback is that case studies can oversimplify and exaggerate factors in a situation, leading to the reader making inaccurate conclusions. Qualitative studies are also limited to the sensibility of the researchers (Merriam, 1994). To prevent this, interviews are held to the reasonability of the assumptions and interpretations of the data.

4. Case Background

4.1 OX2’s History and Business Model

OX2 was founded in 2004 with the ambition to drive growth in the energy sector forward. The core business was initially focused on developing and selling onshore wind farms. Progress was made quickly within this area and OX2 became a leading developer of onshore wind power in Sweden. Today, OX2’s product portfolio has expanded and includes large-scale energy solutions based on technologies such as on- and offshore wind, solar and energy storage. It launched an initial public offering of its shares on Nasdaq’s First North Premier Growth Market in 2021 and was later listed on Nasdaq Stockholm in 2022.

OX2 is involved in the whole value chain, from acquiring project rights, permit application, realization, procurement and building to technical and commercial management. However, projects are acquired and divested in different development stages. The projects sold in 2021 had an average development time of 18 months before being realized.

Revenues are earned by selling projects and payment is received during predetermined milestones, usually around the construction phase and at the handover of the completed facility. After the handover, operational management is conducted by OX2 in most cases. A key element of profitability is, therefore, successfully realizing projects and securing permit grants. Divestments are done through a well-established process. Most of OX2’s customers are financial investors, such as infrastructure- and pension funds, with long-term investment horizons looking for stable cashflows from sustainable investments. Other typical buyers are industrial investors, who view the investment as a sustainable and cost-efficient way to accommodate their or customers’ facilities with clean energy (OX2, 2023).

4.1.1 Market Strategy

OX2 has not only expanded in terms of broadening its product portfolio but also regarding the company’s geographical presence. Large electricity markets with a considerable amount of fossil energy are targeted, where the need and opportunity for renewable energy are significant.

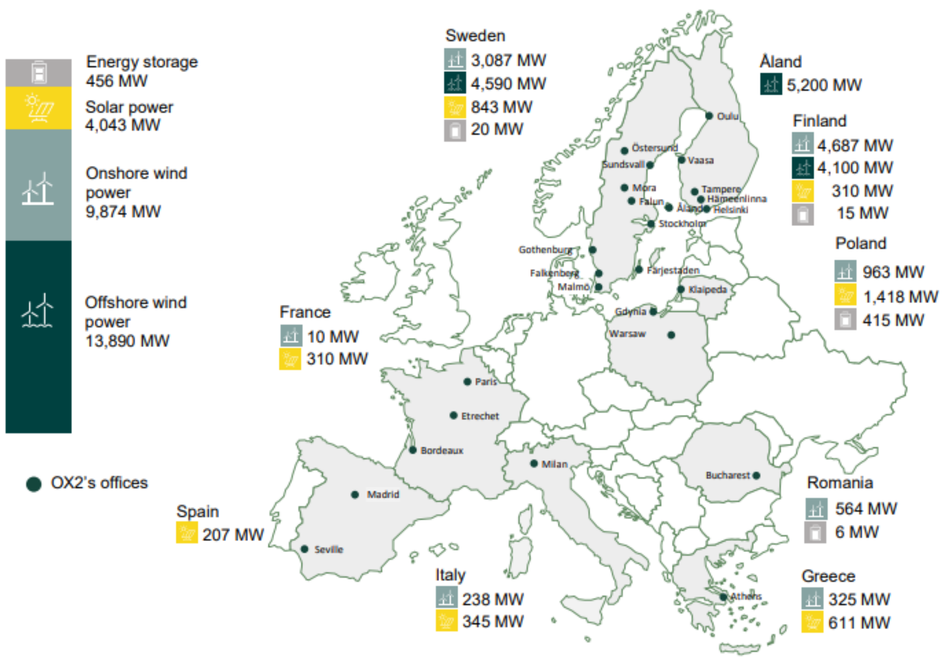
As of 2022, OX2 is present in nine European countries: Sweden, Finland, France, Lithuania, Poland, Italy, Romania, Greece and Spain (Figure 1). The local presence is crucial for OX2 as it contributes to a higher implementation rate and, thus, provides an advantage in obtaining future project rights. The competition within this sector is tough, and OX2 competes with many domestic and international project developers. Traditional power utility companies like Vattenfall, Fortum and Iberdrola are large competitors. Moreover, companies specializing in renewable energy also pose a significant competition threat (OX2, 2022).

4.1.2 Project Portfolio

The current product portfolio comprises roughly 100 projects within different stages, technologies, and markets. The stages are divided into three sections: development, building and operational. Projects within the development phase make up the largest part of the portfolio. The quantity of new projects is essential as this sector's implementation rate is relatively low. Out of the total amount of projects in the different stages, 82% is onshore wind, 7% offshore wind, 9% solar and 2% energy storage.

However, looking at the development stage solely, the division between technologies is more even (Figure 1). This is because all offshore wind and solar projects are in development, while the onshore wind is more spread across different stages. Furthermore, OX2 has not built any co-located projects yet. Sweden remains the largest market and holds approximately 50% of the projects (OX2, 2023).

Figure 1. OX2's project development portfolio and the geographical presence



Source: OX2 Year-end report 2022

4.2 European Electricity Market & Pricing

Since 1996, measures have been taken to liberalize and harmonize the EU's internal electricity market. This has been achieved by promoting openness, competitiveness, consumer protection and interconnection (Ciucci, 2022). Today, the electricity market in Europe is free and unregulated, inferring that buyers and sellers within Europe can trade energy with one another. Thus, electricity flows from lower-price areas to markets where the demand and the price offered are higher. However, it is limited by the transmission capacity and the price will differ between sub-areas since electricity cannot flow freely due to bottlenecks (Nord Pool, 2020a). For instance, Sweden is divided into four bidding areas, SE1-SE4 (Figure 2), with varying prices because of this (Energimarknadsinspektionen, 2021).

Figure 2. Illustration of the Swedish bidding areas

Source: Svenska Kraftnät (2023)

There is an excess in production compared to consumption in bidding zones SE1 and SE2, while SE3 and SE4 have a production deficit. Consequently, much energy is transferred from the north to the south. Discrepancies in prices occur due to bottlenecks in the transmission capacity, causing different demand and supply curves for the various bidding areas (Svenska Kraftnät, 2022). Furthermore, international prices and generation patterns will influence the Swedish markets. This became evident during the current energy crisis, where prices were largely affected by volatility in gas prices (IEA, 2022).

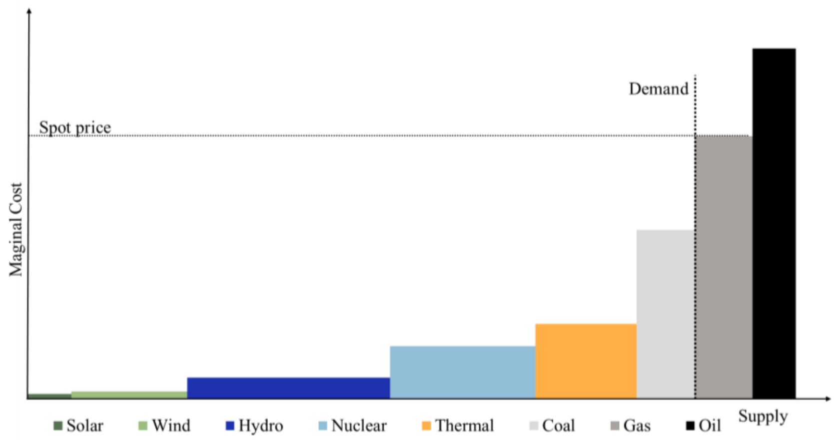
4.2.1 The Nordic Electricity Exchange

In northern Europe, the main exchange for electricity is called Nord Pool, where producers and contractors from the Nordics and Baltics trade electricity. Up to 85% of the electricity consumed in the Nordics is bought through Nord Pool. Most electricity is traded through the primary market: the day-ahead market, also known as the *spot market*. In this market, prices are set in an auction procedure for every hour of the following day, the delivery day, and bids can be submitted until 12:00 CET (Svenska Kraftnät, 2021).

The sales bids submitted on the spot market include information on estimated volumes produced and the marginal cost for supplying that amount. Contrary, the purchase bids are based on expected consumption. The submitted bids on Nord Pool are also matched with orders from other European markets in a coupling process. Based on the aggregated bids, demand and supply curves are compiled for every hour of the upcoming day for each bidding zone (Nord Pool, 2020a).

Prices on the spot market are set by a mechanism called the *merit order*, which reflects the cost of producing the last KWh to meet the demand. The production facilities with the lowest marginal cost are used first and energy sources with higher marginal costs are gradually added to the extent necessary for meeting the demand (Graph 1). Consequently, the consumer always pays for the most expensive generation that provides power to the grid. Solar power has the lowest marginal cost and is, therefore, selected first. Contrary, fossil fuel power stations belong to the energy source with the highest marginal cost and are, thus, used as a final resort (Energimarknadsinspektionen, 2021). Orders are matched to maximize social welfare rather than profit maximization (Nord Pool, 2020b).

Graph 1. Illustration of the merit order pricing mechanism



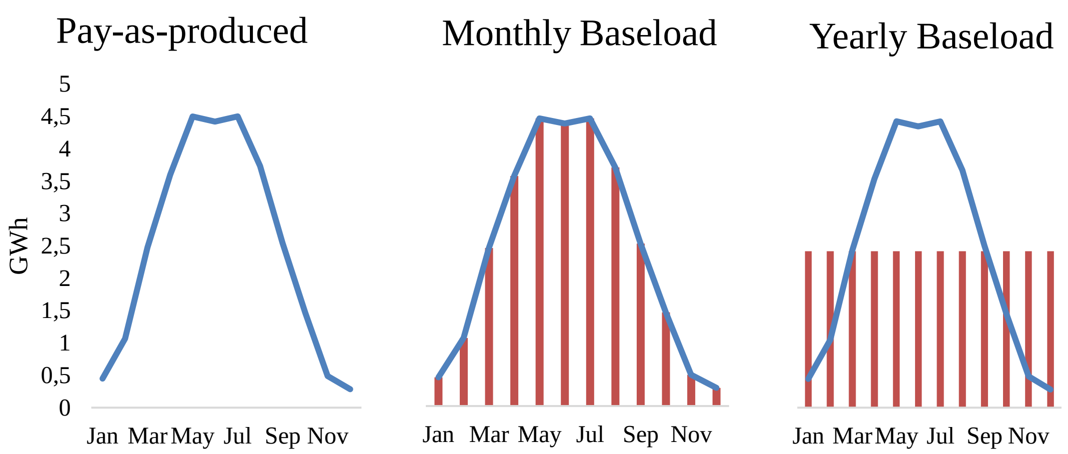
Note: The width of the bars reflects each energy resource's share of the total energy mix. The graph is constructed to imitate Sweden's energy mix today.

4.2.2 Power Purchase Agreement

The commodity price risk, where fluctuations in market prices of electricity are a big threat to profitability, becomes very tangible for actors who are entirely trading electricity on the spot market. However, it is possible to reduce this exposure through hedging. One way is to establish a financial contract, where prices and amounts can be fixed for many years in advance. This is typically done by entering a long-term supply or a future contract (Berk & DeMarzo, 2020). A widely used approach in the electricity market is creating a PPA directly between a producer and a buyer (hereafter offtaker). The offtaker is usually an energy trader or a large consumer of electricity, for example, an IT provider running big servers. The standard length of a PPA is ten years, but it may vary (Kanellakopoulou et al., 2022).

Pay as Produced (PAP) and Baseload are the most common PPA structures. PAP is a popular structure where the producer is guaranteed a fixed price for every MWh they end up producing, which transfers most risks to the offtaker. Contrary, in a Baseload PPA, both price and volume are fixed. Implying a certain volume is agreed upon for every hour of the contract, independent of actual production. However, there are multiple versions of this contract. Yearly Baseload means that the volume is set for every hour for the entire year and in monthly Baseload, the volume is fixed differently between the months (Graph 2) (Kanellakopoulou et al., 2023). Notably, the actual outcome of production volumes will most likely deviate from the forecasted volumes set in the Baseload contract.

Graph 2. Illustrations of different PPA structures



Note: The y-axis of the left-hand graph also applies to the second and third graphs. The blue line is the production and the red columns are the baseload amounts required for delivery.

Each PPA represents a unique contractual agreement with the potential to address risks in various ways. The PPA risks presented on the following page have been deemed crucial when considering the impact of the VRE expansion.

Volume Risk

Volume risk is derived from the difference between contracted volumes in the PPA and the actual produced amount. Since production volumes of VREs are heavily reliant on weather, which can be hard to forecast, the uncertainty in estimating volumes is high. Consequently, the volume risk becomes more tangible for VREs compared to other power plants. (Brindley et al., 2020). To fulfill the agreement, the producer must turn to the spot market to purchase or sell electricity when production volumes deviate from the fixed amount in the contract.

Price Risk

Price risk is caused by the volatility of spot prices in the market. For a producer, it is the risk of prices increasing but having it fixed in the PPA contract and, therefore, losing out on potential revenue. Conversely, decreasing prices would benefit the producer (Brindley et al., 2020). Rising volatility implies a higher price risk.

Profile Risk

Profile risk is linked to the production patterns of energy sources. Unlike fossil-fuelled power, which is not dependent on the time of day or seasonality, solar production is limited to daytime. Since VRE generation is not available during all hours, revenues depend on spot prices during production, which can be above or below baseload prices (Kanellakopoulou et al., 2023). Hence, for the profile risk, it is preferable if the production and consumption profiles of the counterparties in the PPA are closely matched.

4.3 Energy Market Fundamentals

Energy Metrics

Watt is often used when talking about the power of a product and how much energy it uses per time unit. Higher power means that a product uses more energy per time unit. The principles are the same for production; a higher power means a facility can produce more electricity.

The difference between a watt, kilowatt, megawatt, gigawatt and terawatt is three zeros between each metric prefix. A kilowatt is, in other words, a thousand times larger than a watt and a megawatt is a thousand times larger than a kilowatt. Energy is counted in watt-hours and is the total energy produced or consumed during a certain period (See equation 1).

$$(1)\ Energy\ (Wh) = Power\ (W) \times Time\ (h)$$

Table 2. Metrics and examples for quantities of electricity

Metric	Abbreviation	Example
Kilowatt hour	kWh	A dishwasher (1000 W) running for one hour
Megawatt hour	MWh	Average annual consumption for a villa is 20 MWh[1]
Gigawatt hour	GWh	Annual production of a larger wind park is ca 100 GWh[2]
Terawatt hour	TWh	In 2021, 166 TWh of electricity was produced in Sweden[3]

Source: [1]Konsumenternas Energimarknadsbyrå, [2]Vattenfall (2023a), [3]Ekonomifakta, 2021

Levelized Cost of Energy (LCOE)

LCOE is a metric commonly used in the energy sector. It is the present value of total building and operational costs per unit of produced electricity (See equation 2). It enables cost comparisons of different technologies taking their diverse lifespans, risks and capacities into account (DOE, 2015). A high LCOE means a high total cost of producing one unit of electricity and vice versa. In Table 3, the LCOE for different energy sources is compiled. Solar has the lowest LCOE, which indicates strong cost competitiveness.

$$(2)\ LCOE = \frac{PV(Building\ cost + Operational\ cost)}{Lifetime\ Production}$$

Table 3. Current and forecasted LCOE (EUR/ MWh) for energy sources in Europe

Energy source	**2021**	**2030**	**2050**
Nuclear	140	120	105
Coal	180	255	n.a.
Gas CCGT	155	270	n.a
Solar	50	35	30
Wind onshore	55	50	45
Wind offshore	60	40	30

Note: CCGT: combined-cycle gas turbine

Source: International Energy Agency, 2022

Capture Prices & Capture Rates

Forecasting the capture price is crucial when performing financial modeling analysis as it constitutes an essential basis for investment decisions. The capture price defines the revenue potential of a VRE facility by measuring the average electricity price (EUR/MWh) earned during production over a given time. It is derived by first calculating hourly revenues (See equation 3), which is then summed up and divided by the generation of the facility during the corresponding period (See equation 4) (Oliveira, 2023).

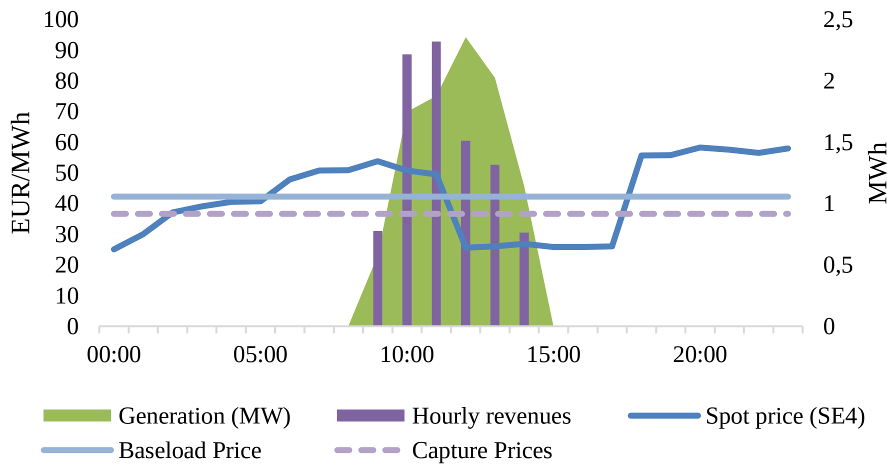
$$(3)\ Hourly\ Revenues = Generation \times Spot\ price$$

$$(4)\ Capture\ Price = \frac{\sum Hourly\ Revenues}{\sum Generation}$$

The baseload price is the average market spot price during a specified period (See equation 5), usually a year (SFC Energy, 2023). If a facility constantly produces electricity, the capture price would equal the baseload price. However, this is not possible for VRE because of the variable production. A capture price below the baseload price implies that a facility produces more when prices are low and less when prices are high (Graph 3) and vice versa. It is essential to highlight that baseload price should not be mistaken for the pricing in a Baseload contract.

$$(5)\ Baseload\ Price = \frac{\sum Spot\ Price}{Time\ (h)}$$

Graph 3. Illustration over baseload and capture prices



Note: Generation follows the axis to the right, while the other variables follow the left axis.

The capture *rate* (See equation 6) describes how well a power source's production profile matches the electricity market's demand. A high capture factor is desirable as it implies that the value of the produced electricity is high in relation to the baseload price. For instance, if a solar facility receives an average price (capture price) during the production of 90 EUR/MWh but the average market price over a year (baseload price) is 100 EUR/MWh, the capture factor equals 0.90 (Blume-Werry et al., 2021).

$$(6)\ Capture\ Rate = \frac{Capture\ Price}{Baseload\ Price}$$

4.4 Technologies

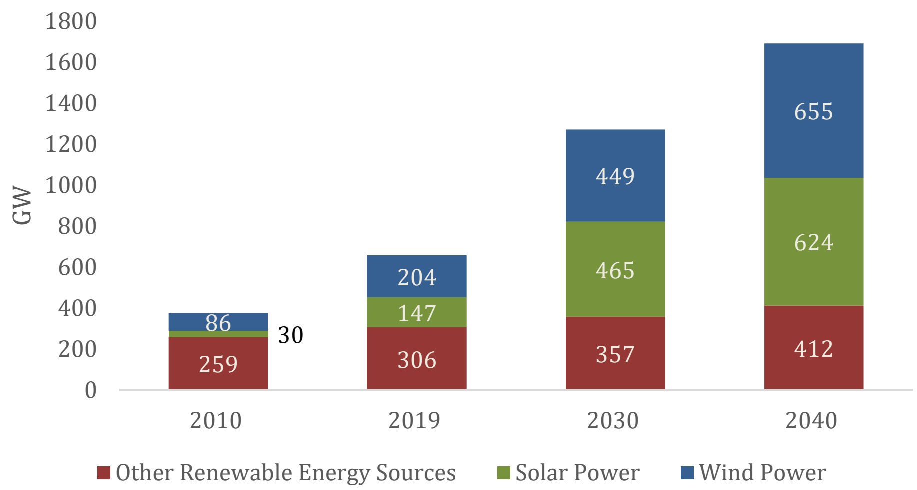
4.4.1 Variable Renewable Energy

Variable renewable energy is the collective name for technologies generating electricity using a main energy source that varies over time and cannot easily be stored. The most common VRE technologies are wind, solar, ocean and hydropower to a certain extent. The variability of VREs refers to the changes in production levels due to underlying resource fluctuations, creating a higher uncertainty in predicting the output. Despite this, VRE sources have gained popularity due to their low carbon footprint and LCOE compared to other power sources (Table 3) (Katz & Cochran, 2015).

Over the last 15 years, the EU's legislation promoting renewable energy has advanced considerably. During this period, targets on the share of EU's energy consumption stemming from renewable sources have been decided and renegotiated several times. In 2009, the target was set to reach 20% by 2020. In 2018, the target was extended and increased to 32% by 2030. In correspondence with the EU's new climate ambitions, policymakers proposed in July 2021 that the target should be revised again, increasing it to 40% by 2030. The Russian invasion of Ukraine and the following energy crisis partly influenced the decision to accelerate the renewable energy transition. Discussions about targets after 2030 are currently being held (Ciucci, 2022).

The compounded annual growth rate of new solar capacity installations in Europe between 2010-2040 is expected to amount to 10,6%. The equivalent number for wind power is 7% and 1,6% for other renewable energy sources (Graph 4).

Graph 4. Installed renewable capacity in Europe and estimated new installations



Source: OX2 Annual and Sustainability Report 2021

4.4.2 Solar Power

Electricity generation through solar power was initially used to power satellites and smaller items like calculators. Today, large-scale and residential solar is deployed to provide power to the grid and supply electricity to the population. The production depends on sunlight availability and the possibility of storing the energy is limited (NREL, 2023). However, its generation profile is more predictable than other VREs because of the repeating pattern of the sun.

Building solar parks has become much cheaper in the last decade. In 2010, the global LCOE for generating a MWh of electricity from solar amounted to €378, excluding any subsidiaries. Nine years later, in 2019, the cost of generating the same amount had shrunk by 82% to €68, making it cheaper than most alternatives (Elliott, 2021). However, evidence from the World Energy Outlook 2020 suggests that solar costs have become even lower. More precisely, it suggests that the LCOE for solar in 2020 was 20-50% cheaper than estimated in last year's outlook, making it the cheapest alternative for electricity sources in history (Evans, 2020). The LCOE in Sweden during the corresponding period, 2019-2020, averaged 40,79 EUR/MWh (Lindahl et al., 2022). Alexander Esser, Senior Commercial Manager at Aurora, expects the cost to decrease even further with more expansion (Esser, 24.03.23).

Moreover, Paul Stormoen, CEO of OX2, reflects on the possibilities that cost reductions in solar power have created for the market and OX2 "As the cost falls, this creates opportunities for solar power in countries with fewer hours of sunshine. We see solar power playing a much greater role at OX2 in the future" (Paul Stormoen, 2022, p.5). The solar industry in Sweden is currently tiny, but it is growing fast. In 2040 it is estimated that 5-10% of Sweden's energy production will come from solar power (Energimyndigheten, 2023). In comparison, solar production in Germany is estimated to reach 20% in 2040 (Statista, 2023).

Sixto Garcia Barea, working with procurement at OX2, says that their reference cost of capital expenditures is 500 EUR/kW per peak production for a 50 MW solar plant located in Sweden, excluding costs related to the land lease, export grid and connection fees. This indicates a minimum cost of 25 million euros for a 50 MW solar facility in Sweden (Barea, 24.04.23).

4.4.3 Battery Energy Storage System

A battery energy storage system is an electrical energy storage system that consists of one or more batteries that can charge, store and discharge electricity when needed. Because of its great versatility, the system can be deployed across the entire value chain of electricity, including generation, distribution, transmission and by end consumers (Kanellakopoulou, 2022).

To accommodate the increasing electricity demand in the future, investments in battery storage also need to grow rapidly. Global energy storage additions are expected to reach 390 GW between 2022-2030, corresponding to a compounded annual growth rate of approximately 30% or 15 times the storage capacity at the end of 2021. The growth is mainly driven by the global integration of renewables and, thus, the increased demand for solving the deficiencies of renewable energy (Adegbesan, 2022).

Between 2017-2025, the average battery cost suitable for a co-location amounted to 500 EUR/kWh (IEA, 2023). However, the cost projection of batteries is more uncertain than for solar, ranging from capital cost reductions between 14-38% by 2025 (NREL, 2021). Brian Knowles, Director of Storage & Flexibility at Pexapark, is also unsure about the cost development of batteries. The earlier conception of decreasing cost is no longer guaranteed; Knowles elaborates on this topic “I do think you will continue to see opportunities for low-cost batteries, but they will likely be coming from different suppliers and different chemistries of lithium-ion technology” (Knowles, 28.03.23). For instance, mega-factories with economies of scale are currently being built, which will likely benefit the stationary storage market.

Lastly, the competitive landscape is evolving and changing the norms in the storage market quickly. Linnea Tjernlund, Lead Analyst of Energy Storage at OX2, highlights the increased interest around storage and explains that many competitors are trying to enter the market; project developers exploring storage, traditional energy companies and network companies are all developing battery storage in various ways (Tjernlund, 09.03.23). Stormoen describes OX2’s intentions of expanding into storage technologies “Alongside wind and solar power, we are also investigating new technologies, such as hydrogen and storage, which will be important elements of the new energy systems currently being planned in Europe” (Paul Stormoen, 2022, p.5).

4.4.4 Co-location

A co-location can be created by combining a solar facility with a battery energy storage system. The requirement for a system to be considered a co-located structure is that there must be an operational and locational linkage between the different technologies. The benefit of a co-location system is the utilization of each technology's strengths. For instance, solar is one of the cheapest technologies for producing energy and batteries can offer controllability of the output (Murphy et al., 2021). This combination has become popular in specific markets, such as California, where 98% of submissions for grid consideration in 2022 are co-located (Knowles, 28.03.23). Contrary, the first Swedish large-scale co-located project was built in November 2022 when a 2 MWh battery was added to an active 12 MW solar park in Linköping (Liljeborg, 2022).

Market preferences on the size ratio between the technologies differ. Current estimations on the battery's effect size range between 25-50% of the solar park's effect. A 50 MW solar facility should, thus, be combined with a 12,5-25 MW battery (Tjernlund, 09.03.23). Hence, the capital expenditure for such an investment could span between 31 250 000–37 500 000 million euros.

5. The Case: Risks, Implications & Solutions

The fast-paced VRE industry growth presents multiple risks and implications for actors operating in the sector, not least for OX2. It is crucial first to analyze the risks and consequences to assess the efficiency of different hedging approaches. Hence, this segment addresses the research questions.

5.1 Evolving Risks from VRE Expansion

(i) What risks does the expansion of VRE create for Swedish solar facilities?

Most of OX2's solar projects are planned to be built in SE4. This bidding zone has been, and is forecasted to be, the geographical area where the growth of solar production in Sweden is most prominent (OX2, 2023). Nevertheless, the European VRE expansion will be considered when studying the risk for solar facilities in SE4 because of the interconnectedness of the electricity markets and the similar transitions ongoing in these countries.

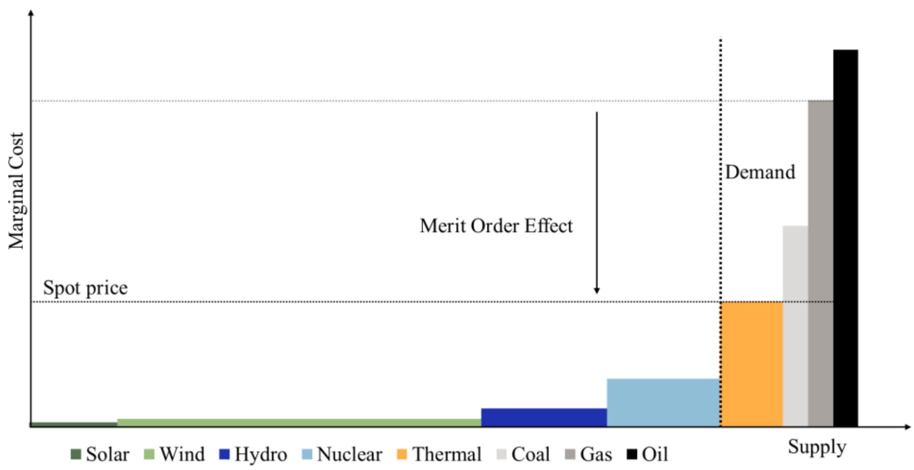
Currently, many renewable projects are being developed in the Nordics, with an increased interest in solar. Compared to the protracted and comprehensive build-out of wind, Nikita Semkin, Principal at Afry, believes that the solar expansion will happen more quickly because of the simplicity of deployment and since many developers are present and experienced in deploying renewable projects by now. Hence, Semkin argues that it is likely that the Nordic system will end up with a momentary abundance of renewables in relation to how much the system can take (Semkin, 12.04.23). The uncertainty of the build-out and its effect creates the subsequent risk, especially if the expansion of VRE occurs faster than expected in Sweden or correlated markets.

5.1.1 Cannibalization Risk

Some natural resources like the sun come at no cost, which is why the marginal cost of solar production equals zero. In accordance with the merit order, solar producers must bid at zero in the spot market. However, the price received is determined by the last power source in the dispatch order needed to provide electricity to meet the demand. This makes solar energy producers "price takers" instead of "price setters" (Kanellakopoulou et al., 2022).

Furthermore, solar power normally produces energy at concentrated hours and facilities in the same pricing zone will, therefore, sell electricity simultaneously. If solar production is sufficient, it can cause a shift in the dispatch order, where energy sources with higher marginal costs are pushed further out in the merit order. Consequently, lowering the marginal cost of the last energy source needed to meet the demand and, thus, decreasing the spot price for the produced electricity at that time. This phenomenon is called the merit order effect (Graph 5). Since the marginal cost of producing an extra KWh for solar is zero, solar producers will always maximize output when able to. VRE production is driven by the availability of natural resources, such as sunlight and wind, rather than economic incentives (Pena et al., 2022).

Graph 5. Illustration of the Merit Order Effect

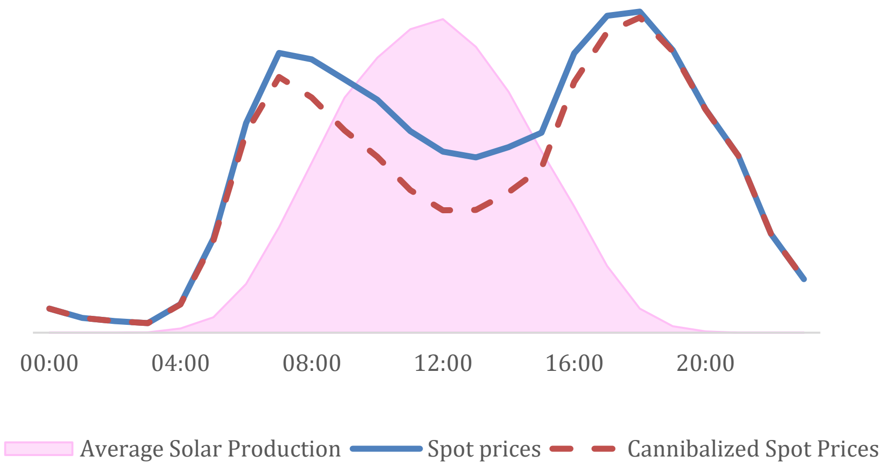


Note: The width of the bars reflects each energy resource's share of the total energy mix. The graph is constructed to imitate Sweden's aspired energy mix by 2040. Compared to Graph 2, the share of renewables has increased while everything else is kept constant, causing a shift in the dispatch order and a reduction in the spot price

Solar cannibalization can come from multiple sources, not only from large-scale facilities but also residential and commercial housing (Knowles, 28.03.23). The increase in rooftop solar is very high, Tomas Sjöberg who is Managing Director at Axpo Sweden contextualizes this growth by comparing Axpo's electricity dealers' current production levels with last year, "In February 2023, our electricity dealers produced more than they did during most of the last summer. So, in February, a winter month, more solar energy was produced than during the summer of 2022" (Sjöberg, 17.03.23). The yearly installed capacity for solar has increased from 160 MW in 2018 to 500 MW in 2021, where the largest growth has come from single-family housing (Svensk Solenergi, 2023).

When the penetration of solar increases, the overall electricity production becomes more concentrated around sunny periods and supply increases at that time. Hence, making it more likely to cover a greater share of the demand during peak production hours. The high correlation of low marginal cost production, combined with an unmatched demand, drives prices down and erodes the revenues, resulting in solar facilities cannibalizing their own profits (Graph 6) (Zipp, 2017).

Graph 6. Illustration of Cannibalization



Note: Simulated production profile of a Swedish solar facility and the forecasted baseload price. The cannibalization effect is illustrated through the downward shift in the price curve. *Source: OX2* (2023c)

Traces of cannibalization has already been observed in Sweden, although Sjöberg points out that it solely applies to SE3 and SE4. He also thinks that the effect will worsen as the growth of solar in Sweden is very high and draws a parallel to Denmark which built a lot of solar parks during winter 2021, resulting in a tangible observed cannibalization in 2022. As a rule of thumb, Sjöberg says that the impact on prices can be observed once a renewable reach 6% of the total consumption (Sjöberg, 17.03.23).

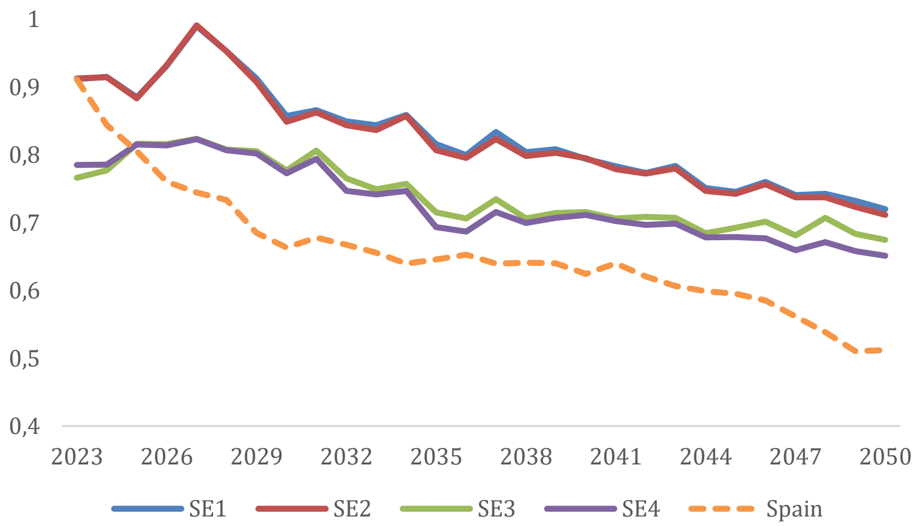
Svensk Solenergi has established a goal of having 30 000 MW of solar in Sweden by 2030, with most of it being SE3 and SE4 (Svensk Solenergi, 2022). Additionally, a couple thousand megawatts will produce energy from nuclear- and wind power during the summer. However, Sweden disposes at most 14 000 MW during the summer. Sjöberg discusses the potential consequences of it "This means that the price will be zero during sunny summer days in 2030. It will happen much faster than you think, already in a couple of years. At the risk of sounding negative, I think that the expansion is great, but I think that the risk of getting very low electricity prices is high. My best guess is that a solar producer's income, who is selling to the spot market, will be quite small in a few years" (Sjöberg, 17.03.23).

5.1.2 Decreasing Capture Rates from Cannibalization

Blume-Werry et al. (2021) examined 20 interconnected European countries and found that increasing solar penetration by 10% significantly affects the average electricity price captured by solar. Current solar capture factors range between 0.9-1 but are expected to decline until 2030 to around 0.7-0.8 due to cannibalization. Implying that cannibalization in the combined markets is modest now but is expected to steadily increase as the solar fraction grows. The most significant price decrease affects countries with higher solar penetration, like Spain (Blume-Werry et al., 2021). For instance, if the target of variable renewables in Span is met, 74% by 2030, market revenues from these energy sources will not cover the forecasted LCOE for the technologies (Pena et al., 2022).

When comparing forecasted capture factors in the Sweden bidding zones with Spain, one can observe a larger decrease in Spain (Graph 7). Similarly, capture factors in southern Sweden are decreasing faster than in the northern bidding zones. The reason for this has been discussed above and is partly explained by the higher fraction of solar production in these areas. A regression in forecasted solar facilities' value factors in SE4 and total solar generation in Sweden between 2023-2060 strengthens this finding by displaying a significant relationship between increasing solar penetration and decreasing capture rates (Appendix 1).

Graph 7. Forecasted development of capture factors in different markets

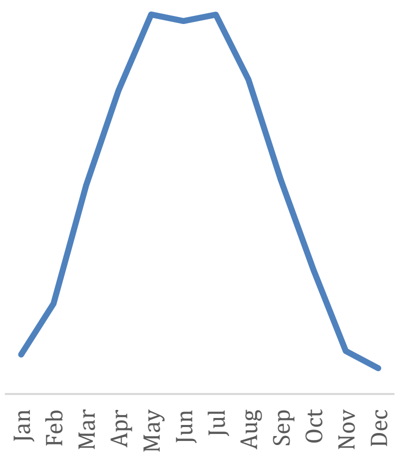


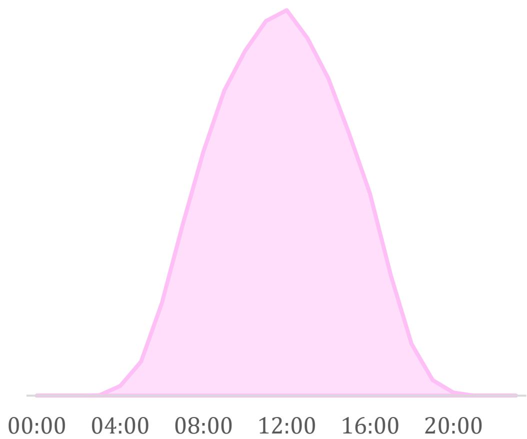
Note: The curves are built on forecasted spot prices and capture prices for solar from 2023-2050
Source: OX2 (2023d)

5.1.3 Increasing Production Concentration

Solar power production is highly concentrated to daytime hours and specific months. The average solar production volume on a monthly and hourly basis from a Swedish facility is presented in Graphs 8 and 9. As shown in the graphs, the production is centered across summer months and middays. The generation profile is characterized by high seasonal and hourly differences in production. Although the output varies throughout the day and between seasons, the production hours are similar for markets at the same latitudes, implying a high correlation in solar facilities' production. Hence, the expansion of solar in nearby regions poses a threat to other producers as the supply becomes even more concentrated. Compared to other VRE sources, geographical diversification is less effective in reducing the correlation of solar facilities' production. For instance, the amount of wind might differ significantly between regions in Sweden, but the sunlight does not vary as much (Esser, 24.03.23).

Graphs 8 & 9. Solar production during different months and hours in Sweden





Note: Production profile of a Swedish solar facility on a monthly and daily basis.
Source: OX2 (2023e)

5.1.4 Import of Cannibalization: Stronger Market Correlation

As the EU electricity market has become increasingly unregulated, the included markets have become highly integrated. This becomes evident when looking at the price correlation among different markets (Table 4). Compared to the two northern bidding zones in Sweden, SE3 and SE4 are stronger correlated to the other countries in the table. This suggests that the southern bidding zones are more influenced by the broader European market and the price movements in these countries. This also implies that changes in foreign energy mixes are highly important to SE4 prices. Foreign cannibalization is likely to spread to other markets, particularly to smaller markets like Sweden, whose price movements are more sensitive to foreign fluctuations.

Table 4. Price correlation between Swedish bidding zones and European markets

	System	Germany	Spain	France	Italy	SE1	SE2	SE3	SE4
System	1,00								
Germany	0,83	1,00							
Spain	0,60	0,72	1,00						
France	0,78	0,94	0,76	1,00					
Italy	0,77	0,93	0,76	0,95	1,00				
SE1	0,61	0,38	0,22	0,30	0,31	1,00			
SE2	0,63	0,41	0,23	0,33	0,34	0,98	1,00		
SE3	0,90	0,76	0,52	0,69	0,68	0,66	0,68	1,00	
SE4	0,88	0,82	0,57	0,74	0,73	0,57	0,60	0,93	1,00

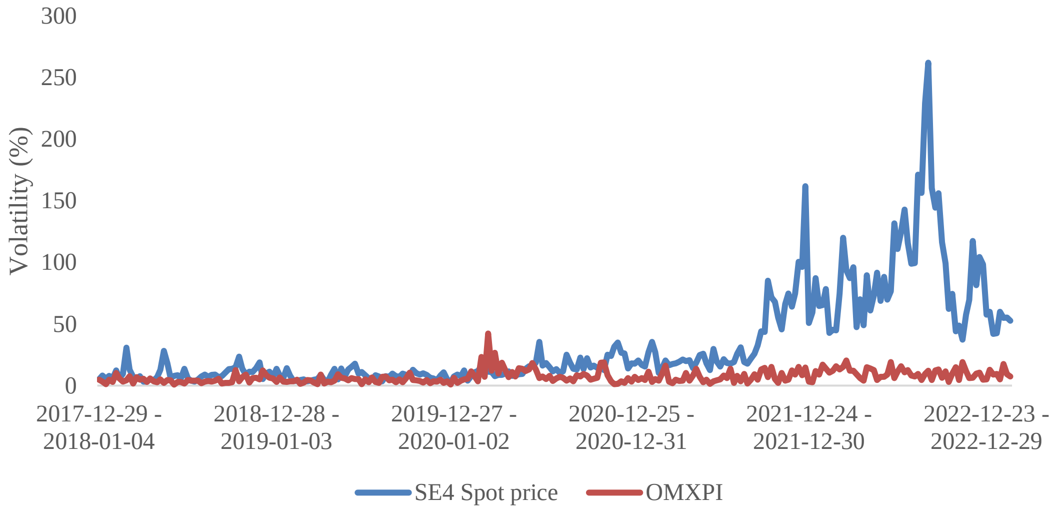
Note: The correlation matrix is based on hourly spot prices from 2010-2023. The correlation coefficient measures the strength of the relationship between two markets. The system price is derived by eliminating transmission capacity constraints in the Nordics. *Source:* (OX2, 2023f)

The high interconnectedness of SE4 means that risks stemming from the VRE expansion abroad are imported and should, therefore, be considered when studying implications in SE4. According to OX2's Energy Market & PPA Consultant Atle Beisland, this risk will be further enhanced by a growing interconnection with Germany, which has a more ambitious target of solar expansion compared to Sweden. The correlation is expected to increase with new investments in transmission infrastructure between the countries being planned, such as Hansa Bridge. This will, according to Beisland, have a significant effect on cannibalization levels in the south of Sweden (Beisland, 17.03.2023).

5.1.5 Increasing Price Volatility & Price Risk

Historically, the price development of electricity has been more volatile compared to other tradable assets such as stocks (Graph 10). It usually fluctuates around 20-50% on a weekly basis. However, since the end of 2021, a significant increase in electricity price volatility can be observed, exceeding 100% for several weeks. During winter 2021/2022, the price of electricity in Sweden rose to exceptionally high levels and volatility spiked. The reason for the significant increase in electricity prices can be derived from several factors. One reason is the unusually cold winter in 2021, combined with little wind, which largely affected Sweden's VRE production. Moreover, since Russia invaded Ukraine on the 24th of February 2022, the export of natural gas from Russia has been reduced, increasing prices for electricity in Europe (Statistikmyndigheten, 2022).

Graph 10. Historical weekly volatility of different tradeable assets



Note: Weekly price volatility of SE4 Spot and OMXPI between 2018-2023. *Source*: OX2 (2023g)

Another risk that evolves from the VRE expansion is the anticipated shift in price volatility. In Svenska Kraftnät's most recent long-term market analysis, forecasted price variation in the future is presented and compared to 2019-2020 values. The study shows that the future price variation within days and weeks is lower than the historical benchmarks. However, looking at the spread between weeks, a significant increase in price variations can be observed. One explanation for this is the increased interdependence between electricity prices and weather. The weather is relatively stable during a day or a week but can shift considerably between more extended periods (Svenska Kraftnät, 2019).

Volatile spot prices also influence the risk aspect of PPAs. In a PAP structure, only the price is fixed, so fluctuations will only cause the producer to lose out on potential revenue if prices increase. However, volatility is more problematic in a Baseload contract because the fixed volume commitment can infer real costs to the producer. Spot prices tend to move unfavorably when deviations must be corrected through the market. This is because there is a strong negative correlation between market prices and the supply from VRE. When production is low and the producer must make complementary purchases, the spot price tends to be high and vice versa. Sjöberg explains this process for solar "If there is no sun during the day, the spot price tends to be higher and the offtaker has to buy from the spot market because the delivery from the PPA is not sufficient" (Sjöberg, 17.03.23). Higher volatility is likely to worsen these effects.

5.2 Implications for OX2

The development of the VRE sector is highly relevant for the long-term durability and profitability of OX2's business model. Assuming cannibalization and price volatility are expected to increase, implications for OX2's business will evolve. The consequences can be observed already in a forward-looking stage but also depending on how the actual outcome realizes. These consequences are discussed in 5.2 and aim to answer the second research question:

(ii) How do the risks in (i) impact OX2's business?

5.2.1 Impact on Valuation of Solar Projects

Forecasted production volumes and market prices are the main drivers for predicting electricity sales revenue. A third-party consultant typically provides projections on the market and capture prices (Afry, 2021). Carl Ferm, Transaction Associate at OX2, clarifies that OX2 orders price curves from highly reputable suppliers that fulfill the "bankable criteria," meaning the banks accept the price curves as a basis for financing. Given that financing is often set in relation to the projects' expected cash flows, the absolute value of debt financing is affected by changes in forecasted electricity prices.

Ferm further explains how recent shifts in price curves have impacted OX2's project valuations "Recently, adjustments in forecasted prices have impacted project valuations by a two-digit percentage. It includes both when looking at different quarterly reports but also depending on which price curve is used. The suppliers of price curves have different views on what the prices will be in the future" (Carl Ferm, 02.03.23). Hence, the price curves provided become a decisive part of the valuation of OX2's projects. Anticipated decreasing capture prices will consequently reduce the valued cash flows of the projects, limiting the amount of debt available and dampening OX2's revenues. Esser expands on this topic "If you end up in a world where the capture prices are below the cost for solar, then this would mean there will be slower deployment or even come to a stand-still" (Esser, 24.03.23).

Moreover, due to the current high fluctuations in prices, the timing of the projects also becomes increasingly important. In the discounting process, cash flows closer in time are more valuable than the ones further out. Short-term volatility will, therefore, significantly affect valuations (Carl Ferm, 02.03.23). Christian Fickler, Commercial and Strategy Manager at OX2, further explains that early- to mid-stage projects are less affected by volatility than late-stage ones since the time until realization is longer. Therefore, the volatility has a larger effect on projects soon to be realized since volatility is expected to go down as the situation normalizes (Fickler, 19.04.23). Since many of

OX2’s projects are in a late stage, they are bound to see the effect of volatility on revenues in the near term. It is, therefore, important for OX2 to realize its late-stage projects before the prices come down. Otherwise, they are likely to acquire expensive projects during a period characterized by higher electricity prices and miss out on similarly higher realization prices.

There are also reasons to believe that the risk profile of solar facilities has shifted with the recent development and prospect of the market. A more volatile electricity market implies higher risk and complexity in asset pricing because of the uncertainty in predicting price movements. The same applies to the pricing of PPA contracts (Fickler, 19.04.23). This could change the risk assessments made by financial investors and, therefore, affect the sales process for OX2. To date, financial investors have mainly invested in OX2’s projects. The common characteristics of these investors are that they have much capital and risk-averse investment profiles (Bergman, 15.03.23). If these investors start to perceive investments in renewables as riskier, they will likely demand a higher internal rate of return or look for alternative assets to invest in. Furthermore, Semkin explains that infrastructure investors prefer safe and well-known assets like wind and solar. However, a battery has asymmetric gains that benefit from volatility, which is why Semkin believes a different type of investor will find this asset class attractive (Semkin, 12.04.23).

Moreover, investors bear the ultimate risk of long-term price development and how the increasing cannibalization should be dealt with after purchasing the asset. This will, however, influence the price they are willing to pay for OX2’s projects today. Evaluating a PPA is crucial in commercial due diligence to understand estimated revenues, risks and how these elements are reflected in the valuation of the financial model (Afry, 2021). While this is very important to consider, predicting the level of cannibalization ten years ahead has proven very complicated. Olli Hagqvist, Director of Power Markets & PPA at OX2, argues that the increased volatility has made it harder to price PPA contracts accurately because there are different views on how much one should calibrate the PPA price against the current “extreme” market environment (Hagqvist, 29.03.23).

5.2.2 Change in Preferences of PPA Contracts

If investors and offtakers become more concerned about cannibalization and increasingly reluctant to its exposure, negotiations on how the risk should be divided in the PPAs will become more challenging. Current market trends show producers are more willing to sign PAPs while offtakers prefer Baseloads. Sjöberg expands on this dilemma “Someone always takes the cost; it does not go away. Who will bear the cost? Is it the investor in the solar farm or the one who buys the electricity? The basic problem in the whole thing lies there" (Sjöberg, 17.03.23). This divergence can potentially harm OX2's business.

With the expansion of renewables, offtakers in more mature markets, like Spain, have started to become more hesitant to sign PAP contracts. This is due to the accumulated risk of cannibalization built up over the years for offtakers entering PAP contracts. Thus, offtakers value these contracts more conservatively, drying up this market in geographical areas with high penetration of renewable energy sources (Pexapark, 2023). One can expect the same movement to occur in Sweden once the solar market matures. Sjöberg shares the same view regarding the observed shift in preferences of PPA structures in the market "Baseload is the future. There are no offtakers who want Pay-as-produced anymore. It has changed very quickly. Everyone who did Pay-as-produced is suffering now" (Sjöberg, 17.03.23).

Contrary, Beisland shares his view from a producer's perspective and explains that PAP was the preferable alternative ten years ago. At that time, the cannibalization risk was small and very few people were concerned about it, which is why these contracts dominated. However, once the expansion began and the cannibalization grew, Baseload contracts became more popular. The price on Baseloads was higher and gave better financing. Nowadays, the trend shows that banks and investors want to return to PAP, but offtakers do not. Beisland explains this dilemma "It is a negotiation on who should take on the increasing cannibalization risk" (Atle, 17.03.23).

Depending on the size of OX2's projects, financiers normally use a mixture of equity and debt. For larger projects, equity is often insufficient, requiring investors to join a consortium or obtain debt financing (Fickler, 19.04.23). The mismatch in PPA preferences may impact OX2's business negatively. If the market for PPA contracts dries up and investors increase their exposure toward the spot market instead of securing prices, debt financing will become more demanding. Hence, it might become more challenging for OX2 to find buyers of larger-scale projects and the investor's return requirements are likely to increase.

5.3 Risk Mitigation Tools

There is an urgency in finding a way to mitigate the previously mentioned risks for OX2 to remain profitable in the long run. In this section, potential solutions are laid out for mitigating the risks. The discussion is centered around the third research question:

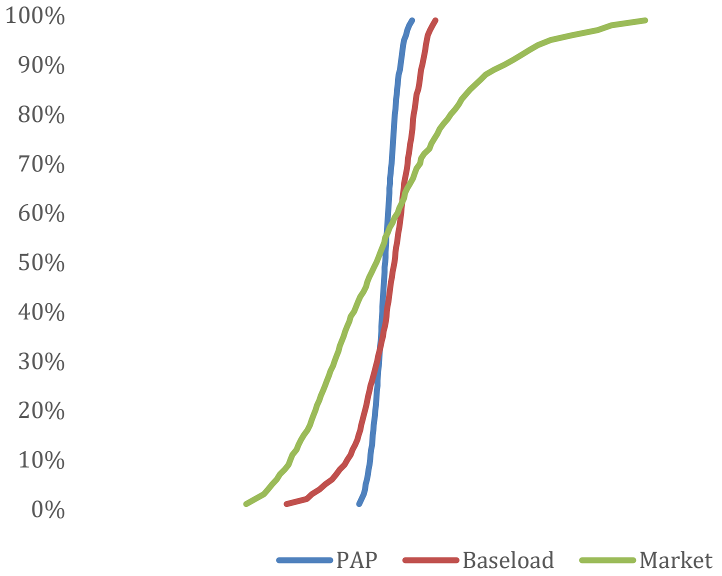
(iii) What are the advantages and disadvantages of financial and operational hedges in mitigating the risks in (i)?

5.3.1 Financial Hedging

5.3.1.1 Power Purchase Agreements

Financial hedging through PPAs has been popular in the energy market to secure long-term prices and de-risk valuations. The most significant advantage of a PPA is that prices are fixed, enabling offtakers and producers to have a higher certainty in costs and revenues. The PPA contracts make the revenue distribution more concentrated, implying a lower probability of extreme outcomes (Graph 11). Reducing the downside risk comes at a cost and will, therefore, lower the expected return. Consequently, the expected hedged return on a 10-year time horizon is lower than the unhedged. However, the left-side tail events are worse with a full market exposure, which requires greater liquidity coverage to handle adverse movements. While PPA contracts can protect from negative price movements, they may also limit the potential upside. However, it is essential to acknowledge that the objective of hedging is not necessarily to boost a firm's profit but to increase the certainty and stabilization of cash flows. This can be highly important as it reduces frictional costs related to financial distress and risk assessment (Berk & DeMarzo, 2020).

Graph 11. Probability distribution of hedged and unhedged revenues



Note: Probability distribution of revenues with and without PPAs. It is simulated on a Swedish project and can be interpreted by seeing what revenue will be achieved under a certain probability. Revenue amounts are anonymized to ensure non-disclosure.

Another benefit is that PPAs facilitate the ability to secure more debt. Energy production facilities usually require sizeable initial capital expenditures and debt financing is, thus, often needed. Since a PPA contract secures a long-term fixed price, cash flows become more stable and predictable. Hence, lenders can accept higher leverage when the security is less volatile (Kanellakopoulou et al., 2023). According to Beisland, this is the most crucial function of a PPA, as it enables smaller actors with relatively little capital to enter the market (Beisland, 17.03.2023). Historically, debt financing has required investors to hedge 50-70% of the expected produced volume over 8-10 years. Nowadays, it is possible to secure debt financing without having a PPA. However, in those cases, the banks are more restrictive and want a higher buffer due to cash flows being more uncertain without a hedge. The need for hedging may also differ depending on the project size; for instance, larger projects often require higher financing volumes which generally implies stricter requirements for hedging agreements (Ferm, 02.03.23).

Although PPAs have their benefits, there are also limitations to them. PPA contracts do not eliminate the risks; instead, their primary function is to divide the risk between the offtaker and producer. Therefore, the price determined in the PPA is discounted based on how the risk exposure is split. This highlights that risk mitigation comes at the expense of lower prices in the PPA. Additional risk transfer to the buyer will result in a more discounted price in the PPA and limit the payoff for the producer. However, it makes the investment safer compared to selling to the spot market (Kanellakopoulou et al., 2023).

As mentioned earlier, PAP contracts have historically been the most common PPA structure. A fixed price on a floating volume is beneficial from a producer's risk perspective, although the price is more discounted than in a Baseload. However, since many of these risks are hard to quantify, it has proven to be a comfortable solution. Contrarily, the most considerable risk for producers entering a Baseload is the risk of large deviations between the fixed delivery volume and production. The producer must buy from the market when the facility produces below the baseload and sell when too much is produced. The exposure is, therefore, in two directions with an amount that is hard to quantify, making the risk hard to value. Hence, the price is less discounted in this contract than in a PAP (Kanellakopoulou et al., 2023).

Today, several wind farms in northern Sweden face financial difficulties due to their binding Baseload contracts. They are obligated to deliver a certain amount to a fixed price and deviations from these amounts must be bought on the spot market. However, since the war in Ukraine, the volatility and higher prices have made this commitment increasingly costly. It has dramatically affected producers' profits, such as Vattenfall, which have taken significant losses from these contracts. Christian Holtz, an analyst at the consultant firm Melin and Metis, believes many investors underestimated the cannibalization effect when building large-scale projects 3-5 years ago (Martin Berg, 2023). Sjöberg shares this opinion and argues that all actors working with wind power have previously underestimated the cannibalization, which has caused offtakers in PAP contracts to lose much money. This is because cannibalization has proven much higher due to the fast expansion and imported effects from other countries. He also points out that the same phenomenon is happening with solar power now (Sjöberg, 17.03.23).

Suggestions of altercations to the existing structuring of deals to reduce risk have also been mentioned in the interviews. Historically, producers have hedged 70% of their sales in a PPA contract; however, reducing this amount to 30-40% implies a higher likelihood of receiving the hedged price more consistently. This would reduce the risk of not fulfilling the PPA commitments (Sjöberg, 17.03.23). Nevertheless, hedging a lower percentage increases the exposure to the spot market, which can cause more significant revenue fluctuations. Adding on to this, Hagqvist discusses active risk management as a possible solution besides hedging a lower percentage of production. For instance, having employees continuously evaluate the risk exposure and examine whether closing out positions before maturity or providing additional hedges is reasonable. Moreover, a mix of Baseload and PAP contracts can help balance the risks while maintaining a suitable average price (Hagqvist, 2023.03.29).

5.3.1.2 Capital Structure Adjustments

By changing the debt and equity financing mix, companies can adjust their capital structures to manage financial risks connected to the exposure of adverse market movements. Debt financing is considered riskier than equity, so investors using more leverage require a higher expected return as compensation for higher risk-taking. The optimal debt level for a firm largely depends on the industry's characteristics in which the company operates. High predictability of cash flows enables higher leverage, while more uncertainty requires more equity (Berk & DeMarzo, 2020). Participants in the energy sector have extensive exposure to energy- and raw material prices which have been volatile historically. Additionally, VRE’s production dependency on favorable weather conditions implies a low control over revenues, making it questionable if high leverage is suitable.

Moreover, Ferm explains that the financing of a project usually depends on the investor type. Infrastructure and renewable funds typically use debt to finance 60-70% of the projects’ enterprise value. While other investors, such as industrial actors, finance their acquisitions solely with equity due to their access to internal cash reserves. The capital structure also depends on the actor's required rate of return, with firms demanding higher returns needing more debt financing to achieve competitive bids on projects (Carl Ferm, 02.03.23).

An essential advantage of using equity instead of debt is the energy producer's ability to meet debt obligations during adverse events, such as poor weather conditions or decreases in energy prices. Another significant benefit is the reduced reliance on external financing and the subsequent movements in the interest rate market. Sjöberg explains that this mainly applies to investors during periods of economic downturn "[…] more equity and less debt will give the firm more flexibility to manage periods when it is tougher" (Sjöberg, 17.03.23).

5.3.2 Operational Hedging

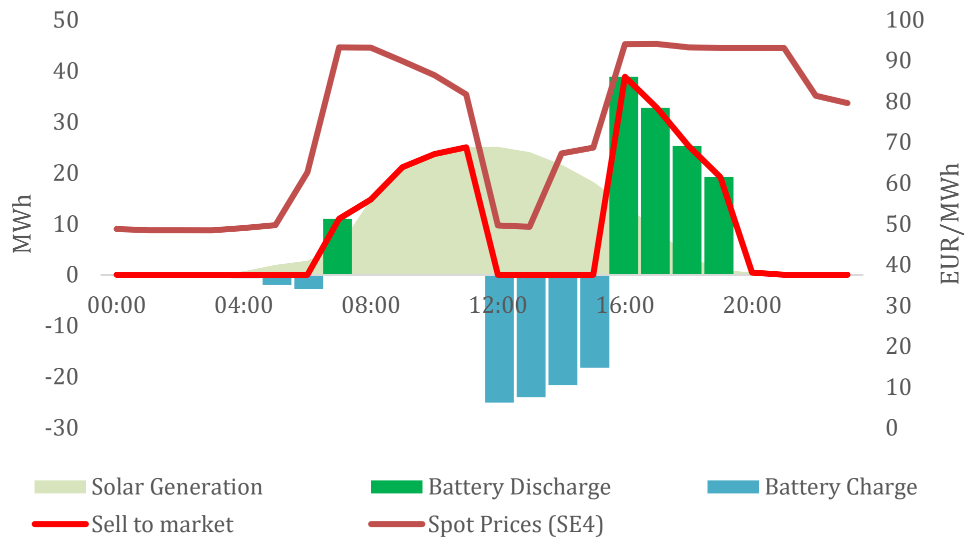
5.3.2.1 Battery Storage Investments

Understanding batteries' functions are crucial for analyzing their effects on the risks imposed by increased investments in VRE. Combining the technologies provides one important new service: performing arbitrage through time-shifting. Time-shift means selling electricity at a different time and price from when produced. This is done by storing the electricity generated from the solar facility through a battery and selling it when prices are higher (Prol & Schill, 2020). Time-shifting serves as an operational hedge by counteracting the decreasing capture prices (Kanellakopoulou, 2022).

Michiel van Asseldonk, Technical Lead of the Storage Team at OX2, argues that a solar facility's unique production profile is the main reason for adding a battery instead of combining it with other VREs. Since battery storage with a 1–4 hour duration is becoming more cost-effective, it matches well with time-shifting the mid-day solar peak. However, it is not feasible to cover longer peaks in wind power that can last many hours or even days. Solar power typically has 2-3 hours of peak production, implying high predictability and reasonability in the duration needed for time-shifting the worst peaks. (van Asseldonk, 09.03.23).

Compared to a PPA contract, the co-location does not limit the upside nor redistribute risks. Instead, time-shifting can boost revenues while also reducing risks. However, this service's profitability lies in optimizing a strategy that can capture the maximum value of the produced electricity. Additionally, the capacity to delay sales will theoretically counteract cannibalization as it creates a new production profile that is less correlated to the traditional productional pattern of solar (Graph 12). When asking Knowles how to mitigate cannibalization, he explicitly mentions co-location systems as a solution "I do not think cannibalization will hinder the growth of renewables, but it certainly will usher in a requirement for co-location sooner than later" (Knowles, 28.03.23).

Graph 12. Illustration over time-shifting with perfect foresight



Note: The spot price corresponds to the right side, while the other variables correspond to the left y-axis. The light green area is the amount produced by a solar facility, while the red line shows what is being sold to the market. The blue bars are the amount charged, while the green bars are the amount of electricity discharged from the battery and sold to the market.

One of the most vigorous counterarguments for using batteries is the cost aspect. The capital expenditure of a battery is substantial, which puts limitations on its size and capacity. Esser shares his view of this matter "I actually do not believe in using batteries to avoid cannibalization. The battery capital expenditure is simply too expensive for that" (Esser, 24.03.23). Moreover, Sjöberg explains that time-shifting is not currently being discussed in the market as a primary reason for investing in batteries; instead, other revenue streams have dominated the conversations (Sjöberg, 17.03.23).

There are also technical limitations to hedging with batteries. Storing electricity comes with time constraints and energy losses. Compared to storing other commodities, such as oil, the storage duration of electricity is much lower. Currently, batteries' typical energy storage duration is 2-4 hours, which implies that they can only utilize intraday volatility and not seasonal price differences (Esser, 24.03.23). Increasing the duration would result in a non-justifiable investment cost. Additionally, storing energy also consumes energy and some is lost along the way (van Asseldonk, 09.03.23)

Another drawback of adding a battery is the existing information asymmetry of this asset class in the market, which creates difficulties for OX2 to obtain maximum value. Van Asseldonk explains this dilemma and how it impacts the willingness to pay for an investor "One limitation of the business case is the scarcity of investors with the technological knowledge of batteries. When a battery is added to a project, the required rate of return for investors for the battery component of the asset increases, which might lower the entire project's value. This is because many investors are not yet comfortable with batteries as technology and operational risks are perceived as higher than for solar energy" (van Asseldonk, 09.03.23).

Furthermore, adding a battery to a project requires associated permit grants and grid connection, which are not always possible to secure. When evaluating the possibility of a battery, it is important to be proactive due to the long lead times in the industry. Estimations on future cannibalization need to be thought of and handled today. Van Asseldonk explains "One reason for the urgency is that it takes several years to develop large-scale solar projects. We believe cannibalization in 2-4 years will be so large in markets like Italy that you must add batteries to every project today. If you want a permit to build batteries in 2-3 years, you must start developing them now. They must be included in the permitting and grid connection processes. To be profitable in large solar projects in 2-3 years, you need to add batteries now" (van Asseldonk, 09.03.23).

5.3.2.2 Pooling of Projects

Transferring from individual project financing to corporate financing was proposed in several interviews. This means that instead of funding projects individually, debt and equity is secured on a firm level. The evolution of actors in the market has changed their financing situation. The renewable energy market has significantly grown in the last ten years, substantially enlarging the actors in the industry (Beisland, 17.03.2023). In line with Berk and DeMarzo's (2021) explanation of hedging, diversification through pooling several projects can be considered an operational hedge. Some risks, such as cannibalization and technology risks, are further spread out when acquiring different VRE technologies. Additionally, since most VREs have different production profiles, they benefit differently from price movements.

Olli Hagqvist explains that the need for financing differs between investor types. Financial buyers like pension funds are likelier to use PPAs to secure financing, while power utility investors can secure financing through corporate financing (Hagqvist, 2023.03.29). Stabilizing a company's cash flows becomes more manageable with an increased number of technologies and projects. Large power utility companies like Vattenfall own various power-producing technologies with different profile risks, including nuclear, hydro, wind, and solar. The total profile of these companies enables the ability to take debt at a company level rather than a project level. Hence, the risks associated with PPAs decrease as the portfolio creates flexibility (Beisland, 17.03.2023).

The benefit of project financing has been that it has enabled small actors to enter the market with relatively little capital (Beisland, 17.03.2023). The risk is also limited to the individual project in case of financial distress and bankruptcy compared to the possibility of spreading to the whole firm if corporate financing was used. However, the interest rate in the financing options will most likely differ due to the difference in collateral. There is also greater flexibility to choose financing structures when having a pool of assets since you retain the possibility to finance specific projects individually but also can assort to financing on a company level.

There are also limitations to pooling assets. If the production correlation is high, the exposure to the spot market will not significantly change and the diversification effect will be limited. Therefore, various technologies and geographical spacing are needed to achieve positive pooling results.

6. Discussion of the Case

In this segment, a discussion of the results is carried out. There are different views on the magnitude of the risks and implications. The reasoning behind the various arguments is presented in 6.1. A few noteworthy differences between operational and financial hedging strategies are stated in 6.2. Moreover, a discussion over the limitation of the study is carried out in segment 6.3.

6.1 The Risks & Following Implications

When looking at the historical construction patterns for wind and its effects on spot prices, similarities can be drawn between the two technologies. Solar power may be in the same stage as wind was a decade ago. Many actors in the industry have pointed out that the risks covered in this thesis were not fully considered back then and it is possible that the same is taking place for solar. Even though cannibalization is not tangible in Sweden currently, investors must consider the development over the 40-year lifetime of a solar facility.

Based on the interviews, the consensus is that cannibalization will negatively affect the revenue of solar facilities in SE4. However, there is no common perception of when it will happen or to what extent. Many market participants are likely to underestimate the cannibalization risk by not considering imported effects, the parallel expansion of residential solar and the simplicity of deployment compared to other VREs. Inaccurate predictions of cannibalization may cause a greater divergence between the price paid during acquisitions and the price received at divestment, negatively affecting OX2's margins. Moreover, the anticipated increase in volatility due to the VRE expansion is in line with Hain et al. (2018) finding that the growth of VREs increases price and quantity risk, making unhedged portfolios riskier due to larger fluctuations in cash flows.

Although solar expansion leads to cannibalization, it also brings positives to the industry. A crucial viewpoint is that a rise in the number of investors within the renewable energy sector facilitates OX2's sales process by creating a more liquid market. Additionally, as the industry expands, technology risks decline and investors become more familiar with the asset. Existing solar technology becomes proven and the necessary actors in construction and operation become increasingly established. Accordingly, investors face reduced risks when entering this relatively immature industry.

OX2 does not own operational assets. However, it is reasonable to assume that the investors' risk exposure ultimately affects OX2's business. Hence, it is beneficial for OX2 to facilitate investors in risk-mitigating strategies. This can be done from OX2's side by, for instance, supporting negotiations of PPAs or developing batteries if needed. Capital structure adjustments and pooling of projects, however, lie solely on the investor. The evolving market dynamics suggest that the industry will see more pooling of assets and equity transactions going forward. Nonetheless, OX2 will be affected by the outcome of this development as well. For instance, the effects of the recent increase in interest rates have already been observed in the market. Higher interest costs have reduced the amount of debt financing significantly. Carl Ferm also explains that it implies that the spread between the cost of equity and debt has reduced, making the returns smaller for leveraged equity (Carl Ferm, 02.03.23). Since many investors in this sector rely on debt financing, this will likely slow down the expansion of solar.

Furthermore, regulatory barriers currently limit the build-out of solar in southern Sweden. Knowles points out the existing regulatory hurdles of converting farmland in Sweden and argues that it will likely hinder the pace of solar expansion. Further reasoning, cannibalization is unlikely to approach levels observed in other markets (Knowles, 2023.03.29). Hagqvist also discusses the impacts of potential legislation in the field. One proposal on an EU level is that for hydrogen to be classified as green, electricity consumed by hydrogen production will need to be hourly matched by the production of VRE. This creates demand for matching production and consumption profiles, making PAP contracts more attractive (Hagqvist, 29.03.23). As seen in this example, legislation can change the preferences of producers and offtakers, disrupting the trends and mismatch of preferences today.

6.2 Comparing Financial & Operational Hedging

A PPA contract does not reduce the cannibalization risk but transfers it to the counterparty, while a battery can partially decrease the underlying risk. Similarly, a battery can reduce price volatility by better synchronizing supply and demand in the system. Operational hedging has many advantages that financial hedging lacks, such as fundamentally reducing the risk of cannibalization, but is limited by technical limitations like storage capacity and duration. Batteries are not a tool for inter-seasonal storage since they cannot store energy over a longer time. There are also technical limitations to how often a battery can be charged and discharged daily. Moreover, increasing these capabilities comes at a higher capital expenditure, which is likely to lead to a similar conclusion made in Staffell and Rustomji’s (2016) study, where they found that the investment cost of batteries is too high for only performing time-shifting.

Building on this, the cost aspect is essential when comparing the strategies. Operational hedging requires substantial capital investment and ongoing maintenance costs. There is no such significant cost associated with a PPA contract. Instead, there are costs related to guarantees, transaction fees and the discount applied to the price (Hagqvist, 29.03.23). Hain et al. (2018) reasoned that financial hedging is the only liquid alternative in the energy market, which currently holds because of the high cost and the limited number of battery storage developed in Sweden.

PPA contracts have functioned well historically when penetration levels of VRE have been lower. However, it has become more challenging for producers to hedge through PPA contracts because offtakers are less willing to bear the growing cannibalization risk and, therefore, less willing to sign PAP contracts. At the same time, producers are getting more reluctant to sign Baseload contracts because of the increasing cost of volume risk. External shocks like the present energy crisis have also proven costly for many actors with binding contracts. These costs are related to the imperfections discussed by Boyabatli and Toktay (2004) and prove that hedging can provide firm value if done thoughtfully. However, it has also shown that PPAs are inflexible and that the performance of the contracts can differ significantly with deviations from normal market conditions, which affirms Berk and DeMarzo’s (2020) argument that hedging rarely provides complete protection from risks.

On the contrary, Knowles describes how companies with co-located solutions have benefited from the recent development “They were certainly able to make a lot of money during this period because of the volatility and the arbitrage opportunity presented, anybody who had an operational asset in the last few years has been doing very well” (Knowles, 28.03.23). This shows that a battery is more agile and capable of utilizing external shocks like price and volatility spikes. However, Semkin argues that building a business case around protection against external shocks, like the current energy crisis, is challenging because they rarely occur (Semkin, 12.04.23).

A mutual disadvantage with both hedges is the insufficient protection provided and the consequences of this. A solar park's lifetime is longer than a battery's and a standard PPA of 10 years. The protection from these hedges is, therefore, incomplete. At maturity, a new PPA or battery must be signed or installed, which presents a long-term risk because of the complexity of predicting the market situation so far ahead. However, mitigating this risk can become costly, considering Berk and DeMarzo’s (2020) finding that hedging during longer periods is very expensive.

Furthermore, it is essential to discuss the classification of the pooling of projects. It can be seen as a financial or operational hedge depending on the actor and the pool of assets. The reason for it to be classified as a financial hedge is if the goal is to manage financial risks associated with, for example, investments or energy price fluctuations. Mitigation of these risks is then done by diversification through financial investments limiting the exposure towards a single asset. The different production profiles of assets create a variety of production times and exposure to the market at different hours of the day.

Pooling can also be seen as an operational hedge if used as a mechanism to secure a physical delivery of electricity. Corporate investors can, for example, use pooling to secure energy for production in their operations. By securing multiple assets, their reliance is less on one production site. This strengthens the findings of Radchik et al. (2013), who found that combining multiple energy sources is appropriate due to their complementary production patterns. Power utility companies can also use pooling to secure physical delivery to fulfill obligations in PPA contracts. They can then use their diversification of production from different technologies and geographical places to ensure that their obligations are met. This shows the critical interplay between operational and financial hedging, which Kim et al. (2006) argued was fundamental for providing firm value.

The drawback of pooling compared to financial hedging is the capital required for obtaining ownership of multiple assets with various technologies. The size of the portfolio limits this option to actors with sufficient capital. It is also hard to combine with lower leverage as it would require a substantially higher amount of equity. Additionally, pooling requires expertise within fields that are technically very different. The size of the organization needed is, therefore, substantially larger. It also takes time to build up a portfolio of assets indicating that the actor has spent adequate time in the field to implement this.

6.3 Limitations of the Results & Future Research

The recent happenings in the electricity market must be considered when analyzing the results. According to Beisland, last year was unique and it is, therefore, hard to generalize the findings from this period. If gas prices had been at normal levels, volatility and spot prices would have been much lower, which would perhaps postponed the discussion of battery storage. Moreover, Beisland speculates on the future scenario for electricity prices "Prices will go down, but there is also a lot of gas from Russia that will not return. We will see higher gas prices than we have had historically" (Beisland, 17.03.2023). As explained earlier, higher gas prices imply more expensive electricity. This can encourage European countries to accelerate the transition toward renewable energy and more self-sufficient energy production.

Another critical point is that although capture factors have decreased due to cannibalization, the recent increase in spot prices has also boosted capture prices. The price estimates for the coming years are still higher than historical prices due to the war in Ukraine and the subsequent effects. In the short term, this has increased the profitability of OX2’s projects. Therefore, decreasing capture factors have not been realized to lower capture prices compared to historical numbers. This has postponed the immediate need for solutions associated with decreasing value factors. Electricity prices are estimated to normalize at the decade’s end and decrease afterward. This, combined with decreasing value factors for solar, would indicate an increasing interest in hedging solutions.

It is also important to remember that time-shifting is just one of the multiple revenue streams a battery can provide. Therefore, the value added from this specific service should not be compared to the cost of a battery since this would give an unfair view of the profitability. Other revenue streams, such as providing ancillary services, are outside the scope of this thesis but are mentioned to give a correct depiction of the business case. Semkin is convinced that ancillary services will become saturated in the foreseen future, forcing battery owners to become creative regarding revenues, potentially increasing the activity of time-shifting (Semkin, 12.04.23). Knowles elaborates on the potential fallback for ancillary services “I think over time what you see is eventually the storage catches up to the problem, which is regulating the frequency. It is supply and demand. If you have too many batteries offering that service, then it is likely to collapse the pricing” (Knowles 2023.03.28).

Financial modeling of batteries in the Swedish market and exploring how different revenue streams can be combined is an interesting field for future research. For instance, modeling a battery into a historical solar site to see the economic effects would provide an exciting insight into profitability. Revenue optimization for a battery is a field where understanding is still limited. This will also become a more relevant topic as the market for ancillary services becomes saturated and the pressure increases to find alternative revenues.

Furthermore, the combination of financial and operational hedging in the electricity market is also an unexplored territory that would be interesting to investigate closer. Co-locating a battery and solar facility will affect multiple risks and quantifying these risks and synergies would constitute an interesting thesis. For instance, examining how the combination of PPA and batteries would affect the volumes and types of contracts signed. As batteries are better understood, specific PPA contracts may be explicitly designed for this technology.

7. Conclusions

The ambition of the thesis has been to provide an in-depth understanding of the long-term risks associated with the increasing investments of VREs, its implications for OX2 and the effect of different hedging strategies. Considering the lack of research and the nascency of the topic, empirical evidence has been complemented with insightful comments from experienced market participants.

Cannibalization in Sweden has emerged, with only minor effects observed in SE3 and SE4 so far. However, due to the interconnection of European markets and the rapid expansion of VRE, cannibalization is anticipated to accelerate. Additionally, the reliance on weather-controlled energy production is expected to increase price volatility. The potential consequences have been discussed, including value reduction of projects, more complex asset pricing and a shift in OX2's customer base. While OX2's ability to prevent this is limited, efforts should be made to facilitate investors to mitigate the long-term risks in the market.

Financial hedging offers the possibility to transfer risks to the counterparty but at the cost of lowering prices obtained in PPAs. Similarly, implementing capital structure adjustments by reducing the leverage in projects will strengthen the firm's resilience to volatile cash flows. Investors signing PPA contracts will need to have more knowledge today than previously. This is because the volatility in the market creates a greater spread between PPA and market prices, which has proven very costly during the current energy crisis. The pricing of various PPA risks is also probable to be refined as the risks are better understood in the market.

Currently, operational hedging requires a high up-front cost unlikely to justify the reduction in the underlying risk or generate additional revenue to suffice the investment cost. However, battery storage has proven beneficial during the energy crisis. Nevertheless, the industry is generally pessimistic about using batteries solely for time-shifting because of the high cost and the perception of the crisis as a rare event. Most interviewees agree that time-shifting will be increasingly crucial in maximizing profits if the ancillary market becomes saturated. This trend is also expected if the costs of batteries come down significantly. Furthermore, pooling of projects can increase with the industry's growth and the actors operating in it, which would help mitigate individual projects' profile and volume risk.

To conclude, the study provides valuable insights into the evolving risks stemming from the VRE expansion and the challenges this brings for different market actors. The thesis explores the mitigating factors of financial and operational hedging and highlights the advantages and disadvantages of the methods. While our thesis has provided a greater understanding of the topic in a qualitative sense, future research is needed to quantify the risks and solutions to develop a greater understanding of their effects.

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9. Appendix

Appendix 1. Regression of capture factor and generation

Variable	Value factor
Generation	-0,014***
Constant	0,905
Observations	38
R-squared	0,729

Note: The table above summarizes the regression of the independent variable *Generation* associated with the dependent variable *Capture Factor*. *** $p<0.01$