Off-site PPA as a tool to protect against electricity pricespikes: developing a framework for risk assessment and mitigation

Karolina Anna Kapral

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Supervisors: Prof. Rui Manuel Gameiro de Castro

Dr. Kobe Soetaert

Examination Committee

Chairperson: Prof. Susana Isabel Carvalho Relvas

Supervisor: Prof. Rui Manuel Gameiro de Castro

Member of the Committee: Prof. Hugo Gabriel Valente Morais

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I declare that this document is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the *Universidade de Lisboa*

Abstract: English

This dissertation was developed in collaboration with E&C Consultants, an international energy procurement consultancy, to gain a deeper understanding of the impact of the energy crisis on Power Purchase Agreements (PPAs). Electricity price spikes occurred as early as 2021, initially driven by low gas storage levels, a post- pandemic economic rebound and then exacerbated by the Russian invasion of Ukraine. The situation had a range of consequences, from rising inflation, increasing energy poverty, food insecurity, and recession. PPAs are a well-known tool to protect energy consumers from price spikes, while at the same time contributing to the sustainable technologies. PPAs are long-term bilateral contracts for the purchase and sale of electricity, usually generated from renewable sources. Volatility in the energy market in 2022 negatively affected the PPA market, causing a rise in prices by up to 10-15% only in the first quarter of 2022 and development of a new trends. The primary goal of this Master's Thesis is to assess how the risk associated with PPAs has evolved between 2020 and 2023. It aims to examine whether, after the events in 2022, PPAs remain a robust solution that protects the off-taker from energy price spikes, ensures greater energy budget stability, and enables savings. To achieve this, the probability of PPA prices being higher than market prices is evaluated. Furthermore, this Thesis intends to gain a thorough understanding of each risk related to PPAs and the best strategies for mitigating it, in order to maximize the protection of the off-taker.

Keywords

Power Purchase Agreement, Risk Assessment, Monte Carlo Simulation, Energy Crisis

Abstract: Portuguese

Esta dissertação foi desenvolvida em colaboração com a E&C Consultants, uma empresa internacional de consultoria em contratos públicos de energia, para compreender melhor o impacto da crise energética nos contratos de aquisição de energia (CAE). Os picos de preços da eletricidade ocorreram já em 2021, inicialmente impulsionados por baixos níveis de armazenamento de gás, uma recuperação económica pós-pandemia e depois exacerbados pela invasão russa da Ucrânia. A situação teve uma série de consequências, desde o aumento da inflação, o aumento da pobreza energética, a insegurança alimentar e a recessão. Os CAE são uma ferramenta bem conhecida para proteger os consumidores de energia dos picos de preços, contribuindo ao mesmo tempo para as tecnologias sustentáveis. Os CAE são contratos bilaterais de longo prazo para a compra e venda de eletricidade, geralmente produzida a partir de fontes renováveis. A volatilidade do mercado energético em 2022 afectou negativamente o mercado dos CAE, provocando um aumento dos preços até 10-15% apenas no primeiro trimestre de 2022 e o desenvolvimento de uma nova tendência. O principal objetivo desta Tese de Mestrado é avaliar a evolução do risco associado aos CAE entre 2020 e 2023. Pretende-se analisar se, após os acontecimentos de 2022, os CAE continuam a ser uma solução robusta que protege o off-taker dos picos de preço da energia, garante uma maior estabilidade do orçamento energético e permite poupanças. Para o efeito, é avaliada a probabilidade de os preços dos CAE serem superiores aos preços de mercado. Para além disso, esta Tese pretende conhecer em profundidade cada um dos riscos relacionados com os CAE e as melhores estratégias para os mitigar, de forma a maximizar a proteção do off-taker.

Keywords

Contrato de aquisição de energia, avaliação de riscos, simulação de Monte Carlo, crise energética

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List of Abbreviations

BRP - Balancing Responsible Party

CDS - Credit Default Swaps

CDS - Credit Default Swaps

CAPEX - Capital Expenditure

COD - Commercial Operation Date

CfD - Contract for Difference

EOE - Estimated Operating Efficiency

EPC - Engineering, Procurement, and Construction

LNG - Liquefied Natural Gas

LoC - Letter of Credit

MAC - Material Adverse Effect Clause

OPEX - Operating Expenses

PAP PPA - Pay-as-Produced Power Purchase Agreement

PCG - Parent Company Guarantees

POI - Point of Interconnection

PPA - Power Purchase Agreement

REP - Retail Electricity Provider

TSO - Transmission System Operator

VFA - Volume Firming Agreement

VPPA - Virtual Power Purchase Agreement

Wh - Watt-hour

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1. Introduction

In 2022, the global energy markets encountered an extraordinary surge in price levels with consequences that are expected to have a lasting impact for years to come. The evident price increase was not attributed to a single factor, but rather resulted from a sequence of events starting in 2021.

Firstly, following the economic slowdown caused by the COVID-19 pandemic, the end of lockdown resulted in the rapid recovery of various industries and businesses. Removing restrictions on mobility and travel led to a revival of the transport sector. Companies that had previously been blocked by lockdown protocols were finally able to resume their activities. As a result, demand for all forms of fossil fuels increased by at least 5% in 2021. In this situation, insufficient supply put increased pressure on the global supply chain, consequently affecting energy prices (World Energy Outlook 2022).

Secondly, major natural gas suppliers such as Gazprom reduced their short-term volumes and did not refill their storage facilities in Europe to the levels seen in previous years. This shortage exacerbated the market reaction when, in December 2021, Europe was struck by negative temperatures (World Energy Outlook 2022).

Thirdly, weather-related events had a major impact on the trends of demand and electricity production. Some of the major impacts included droughts in Brazil, which significantly reduced hydropower production, causing imports of liquefied natural gas (LNG) to increase threefold from the previous year. In addition, heat waves in France reduced the availability of nuclear power, due to the limitations of the allowed temperature at which the water that is cooling a reactor can be returned to a river. Moreover, lower than average wind speeds affected overall wind power output in Europe (World Energy Outlook 2022).

Further reasons that have increased the pressure on energy prices include the postponement of some maintenance work until 2021 due to the pandemic, leading to disruptions in energy supply. For example, natural gas markets have been affected by unplanned outages at LNG liquefaction plants, unforeseen repair work and various project delays (World Energy Outlook 2022).

The already pronounced strain on the global supply chain and energy price dynamics experienced an escalation on February 24, 2022, when Russia invaded Ukraine. This event not only caused tremendous damage to the Ukrainian energy sector, but also had a far-reaching impact on the global energy system, disrupting supply and demand dynamics and severing long-standing trade relationships. Russia is the world's largest exporter of fossil fuels, particularly important for Europe, where in 2021 one in five units of energy was supplied from Russia. The substantial reliance of European nations on Russian resources, coupled with the constrained availability of alternative energy sources, has subjected the energy supply to considerable strain. Moreover, Russia has sought to use its position as an export leader to influence European countries, exposing consumers to higher energy bills and supply shortages. Europe, in turn, imposed sanctions on fuel imports as a tool of political pressure and a sign of support for Ukraine, thus seeking to reduce Russian energy export revenues and discourage them from further aggression. These actions have cut off one of the main arteries of global energy trade, demonstrating the extreme vulnerability, fragility, and unsustainability of the energy system, having significant and widespread consequences in various sectors (World Energy Outlook 2022).

As European electricity prices are closely linked to wholesale gas prices, both commodities have experienced significant spikes and volatility. For instance, in the first quarter of 2022 the average monthly wholesale gas price exceeded 120 €/MWh, which was six times the historical average (Bohmert, Bosquet, Gonzalez, & Veillard, 2022).

High energy prices had a major impact on inflation, exacerbating a phenomenon of energy poverty and food insecurity, with the greatest burden falling on poorer households. Nearly 100 million people faced the risk of reusing firewood for cooking instead of cleaner and healthier alternatives. Furthermore, several industries have been unable to withstand rising energy costs, leading to reduced operations, factory closures, financial insolvency and ultimately contributing to the recession (World Energy Outlook 2022).

The energy crisis and its consequences led to a reassessment of energy security needs in many countries and a profound shift in the investment landscape. At the 26th Conference of the Parties (COP26), governments made a set of commitments to sustainability and redefined their energy strategies. The European Commission published the REPowerEU plan, which aimed to end Europe's dependence on Russian fossil fuels well before 2030 (World Energy Outlook 2022).

One of the strategies formulated by the European Commission in line with the REPowerEU plan aimed to accelerate and facilitate authorization procedures for Power Purchase Agreements (PPAs), thus reducing one of the major obstacles to their development. Through PPAs, energy consumers can be protected from energy price spikes while contributing to the development of environmentally friendly technologies. PPAs are long-term bilateral contracts for the purchase and sale of a certain amount of electricity. In most cases, this energy is generated by renewable sources such as photovoltaic installations or wind turbines (World Energy Outlook 2022; De Meulemeester, 2019).

The importance of Power Purchase Agreements as a tool to stabilize prices and contribute to the achievement of clean energy is evident in some of the European Commission's actions. For example, the Commission, in cooperation with the European Investment Bank (EIB), planned to set up a technical advice facility within the InvestEU Advisory Hub to support renewable energy projects financed through PPAs and increase their total volume. By increasing the number of Power Purchase Agreements, the share of renewables in the grid will increase, leading to reduced dependence on fossil fuels and increased energy security (EU Solar Energy Strategy, 2022; Short-Term Energy Market Interventions and Long-Term Improvements to the Electricity Market Design – a course for action, 2022).

Nevertheless, the volatility in the energy market in 2022, affecting all sectors of the economy, has not spared the PPA market either. The energy crisis has not only increased the price of PPAs but has also resulted in significant changes in their structure. For instance, Zeigo and S&P speculated that depending on a market, PPA prices in the first quarter of 2022 increased even by 10-15% (Zeigo and S&P Global Platts PPA Pricing Report, 2022). Evidently, such an environment was not ideal for the negotiation of PPAs, which influenced the formation of new trends related to certain parameters, such as the duration of the PPA or pricing mechanisms. In addition, risk management and the development of an appropriate purchasing strategy became even more important (World Energy Outlook 2022). The aim of the dissertation is to develop, together with E&C Consultants, an assessment framework to quantify the risks associated with PPAs and their developments caused by energy crisis. E&C Consultants is an energy procurement consultancy, offering services related to managing energy portfolios for industrial clients, monitoring energy market developments, and providing services in the field of risk management and sustainable development. E&C Consultants has contributed to the conclusion of many Power Purchase Agreements (PPA) worldwide, providing specialized knowledge in this field (E&C Consultants, 2023).

The primary goal of this Master's Thesis is to assess how the risk associated with Power Purchase Agreements (PPAs) has evolved between 2020 and 2023. It aims to examine whether, after the events in 2022, PPAs remain a robust solution that protects the off-taker from energy price spikes, ensures greater energy budget stability, and enables savings. To achieve this, the probability of PPA prices being higher than market prices is evaluated, considering the changing market landscape. Furthermore, this Thesis intends to gain a thorough understanding of each risk related to PPAs and the best strategies for mitigating it, in order to maximize the protection of the off-taker.

This Master´s Thesis begins with a state-of-the-art review of Power Purchase Agreements (PPAs), as presented in Chapter 2, including their definition and main types. Due to their greater complexity, this dissertation focuses on off-site PPAs. Subsequently, Chapter 3 analyzes the risks associated with PPAs and the most popular strategies for mitigating them. In Chapter 4, a market study of PPAs is presented, centering on the evolution of PPAs in 2022 influenced by the energy crisis. Chapter 4 also examines new trends in 2023 to compare how parameters associated with Power Purchase Agreements changed in response to the relative decline and stabilization of electricity prices. Chapter 5 contains the risk evaluation, using Monte Carlo simulation to assess the probability of PPA prices surpassing the market price from 2020 to 2023. Chapter 5 also determines the benefits of these contracts before, during, and after the energy crisis. In the simulations, Spain, known for its prominent role in PPA agreements, and Germany, with differing market characteristics and fewer PPA agreements, are analyzed. Chapter 5 concludes with a summary of simulation results and a discussion. This Master’s Thesis ends with the Chapter 6, presenting a conclusion of all the findings.

2. Overview of Power Purchase Agreements

To gain an in-depth understanding of the correlation between Power Purchase Agreements (PPAs) and power market prices, it is first necessary to comprehend the definition and characteristics of PPAs. The following section provides a state-of-the art overview of PPAs, providing a definition and description of their types, broken down by point of delivery, settlement method, supply profile, inclusion of residual and balancing energy, pricing mechanism and geographic scope.

2.1. Definition of PPAs

PPAs are bilateral contracts for the purchase and sale of a certain amount of electricity, typically from renewable sources at an agreed tariff over the contract period. PPAs are long-term agreements, which in the past were commonly concluded for 10-20 years. Currently, due to price risk and market volatility, this period is being shortened and the most common models are 6-10 or 4-5 years (Kanellakopoulou M.).

PPAs are also an effective financial instrument for both sellers and buyers of energy. For the former, they secure revenues at a certain level in the future, reduce price risk and uncertainty associated with the large upfront investment cost (CAPEX) when building a renewable power plant. For the latter, PPAs provide greater price stability, may act as a hedge against fluctuating energy prices, allow for budget planning and provide long-term savings (De Meulemeester, 2019).

PPAs have several parameters to be determined before the contract is concluded such as the length of the agreement, the pricing mechanism, or the energy supply limit. The selection of the suitable PPA depends on the company's business model and is determined after a thorough risk analysis (Mendicino, Menniti, Pinnarelli, & Sorrentino, 2019).

Of the many types of Power Purchase Agreements, the fundamental and best-known division is between on-site and off-site PPAs. In the case of on-site PPAs, the installation is located on the off-taker's premises and no distribution network is required to transport the electricity to the consumer. On-site PPAs are typically smaller projects, such as photovoltaic panels on rooftops, windmills, or small biomass power plants. Despite their smaller capacity, they have significant savings potential, because of the avoidance of grid charges and regulated tariffs. Such costs can account for as much as one-quarter to two-thirds of the total cost of the electricity bill. Additionally, on-site installation can reduce energy consumption during peak hours, minimizing the overall cost. Furthermore, the energy consumed from on-site PPAs is unquestionably green and the customer does not need to additionally purchase Energy Attribute Certificates (EACs). On the other hand, the variable nature of renewable generation leads to lower load duration, which means that less time during the day the required load is met. This results in higher surcharges and increased profile costs for the remaining MWh of grid electricity (De Meulemeester, 2019).

In the case of off-site PPAs, the installation is located far from the consumer, which means that electricity must be transported through the distribution network. For this reason, grid charges and tariffs cannot be avoided, and all the savings potential lies in the commodity part. Off-site PPAs are usually larger projects, such as wind turbine fields with high power output and large amounts of energy, which must be balanced during periods of under- and overproduction. If the wind turbines produce too much energy, it must be resold on the spot market, while in the opposite case the energy must be purchased. This is an additional aspect that affects the overall price of the PPA. In general, off-site PPAs may generate less savings in terms of price per MWh, but given the size of the project, they can be very beneficial to the company. Off-site PPAs are characterized by greater complexity in terms of different delivery points, settlement methods, delivery profile, pricing mechanisms and geographic coverage. For this reason, this dissertation focuses on off-site PPAs, which will be described in more detail in the sections below (De Meulemeester, 2019).

2.2. PPAs typology

Selection of the most suitable PPA for a particular enterprise is crucial to avoid getting locked in long-term contracts with an energy price significantly above the market price. Such a situation can lead to a lack of competitiveness and ultimately bankrupt the company. For this reason, the PPA structure is chosen only after a detailed risk assessment and examination of all conditions. The following section describes the different types of PPAs including their features, advantages, and disadvantages. In addition, along with a description of each typology, the main PPA risks are listed and will be described in more detail, along with mitigation strategies, in the section 3 (De Meulemeester, 2019). The characterization is carried out according to the classification shown in Table 1.

Table 1. Types of off-site PPAs (De Meulemeester, 2019).

Delivery Point	Entry		Exit	
Settlement Method	Physical (sleeving)	Financial (swaps)		
Delivery Profile	As produced- real or synthetic		Baseload	As consumed
Residual & Balancing Energy	Included		Not included	
Pricing Mechanism	Fixed price: one-shot or with escalation		Spot with discount	Floors / caps / collars
Geographical Scope	In the country		Cross-border	

2.2.1. Delivery Point

In the case of off-site PPAs, energy is generated far from the end user and therefore must be transported through the distribution network. Depending on the point of delivery, which is where the generation facility is connected to the grid, PPAs with delivery at the point of exit and at the point of entry can be distinguished (De Meulemeester, 2019).

Under a PPA with delivery at the exit point, which is where the consumer's facility is connected to the grid, the seller is responsible for transportation through the distribution network. This option is less popular due to the challenges of having two suppliers at a single point of connection (De Meulemeester, 2019).

The second option is a PPA with delivery at the point of entry, which is where the production facility is connected to the grid. In this case, the seller is not responsible for transporting electricity to the end user and the energy sent through the distribution network is settled in different ways, described in detail in the subsequent part. (De Meulemeester, 2019).

2.2.2. Settlement Method

Under a PPA with delivery at the point of entry, there are two options for settling the energy transmitted over the distribution line: physical through sleeving and financial through swaps.

A Power Purchase Agreement with a physical settlement method, also known as a sleeving PPA, involves the integration of energy generated from a renewable power plant into a conventional power supply contract by a supplier. In this scenario, the supplier assumes responsibility for balancing the energy supply and managing related pricing aspects. Figure 1 presents a scheme of a sleeving PPA.

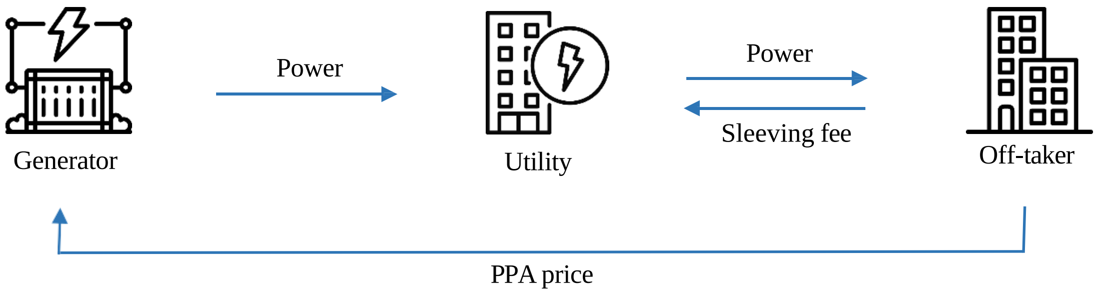


Figure 1. Scheme of a sleeving PPA.

The second method of accounting for energy transmitted through the distribution network is financing through swaps. In this model, a third-party buys energy at the entry point at SPOT prices to then resell it at the exit point at SPOT prices. Energy is sold and bought at the same spot price for each MWh, so the effect of these transactions is neutral (De Meulemeester, 2019). Figure 2 shows a scheme of PPA financed through swaps.

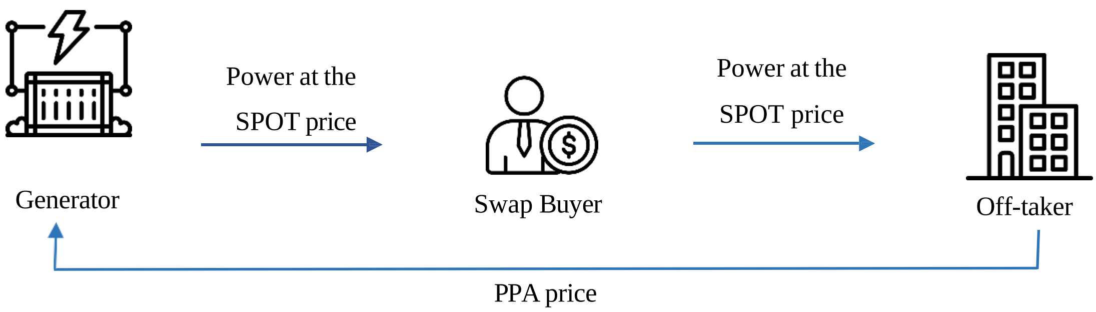


Figure 2. The scheme of PPA financed through swaps.

One type of financial PPA is the Virtual Power Purchase Agreement (VPPA), also known as a contract for difference (CfD) or fixed-flow financial swap. This contractual agreement acts primarily as a financial instrument and does not involve the physical transfer of energy from the project developer to the buyer. The agreement requires a mutual consensus between the parties involved on a fixed PPA price and a predetermined settlement period, usually a month or quarter. During this interval, the developer sells energy on the wholesale market at a specific clearing point, such as a hub or load zone, at a variable market price. The developer then calculates the difference between the variable market price and the predetermined VPPA price, typically for each hour of the billing period. If the cumulative value is positive at the end of that period, the developer pays the buyer the difference. Conversely, if the cumulative value shows a negative value, the buyer pays the developer the amount of the discrepancy. This structural framework ensures that the project consistently receives the agreed VPPA price for each megawatt hour, thus strengthening the financial stability of the parties involved. It is important to recognize that while the VPPA does not involve the physical transmission of electricity, nevertheless it imposes a binding obligation on both the buyer and seller to procure and sell a predetermined amount of electricity specified in the agreement (Starsia, 2019; Virtual PPAs: the shift from hassle to bustle, 2022).

Virtual Power Purchase Agreements are very beneficial for both the buyer of energy and the project developer. For the former, an important benefit is the ability to purchase Energy Attribute Certificates (EACs), which confirm the renewable origin of electricity. Each EAC contains information on when, where, and how 1 MWh of electricity was generated, and by purchasing it, companies and end users can confirm the green nature of their energy consumption. EACs are issued, sold, and cancelled through a central registry, often managed by the transmission system operator (TSO). Depending on location, several standards are currently implemented (Sotos, 2015).

In Europe, the prevailing system involves Guarantees of Origin (GOs), which are issued, sold, and cancelled in countries belonging to the European Energy Certificate Scheme (EECS) (Renewable Energy Guarantees of Origin). This system is currently in operation in more than 20 European countries, including France, Sweden, and Germany. Conversely, the United States and Canada use Renewable Energy Certificates (RECs), while the International Renewable Energy Certificates (I-RECs) are adopted in countries that do not have an EAC system (Center for Resource Solutions; The International REC Standard Foundation, 2020). Figure 3 presents where each certification system is applicable.

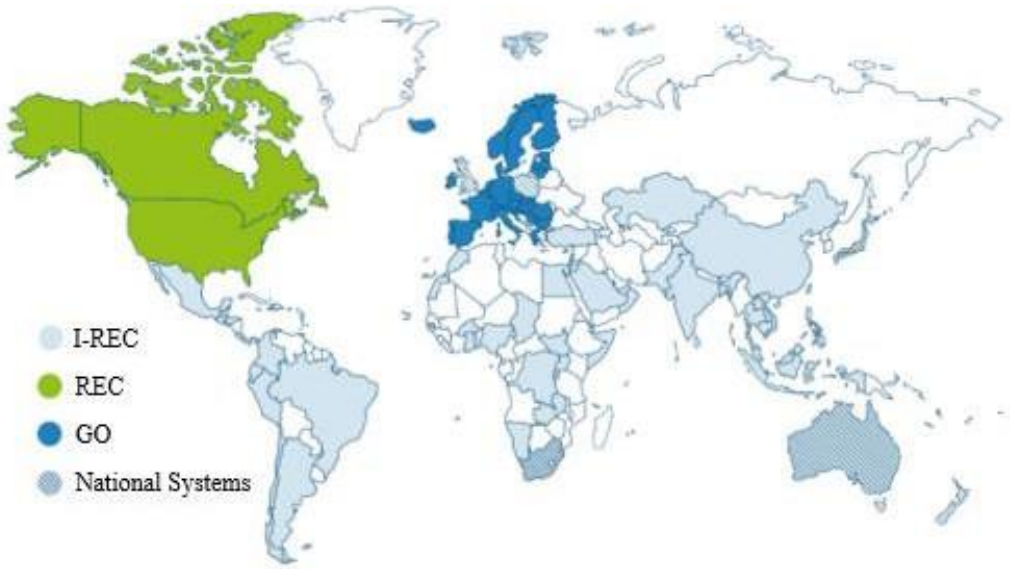


Figure 3. Overview of various certification systems (First Climate, n.d.).

The structure of virtual PPAs is beneficial to both the developer and the energy buyer, as it provides price certainty. From the developer's point of view, setting a minimum energy price is of significant value, especially for project financing. For the corporate buyer, on the other hand, concluding a virtual PPA is not only in line with sustainable development goals, but also serves as a hedge against price fluctuations in the electricity market. It is important to mention that obtaining EACs is not limited to Virtual PPAs, as they can also be purchased separately. However, the acquisition of these certificates under the vPPA provides an incentive for the construction of new renewable power plants and a contribution to sustainability efforts. When EACs are acquired through a traditional bidding process, they are sourced only from existing renewable installations, without the additionality of the development of new projects (Marks & Rasel, 2014).

Moreover, for VPPA the power buyer may be located on different power grid as the renewable power plant, as there is no physical delivery of power. For this reason, virtual PPAs are not constrained by a specific, limited location, which creates great potential for cross-border PPAs (Collell, 2023). Figure 4 represents a scheme of Virtual Power Purchase Agreement.

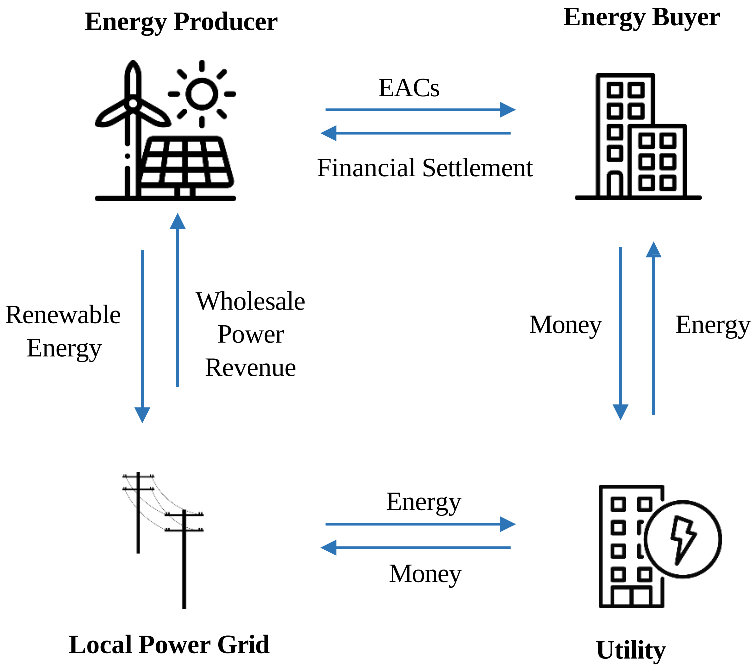


Figure 4. Scheme of Virtual Power Purchase Agreement (VPPA).

2.2.3. Delivery Profile

The third criterion in Table 1, differentiates PPAs based on their delivery profile. According to this factor, pay-as-produced, baseload and pay-as-consumed PPAs can be distinguished. They differ not only in their supply profiles, but also in the risks taken by the energy buyer and supplier.

The most common structure to date has been the pay-as-produced (PAP) Power Purchase Agreement. As the name implies, the energy consumer is obliged to purchase all or a predetermined portion (%) of the energy produced by the renewable installation. The produced energy is most often sold at a fixed price, but sometimes the price for some volume is left to be determined in the SPOT market. With this type of contract, the entire risk of mismatch between the customer's actual consumption and the energy produced from the renewable installation is borne by the customer. The off-taker is obliged to purchase the energy produced, even if the consumption is lower than the renewable energy production in a given hour. Figure 5 shows an example of renewable energy production and consumption of a hypothetical production facility. It is evident that in a shortage of renewable energy produced, the plant must buy energy on the SPOT market. On the other hand, in case of excess production of renewable energy, the plant must resell this energy on the SPOT market. This creates a large volume risk and the difficulty of predicting the final cost of the PPA in the future (Trabesinger, Kanellakopoulou, & Bavin, Deconstructing Baseload PPA).

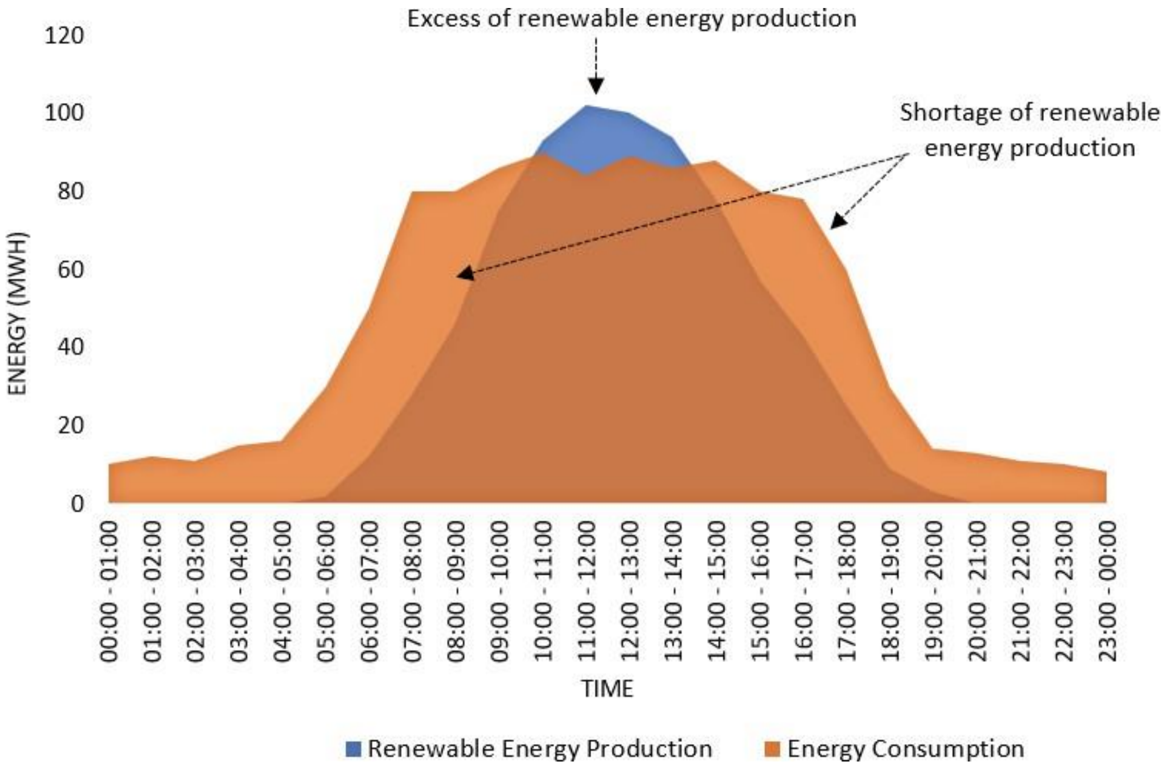


Figure 5. Pay-as-Produced PPA- mismatch between the output of renewable power plant and the consumption of a hypothetical consumer.

In addition, pay-as-produced PPAs have several significant drawbacks, such as the fact that some of the main risk associated with cannibalization and capture prices is transferred to the customer. Cannibalization occurs when an increasing number of renewable sources with the same technology produce at the same time, reducing demand for more expensive fossil fuel energy. As a result, capture prices - the actual price a generator receives based on the time it injects electricity into the grid - fall during those hours. Increasing cannibalization and falling capture prices are causing a large profile risk, which refers to the difference between wholesale market prices, known as baseload prices, and power plant capture prices (Kanellakopoulou M.). Profile and cannibalization risk will be further explained in section 4.

The second type of contract based on delivery profile is a baseload PPA, under which the supplier agrees to supply the customer with a fixed amount of energy every hour of the day for a specified period - a month or a year. As a result, the supplier is responsible for balancing surpluses or shortages to ensure the consistent energy profile over the agreed timeframe. In this case, the risk, which for a PAP structure is borne solely by the customer, is shared between the seller and the energy consumer. It is crucial to note that the consumer still bears some of the risk, as there are times when they consume more or less than a set baseload profile, in which case they must buy or sell energy on the spot market. Nevertheless, the baseload profile provides the certainty of receiving a certain amount of energy in the future, which can act as collateral. On the other hand, the supplier is responsible for the entire balancing of excess and surplus of energy production. Therefore, the prices of baseload PPA contracts are often higher than PAP contracts, due to the additional costs incurred by the seller for the risk incurred (Trabesinger, Kanellakopoulou, & Bavin, Deconstructing Baseload PPA). These types of agreements are especially beneficial for customers with relatively stable consumption, as shown in Figure 6.

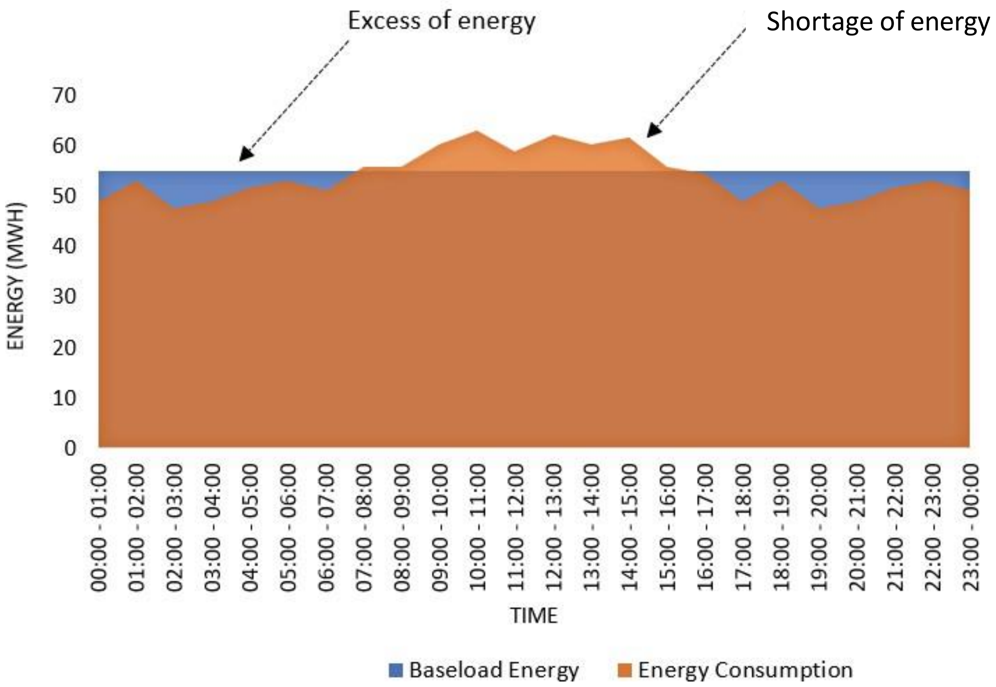


Figure 6. Baseload PPA- comparison of energy delivered and consumed.

Another type of Power Purchase Agreement that differs in terms of supply profile is pay-as-consumed PPA. In such a contract, the renewable energy producer adjusts generation to a curve that reflects the customer's consumption pattern. This type of contract proves to be very beneficial to energy buyers, as it eliminates the profile risk, which is borne solely by the energy producer. It is worth noting, however, that as-consumed PPAs often incur higher prices compared to other types of contracts and are generally not widely used in the market (What is a PPA?, 2019).

2.2.4. Residual & Balancing Energy

When discussing Power Purchase Agreements, it is important to clarify the concepts of balancing energy and residual energy. Balancing energy refers to the mismatch between projected production and the actual production profile. If there is an overproduction of energy, part of the balancing energy, called long volume, must be sold back to the grid. In case of insufficient production, the balancing energy, called short volume, must be additionally purchased from the grid. On the other hand, residual energy refers to the difference between the projected production and the consumption profile. For example, if a customer consumes 50 GWh per year and enters into a PPA for 30 GWh, the remaining 20 GWh to be sourced from the grid is residual energy.

When signing a PPA, balancing and residual energy services are also negotiated. These services can be provided by the supplier covered by the PPA or by another supplier selected through a separate bidding process. In the first case, there is a risk of being tied to one supplier for a long period of time. On the other hand, having two different suppliers increases the complexity of the project, but offers the possibility of changing the balancing service provider during the PPA (De Meulemeester, 2019; A simple guide to PPA pricing structures, 2021; Residual Load, 2023).

2.2.5. Pricing Mechanism

PPAs can be characterized by different pricing mechanisms. The most popular and simplest of these is the fixed-price PPA, which can be divided into a one-shot fixed-price PPA and a fixed-price PPA with escalation. A one-shot fixed-price PPA means a predetermined fixed electricity price for the entire term of the contract. This type of contract is very favorable for the seller, as it provides steady profits, but for the customer it involves a high price risk. In situations where market prices fall, the PPA price can quickly become financially unviable. This phenomenon is further exacerbated by the long-term nature of PPAs. Being tied into a multi-year contract with a price higher than the market price for a company can mean a loss of competitiveness and lead to bankruptcy (De Meulemeester, 2019) (A simple guide to PPA pricing structures, 2021).

The second type of fixed-price PPA is a fixed price contract with an escalation. Under this arrangement, the energy price for a year is fixed in advance and then escalates each year by a predetermined rate or external benchmark. This annual escalation can be limited to the initial contract period, such as 3-5 years. A fixed price PPA with an escalation not only poses the same risks as a one-shot fixed price, but also involves a yearly price increase. A fixed-price PPA with escalation can also be linked to inflation rate, in which the price increases annually according to a publicly developed inflation index (De Meulemeester, 2019) (A simple guide to PPA pricing structures, 2021). Described pricing mechanisms are graphically presented in Figure 7.

Figure 7. Graphic representation of different pricing mechanisms: one-shot fixed price and fixed price with an escalation (De Meulemeester, 2019).

A more alternative pricing mechanism is a Power Purchase Agreement with the price set as a discount to the market price- spot or future. The specific percentage of the discount is usually negotiated and specified in the PPA. Such contractual arrangements provide a more accurate reflection of the real-time market price, which fluctuates depending on the dynamics of supply and demand. For this reason, this type of contract allows tracking the market price while providing a cost advantage to the buyer by allowing him to purchase electricity at a reduced rate. Under a discounted-to-market PPA, the parties can take advantage of market price fluctuations while providing a relatively predictable and potentially profitable electricity price structure. PPAs at a discount to the market price, however, can be more complicated from a project financing perspective, as they generate less predictable cash flows than fixed price contracts (De Meulemeester, 2019).

PPAs with a price discount to market price can be combined with other alternatives, such as a price ceiling, price floor and price collar. The price ceiling sets an upper limit on the price of electricity that the buyer is obligated to pay, which acts as a protection against excessive prices during periods of market volatility or unexpected price spikes. The price floor, on the other hand, sets the minimum price the seller will receive for the electricity generated, which protects it from extremely low market prices by guaranteeing a minimum level of revenue. The price floor gives the seller the assurance that its investment in renewables will generate a certain level of financial return. Finally, the price collar includes both a price ceiling and a price floor, effectively defining the range within the price of electricity will fluctuate. By using a price collar, both buyers and sellers have a level of price certainty and protection from extreme price fluctuations. The price collar provides stability and mitigates the risks associated with volatile energy markets, ensuring that the price remains within a certain range that is acceptable to both parties involved in the PPA. Figure 8 illustrates a PPA with spot indexation with a discount and the same mechanisms with a price collar (De Meulemeester, 2019) (A simple guide to PPA pricing structures, 2021).

Figure 8. Graphic representation of different pricing mechanisms: SPOT indexation with a discount and SPOT indexation with a price collar (De Meulemeester, 2019).

2.2.6. Geographical Scope

The last criterion considered in distinguishing PPAs is geographic scope. Based on this factor, it is possible to identify a cross-border PPA, which is a contract for the purchase of electricity produced in a country other than the one where the customer is located. According to publicly available information, the cross-border PPAs signed in Europe are Virtual Power Purchase Agreements. Physical cross-border PPAs are theoretically possible, but the market has not yet seen a confirmed agreement of this type. Conclusion of physical cross-border PPA requires multiple supply contracts, which would make the process much more complex and time-consuming. The lack of physical delivery of energy between producer and consumer reduces the constraints on project locations, thereby increasing optionality and allowing entry into more markets (Carrillo; Niklaus & Kanellakopoulou, Virtual PPAs: the shift from hassle to bustle, 2022).

Nonetheless, cross-border PPAs involve significant basis risk, which is related to the price correlation between two or more markets: the one where the production takes place and the one where the electricity is consumed. The higher the price correlation between the two markets, the lower the basis risk. Basis risk is described in more detail in the following section (Carrillo; Niklaus & Kanellakopoulou, Virtual PPAs: the shift from hassle to bustle, 2022).

3. Risks of PPAs & Mitigation Strategies

Power Purchase Agreements have gained popularity in recent years in the corporate and non-profit sectors. These contracts offer several important benefits, including enhanced sustainability commitments, the purchase of Energy Attribute Certificates (EACs) to mitigate carbon tax liabilities, and protection from market volatility. Despite their undeniable attractiveness, it is important to remember that PPAs are not without inherent risks. A thorough understanding of each type of risk is crucial for organizations to develop effective risk management and mitigation strategies. The following section aims to outline and describe in more detail the most important risks associated with PPAs. While some risks have already been mentioned earlier in the discussion of different types of PPAs, this part will focus solely on the description of each risk with some of the most well-recognized mitigation strategies and its examples.

3.1. Price risk

For companies considering signing a Power Purchase Agreement, speculating on future electricity prices poses a significant gamble. This uncertainty, referred to as price risk, is often defined as a PPA going "out-of-the-money," which means that a customer buys electricity - potentially even for a very long period - at a higher price than the power from the grid. As a result, the company may have to pay higher rates compared to its competitors, leading to a loss of competitiveness and bankruptcy (Shea & Abbott, 2020; Meulemeester, 2022).

Clients can adopt certain strategies to address a price risk, including implementing alternative pricing mechanisms, such as collars or spot with indexation, as described earlier in section 2.2.5. Leveraging these solutions, companies can have a more direct relationship with the current market price, better manage the uncertainty associated with future price changes, increase their operational resilience, and reduce the risk of adverse financial consequences (Shea & Abbott, 2020).

Another widely used approach adopted by corporations to shield themselves against the volatility of energy prices and effectively manage energy price risk is hedging. Hedging entails entering into contractual agreements that fix electricity prices at predetermined levels for a specified duration. This is achieved using standard exchange-traded products or through over-the-counter (OTC) transactions, facilitating the transfer of price risk to other participants within the market. The transfer of risk can take place through various means, including PPAs or other bilateral agreements, by hedging the volume of electricity that must be additionally purchased or sold to the grid (PPA Glossary, 2021; Meulemeester, 2022; Sainio, 2021).

In the case of electricity additionally purchased from the grid, the hedging strategy aims to stabilize costs. Hedging is done when energy markets are low, and in rising markets the stop-loss function protects against excessive year-on-year increases in energy costs. Stop-loss is a simple setup that automatically closes a position when the price reaches a certain level (Meulemeester, 2022).

In contrast, for volumes sold to the grid, the opposite version of the strategy is used, in which large volumes are hedged by selling futures contracts when markets are high, and then more volumes are hedged when markets begin to fall (Meulemeester, 2022).

In addition, spread hedging is used to mitigate price risk. Spread trading takes advantage of fluctuations in the price of futures or forward contracts resulting from time and geographic disparities in the relationship between commodity markets. When the spread between a producing country and a consuming country is significant, it is possible to hedge the price by executing a combination of selling and buying futures contracts in different countries (Meulemeester, 2022).

Implementing these strategies plays a key role in reducing price risk. A considered approach to risk management that includes hedging enables organizations to achieve cost stability, effectively protecting them from irregular price fluctuations. As a result, consumers can operate in the complex energy market with increased resilience and precision, ultimately mitigating the negative impact of price volatility on their operational and financial aspects (Meulemeester, 2022).

3.2. Shape Risk

Shape risk, also known as profile risk, arises from the unpredictability of the timing of renewable energy generation. While the total power output may align with expectations, there are variations in hourly production. This uncertainty forces buyers to purchase and sell electricity on SPOT market, exposing them to the impact of price volatility and increasing price risk (Shea & Abbott, 2020).

Profile risk should not be underestimated, as it can be quite significant. For example, based on an analysis conducted by E&C for a specific customer with a solar PPA in Spain, only 26% of the total contracted energy volume was generated by the solar plant and used by the customer. The rest of the energy had to be resold or purchased on the spot market. Contrary to the popular belief that PPAs provide greater price stability, they expose the parties involved to increased volatility in the spot market. Profile risk is also closely linked to price risk, as selling, and buying energy from the spot market can involve a large incremental cost depending on the current state of the market (Meulemeester, 2022).

One simple strategy to mitigate shape risk for the electricity consumer is the sleeved PPA mentioned earlier in section 2.2.2, signed with a retail electricity supplier (REP) that integrates renewable generation into the energy supply contract, managing any over- or under-production. In that case, a supplier undertakes the risk of irregular production from renewable asset for an additional price premium (Shea & Abbott, 2020).

Furthermore, a shape risk is completely born by the supplier in pay-as-consumed Power Purchase Agreements described in section 2.2.3. In such a contract, the renewable energy producer adjusts energy production to the customer's consumption profile. Naturally, this involves a higher price for the supplier's risk, hence these contracts are much more expensive than pay-as-produced PPAs and are generally not widely used in the market (What is a PPA?, 2019).

3.3. Volume Risk

Volume risk originates from the uncertainty associated with a power plant's ability to achieve its projected volume, estimated based on long-term meteorological data typically covering 20-

30 years. Failure to achieve the intended level of production can be attributed to unpredictable fluctuations in resource levels, such as wind speed or solar insolation (Shea & Abbott, 2020).

This risk is significant for several key reasons. First, annual electricity production from wind turbines or solar panels exhibits inherent volatility. Second, with contractual commitments lasting a decade or more, accurately predicting energy consumption is difficult (Meulemeester, 2022).

Volume risk may include not only insufficient production from renewable sources but may also involve the inability to meet planned environmental claims. As a result, the buyer may be forced to purchase separate Energy Attribute Certificates (EACs) to meet the desired sustainability targets (Shea & Abbott, 2020).

One method to mitigate not only volume risk, but also profile risk, is through a multi-technology Power Purchase Agreement, which combines different power generation technologies, or a multi-location Power Purchase Agreement, which diversifies the geographic locations of renewable energy projects. The first type of agreement can include sources such as solar and wind power, which have limited correlation, primarily resulting in a shorter period of insufficient production. Similarly, in the case of multi-location PPA, renewable energy projects located in different regions, that operate in separate markets can exhibit uncorrelated production profiles due to site-specific behavior. Therefore, by signing a PPA covering multiple technologies or locations, a customer can reduce the amount of energy required to purchase while reducing its exposure to market volatility. The extent of this benefit depends largely on the correlation between energy generation profiles and the relative size of various assets. Nevertheless, this strategy is very effective in reducing profile, volume, and previously described price risk (Gabrielli, Aboutalebi, & Sansavini, 2022; Hedges & Duvoort).

3.4. Cannibalization

A phenomenon closely related to profile and price risk is cannibalization when renewable energy sources "cannibalize" their own profits. A major cause of this phenomenon stems from the current marginal pricing system, which determines the price of energy based on the cost of the most expensive generation technology required to operate at the specific moment to meet the demand. When technologies with low marginal costs, such as wind and solar power, are available, the system operator gives them a priority dispatch and does not need the energy produced by more expensive sources based on fossil fuels. As a result, the average price for a given period drops. At times when renewable energy sources are in abundance, there is a surge in energy production from these technologies. However, due to limitations in energy storage capacity, excess energy is sold at a reduced price (Kanellakopoulou & Trabesinger).

When considering the effect of cannibalization, it is necessary to explain the capture price and the capture factor. The capture prices are the average prices that each generator is able to receive for the sold energy in a specific period. Spot prices are the same for all technologies, but for capture prices seasonality of production and the ability to provide baseload power comes into play. Baseload power refers to the average daily demand that is delivered continuously. Fossil fuels or nuclear power plants are usually referred to as baseload power plants because they have the ability to ensure the continuity of production, unlike renewable power plants. For example, the capture price of solar photovoltaic (PV) system is lower than for natural gas plants, since PV usually produces energy at times when the spot price is low. On the other hand, a gas-fired power plant generates energy during the morning or evening peak hours, receiving higher spot prices. The capture prices are calculated as the average price weighted by the volume of the asset. On the other hand, the capture factor is the capture price divided by the baseload price. Capture factors are unique to each generation technology and every asset. As more renewables with the same generation profile are in the grid, capture factors are falling, as can be seen in mature renewable markets (Kanellakopoulou & Trabesinger).

To examine the impact of increasing renewable abundance on spot prices, a real-world example was analyzed. Hourly spot prices in Germany were compared with the corresponding hourly irradiance levels observed in the country. Greater solar irradiance is associated with greater photovoltaic generation, and as discussed in the case of cannibalization, can result in lower spot prices.

The European Commission's interactive tool was used to gather localized information on irradiation intensity in Germany. Although the tool compiles global data through 2020, it was decided to rely on 2018 data due to the potential significant impact of the COVID-19 pandemic on German spot prices in 2019 and 2020. Nevertheless, it is important to remember that spot prices are affected by many variables, including supply and demand dynamics and prevailing weather patterns. In particular, wind conditions have a significant impact on spot prices, especially given Germany's leading position in Europe with 59,311 MW of installed capacity (Wind Europe, 2019).

Figure 9 and Figure 10 below show a comparison of hourly spot prices and hourly irradiance in Germany in January and June 2018. These two 15-day timeframes were chosen with the aim of presenting the impact of irradiance more clearly and facilitating comparisons between months characterized by different levels of solar radiation.

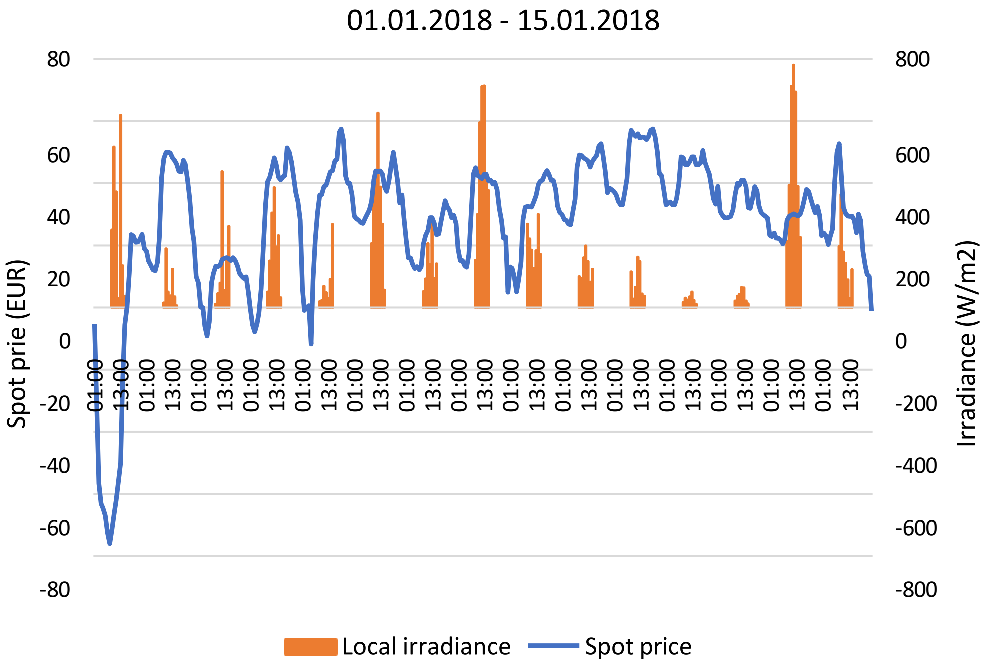


Figure 9. Comparison of spot prices and solar curve from 01.01.2018 to 15.01.2018 in Germany (Comission, 2023)

Figure 9 demonstrates a comparison of hourly spot prices and hourly irradiance in Germany in January 2018. The chart represents an interesting phenomenon of negative electricity prices, which occur in situations where the demand for electricity is not balanced with the supply, resulting in electricity producers being forced to pay energy consumers to receive excess of the produced energy. In countries such as the Germany, UK and the Netherlands, there is no lower limit to how low prices can be, which means that they can even go negative in a situation of overproduction and very low demand. The phenomenon of negative pricing is further exaggerated by the limited flexibility of conventional power plants to reduce their power output. For instance, nuclear power plants are typically able to reduce their output by only 35%, while lignite plants have shown a 50-60% reduction. Interestingly, heat-controlled CHP plants continue to produce electricity despite the unfavorable price environment. Despite the negative impact of negative electricity prices on power producers, they can be perceived as a valuable signal providing an initiative to increase the flexibility of energy systems, potentially by investing in energy storage systems (Götz, Henkel, Lenck, & Lenz, 2014; Kanellakopoulou & Trabesinger). Figure 10 demonstrates the same comparison, but for June 2018, without negative trends of the prices.

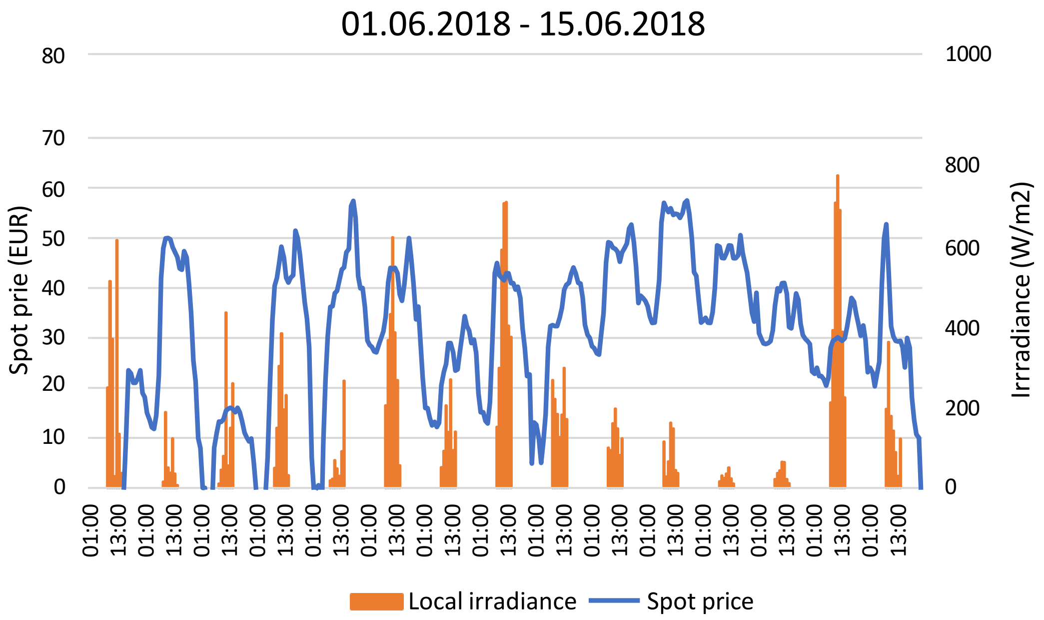


Figure 10. Comparison of spot prices and solar curve from 01.06.2018 to 15.06.2018 in Germany (Comission, 2023)

Both charts illustrate an increase in energy prices during the afternoon hours, particularly around 1:00 pm, which can be attributed to a general increase in energy demand during this time. Conversely, prices tend to decrease during nighttime hours as energy demand decreases. A similar pattern can be observed for local irradiance, which peaks at midday. Nevertheless, it is apparent that on days with higher solar radiation, the spot price during peak hours tends to be lower compared to days with lower radiation. This confirms that the greater availability of renewable sources has a downward effect on the spot price.

The phenomenon of cannibalization also has a significant impact on the development of renewable energy projects in Spain. The country aims to achieve an 81% penetration of renewable energy sources by 2030, leading to an unprecedented rush in building gigawatts of new capacity. For instance, projects set to be operational by 2025 will double Spain's total installed grid-connected solar capacity within two years. This influx of new solar energy is already lowering Spanish energy prices, sometimes pushing them close to zero. With this solar development, the "duck curve" will deepen in the coming years, as indicated in Figure 11 (Blackburne, 2023).

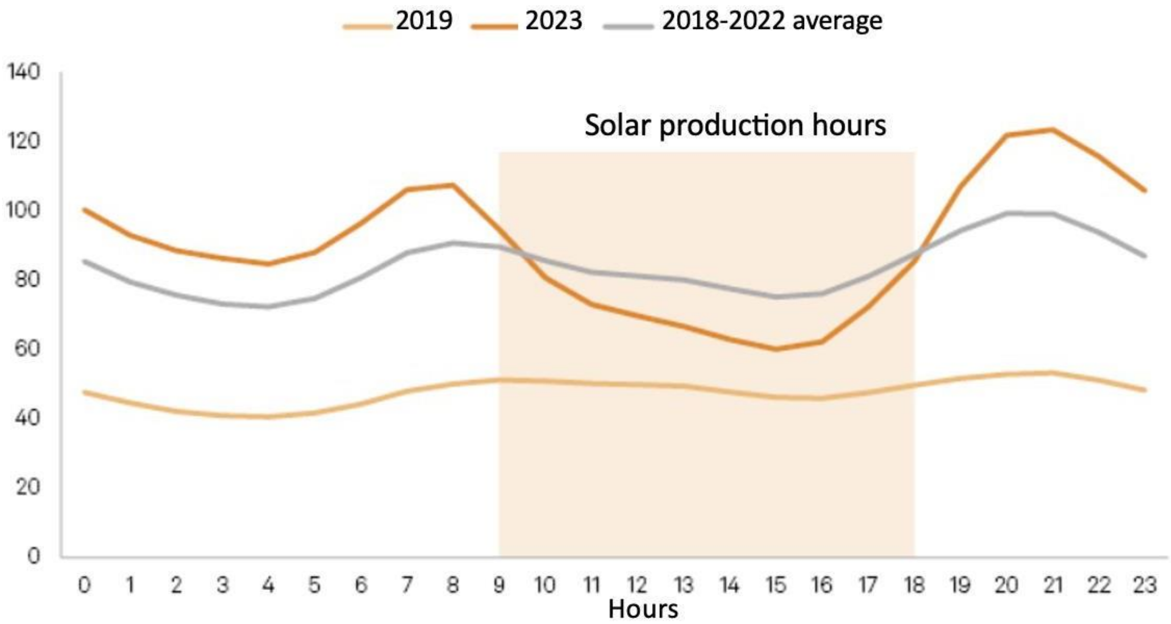


Figure 11. Day-ahead hourly power price profile in Spain (EUR/MWh) representing a ´duck curve´ (Blackburne, 2023).

The "duck curve" is a chart illustrating daily patterns of electricity demand. It shows higher energy prices in the early morning and evening when demand rises but solar energy generation is limited. Then, there's a sharp drop in prices during midday when sunlight is abundant, but demand is lower (Blackburne, 2023).

The deepening "duck curve" phenomenon and increasing cannibalization should not be disregarded, especially given the projected decline in annual solar capture rates from the current 80% to an estimated range of 15%-20% after 2025. In addition, this year has already seen approximately 300 hours of cheap energy, defined as under 5 €/MWh, surpassing the previous record of 202 hours set in 2021 (Blackburne, 2023).

The "duck curve" underscores the challenge of balancing supply and demand in regions with abundant solar energy, requiring grid management strategies and energy storage to ensure grid reliability. Furthermore, a stronger emphasis should be placed on enhancing grid flexibility. Methods to increase this flexibility include voluntary demand reductions, known as demand-side management, or adjusting consumption to increase energy efficiency. In addition, investments should target energy storage systems, such as power-to-heat conversion, and the expansion of cross-border grid connections. The greater the flexibility of the system, the flatter the demand curve, leading to a lower probability of extreme price spikes (O'Brian & Harrison, 2017).

3.5. Operational Risk

Operational risk, also known as performance risk, arises when renewable energy systems fail to meet predefined operational availability level. This risk is driven by internal challenges within a renewable energy project, such as malfunctioning processes, personnel or equipment issues, or system problems. Additional examples include shutting down key equipment for maintenance, gradual degradation due to wear and tear, operational errors or energy curtailment implemented by the transmission system operator (TSO). TSO can order curtailments at the local level if transmission line capacity is insufficient to transport renewable electricity to required areas on the system (Shea & Abbott, 2020).

One strategy to mitigate operational risk for Virtual PPAs is to redefine the method used to determine the trade quantity. The trade quantity refers to the pre-agreed number of megawatt hours (MWh) of energy and Energy Attribute Certificates (EACs) to be exchanged between two parties under this contract. In a traditional VPPA, the trade quantity is defined by the actual energy delivered to the grid, as measured by the electric meter at the point of interconnection (POI). However, billing at the POI on the as-produced basis exposes the purchaser to operational high risk. In the case of plant underperformance, the purchaser is exposed to not receiving expected energy, EACs and unanticipated settlement prices. To protect the buyer from this risk, conventional VPPAs often include availability guarantees that impose penalties on the seller if the plant fails to meet a predetermined production threshold. While these guarantees provide some protection, the buyer still bears significant operational risk. To address these concerns, an innovative type of Virtual PPA, known as Proxy Generation or 'Proxy Gen' VPPA has been introduced.

In Proxy Gen VPPAs, the size of the contract is determined by the amount of energy the plant could deliver to the grid if it were operating at maximum equipment capacity and in accordance with best operating practices. For Proxy Gen VPPAs, the actual wind or solar resource available at the plant is assessed, considering weather conditions. This measurement is then processed through a predefined mathematical formula that estimates the expected energy production, considering the size of the facility, the estimated operating efficiency (EOE) and the expected fuel-to-power conversion efficiency represented by the power curve. Therefore, in a Proxy Gen Virtual PPA, the energy quantity does not directly represent the actual energy production, but instead serves as a calculated estimate or 'proxy' of the expected energy production under the best operating conditions. Proxy Gen VPPAs place the operational risk entirely on the sellers, providing them with an incentive to operate at maximum efficiency. This type of contract ensures that the vendor does not neglect the risks associated with staff or equipment problems, system issues, gradual degradation, or operational errors (John, Taylor, & Davies, 2018; Tundermann, 2019).

While Proxy Generation Virtual Power Purchase Agreements (PPAs) offer undeniable benefits, they are not without their drawbacks. Firstly, they are relatively new contracts, which means that the parties involved, including buyers, sellers, lawyers, and financiers, have limited exposure to them. As a result, the process of negotiating Proxy Gen PPAs can involve delays and increased costs. Moreover, due to the complexity and risks associated with such agreements, sellers may choose to increase PPA prices to compensate for the additional risks they take on (John, Taylor, & Davies, 2018; Tundermann, 2019).

Another aspect worth noting is that the determination of proxy energy production is done by an independent calculation agent, which adds a third party to the projects and incurs additional costs. Typically, the calculation agent's commission is equal to approximately 0.5% of Proxy Gen's annual trade volume multiplied by the PPA price. For example, a PPA of 20.00 €/MWh would incur an additional fee of 0.10 €/MWh over the life of the contract (John, Taylor, & Davies, 2018; Tundermann, 2019).

In addition, Energy Attribute Certificates (EACs) for a project are generated based on actual energy production, not proxy production. Therefore, if actual production is insufficient, the seller cannot provide the buyer with EACs that the project has not actually generated. Under the Proxy Gen VPPA, when actual production is less than the amount of Proxy Gen, the seller usually must compensate for the shortfall with additional replacement EACs from similar projects. This situation can be disadvantageous to the buyer, as the buyer would be paying VPPA prices for EACs unrelated to a specific project. On the other hand, if the actual generation exceeds the Proxy Gen Trade Quantity, the buyer would typically only pay for the Proxy Gen trade quantity. In this scenario, the negotiated contract terms would determine the allocation of the project's incremental EACs beyond the Proxy Gen trade quantity, to the seller, the buyer or both. Careful consideration of these factors is essential so that buyers can make informed decisions tailored to their specific preferences (John, Taylor, & Davies, 2018; Tundermann, 2019).

Nevertheless, a significant advantage of the Proxy Gen VPPA is the option to conclude additional contracts that can further reduce project risk. Buyers can secure insurance policies against adverse weather conditions or uncertainty associated with wholesale market fluctuations for up to 10 years by paying an additional fee. These agreements are only offered to Proxy Gen VPPA, as third-party insurers can estimate the cost of weather and market risks but are unable to accurately assess the risks associated with operating the facility. Therefore, the elimination of operational risk from the VPPA makes it cost-effective to invest in these projects with insurance cover (John, Taylor, & Davies, 2018; Tundermann, 2019).

An example of such an agreement is the Virtual Power Purchase Agreement (VPPA) integrated with the Volume Firming Agreement (VFA) concluded by Microsoft in 2018, which enabled not only the reduction of operational risk, but also price risk, volume risk and profile risk. After finalizing the initial conventional VPPA, Microsoft encountered persistent challenges regarding the mismatch between energy consumption patterns and renewable energy production. Fluctuations in monthly and quarterly generation led to selling surplus energy at low prices during overproduction and buying expensive energy during underproduction. To overcome these obstacles, the Proxy Generation VPPA was adopted with a Volume Firming Agreement, transferring risk to renewable energy developers or third parties capable of managing and diversifying risk across multiple projects. Such third parties are insurance companies specializing in weather-related risks such as temperature, rain, snow, and wind. As the VFA market develops, insurance companies are encouraged to invest in storage and other solutions that balance renewable energy supply and demand, supporting the sustainability of renewable energy. The cost of this service to corporations depends on wholesale market conditions and the penetration of renewable energy (John, Taylor, & Davies, 2018; Tundermann, 2019).

3.6. Balancing Risk

Balancing risk refers to the exposure to power system costs that arise when forecasted renewable energy production differs from actual production. Balancing risk is related to the structure of energy trading in the spot market, which begins day-ahead (D+1) of the delivery and ends just before delivery at the gate closure. Spot trading can be divided into several segments: day-ahead auctions for D+1 delivery, intraday auctions, and continuous trading for D+1 delivery, and very short-term balancing transactions with the TSO for delivery in the next

60 minutes. Every day at some point in the afternoon on D-1, balancing responsible parties (BRPs) must send the Transmission System Operator (TSO) their expected consumption for the next day, which is called an e-program. Imbalance volumes are the difference between the volumes in this e-program for one hour and the actual volumes in a 15-minute interval. Depending on the costs incurred by the TSO to equalize the net imbalances of all balancing entities in the system, an imbalance price is set. The greater the share of an asset in the imbalance of the power system, the higher the imbalance cost. Due to increasing renewable capacity with intermittent generation, balancing costs are increasing year by year, contributing to higher balancing risk (Cyriel, 2021; WBCSD).

One strategy to reduce balancing risks and minimize costs of imbalances is previously mentioned multi-technology Power Purchase Agreement. These contracts provide greater stability of supply, as production from different renewables has limited correlation. Moreover, various renewable sources exhibit varying levels of predictability. For instance, wind energy is less predictable and entails higher balancing risks compared to solar energy. Multi-technology PPA agreements can contribute to overcoming challenges associated with this lower predictability. (Hedges & Duvoort).

An alternative strategy to reduce balancing risk involves the inclusion of an external entity, such as a utility, which can aggregate assets into a pool of resources to manage balancing risk. These utilities can use energy storage systems or smart-charging electric vehicles to offer grid services during periods of lower demand (Ellefsen, 2019; Electric-Vehicle Smart Charging Innovation Landscape Brief, 2019).

3.7. Basis Risk

The basis risk is mainly related to Virtual Power Purchase Agreements (VPPAs) and is due to the discrepancy between the market price at the power producer's operating location and the power consumer's location. For example, if a company in Germany signs a cross-border VPPA with an electricity procurement from France, they must determine which domestic spot prices will govern the PPA price settlement. This decision is crucial because it directly affects cash flow. Typically, market choice is one of the main subjects of negotiation and requires a thorough understanding of the market's dynamics by all parties (Understand Basis Risk, n.d.; Collell, 2023).

Basis risk is also of significance importance in the United States, and it relates to differences between nodal and hub prices. Nodal prices are prices at connection points for generators, loads or the transmission system, that aggregates into regional "nodes" or "zones" creating an organized wholesale market. Aggregation makes the prices more stable over time because they are less affected by local energy market fluctuations. When a customer negotiates a VPPA, the price is typically tied to a hub price, while a renewable energy generator receives a nodal price. As a result, the project owner must absorb all price discrepancies, which can potentially lead to losses. Basis risk is generally less pronounced in Physical Power Purchase Agreements, as power production and consumption occur in proximity, leading to similar prices. In addition, basis risk is more prominent in regions with numerous renewable projects, such as northwest Texas with significant wind power capacity and southeastern California with significant solar power capacity (Understand Basis Risk, n.d.; Collell, 2023).

One approach to mitigating the exposure to basis risk involves engaging in supply contracts that refer to well-established index such as Nordic Power Exchange price index (Nordpool) for Norway, Sweden, Denmark, Finland, and parts of Germany. This hub or load settlement can efficiently reduce a vulnerability to basis risk in Virtual PPAs (How to Reduce Basis Risk by Hedging with Options, 2023).

In addition, to reduce basis risk in cross-border Virtual Power Purchase Agreements (PPAs), such contracts are concluded in countries with highly correlated markets. Such an alignment ensures that energy price fluctuations and market dynamics in one country closely mirror those in another, reducing the risks associated with diverging market conditions (How to Reduce Basis Risk by Hedging with Options, 2023).

3.8. Credit & Counterparty Risk

Credit risk in Power Purchase Agreements involves uncertainty about whether the buyer will meet its payment obligations on time, or at all. Such noncompliance can have serious consequences, potentially disrupting the seller's cash flow and undermining its overall financial stability. Effective credit risk management becomes crucial for all parties involved in a PPA, as it not only ensures that the seller receives timely payments, but also protects the buyer's credit reputation (Brindley, et al., 2020).

There are various approaches to effectively mitigate credit risk. For instance, an energy seller may try to secure its future profits through various contractual mechanisms, including advance payments, increased payment frequency or the inclusion of material adverse effect clauses (MACs). MAC clauses are legally binding provisions in contracts that set specific terms, granting the buyer the right to terminate the contract under certain circumstances (Material Adverse Change (MACs); Trabesinger, Pricing Credit Risk in the PPA Market, 2020).

In addition, third-party assistance is sought to provide additional credit support, which can include trade credit insurance, letters of credit (LoCs) and parent company guarantees (PCGs). All of these arrangements protect the seller against the risk of not receiving a payment for the services sold. In addition, collateral exchanges are also employed, where counterparties can use assets such as cash or liquid securities held in trust accounts. In the event of a default, the affected party has the right to liquidate the collateral, thus protecting itself from potential losses (Trabesinger, Pricing Credit Risk in the PPA Market, 2020).

Another credit risk mitigation strategy is credit default swaps (CDS), which are one of the most widely used credit derivatives. A CDS transfers credit exposure to another investor who undertakes to repay it if the borrower defaults. A CDS involves an appropriate fee to the investor bearing the risk (Trabesinger, Pricing Credit Risk in the PPA Market, 2020; Material Adverse Change (MACs)) (Hayes, 2023).

On the other hand, counterparty risk is the probability that one of the parties involved in a transaction will not fulfil its contractual obligations. Most commonly it relates to a scenario in which the purchaser may fail to meet its obligations or if the subsidy is revoked or altered, leading to setbacks or challenges in the construction of the renewable installation contributions (Niklaus).

To mitigate this, the parties involved agree on a Commercial Operation Date (COD), marking the point at which the renewable assets are fully functional, connected to the grid and start generating energy in accordance with the Power Purchase Agreement (PPA). COD also represents the start of the purchaser's obligation to purchase energy. Commonly, this date coincides with the disbursement of a portion of the project financing - including remaining construction expenses, potential ancillary charges, and tax equity, often referred to as COD financing. COD financing can combine various sources of capital, including long-term debt, tax equity and sponsor contributions (Niklaus).

3.9. Non-market Risks

Non-market risks arise from events unrelated to the energy market that may affect the performance of PPAs, such as regulatory changes, adjustment of incentives or fluctuations in various cost factors that may cause losses to PPA parties.

One example of non-market risk is the regulatory changes that came into effect in April 2023 in the UK. The regulations implemented included an end to the recognition of European Union Guarantees of Origin (GoOs), and only UK Renewable Energy Guarantees of Origin (REGOs). In previous years, both certificates had been accepted in the country's territories. Between 2021 and 2022, the UK has procured an estimated 42 terawatt-hours (TWh) through GoOs, representing about 28% of total domestic energy supply. The requirement to replace previously purchased GoOs with REGOs has increased pressure on demand for these certificates and raised their market price. Such disruptions could have adverse consequences, including the potential escalation of costs for consumers and industry participants who were adjusting to the changed regulatory landscape. In addition, a sudden increase in demand for REGO certificates could strain supply chains and require adjustments to energy supply strategies, thereby introducing complexity and uncertainty into the market (Guarantees of Origin (GoOs), 2023).

A similar example is the amendment to the law announced in July 2023 by the Polish Senate, which introduces a 97% tax on revenues generated from the sale of guarantees of origin (GO) for renewable energy producers. This requirement raises concerns about its potential consequences for the profitability and viability of renewable energy projects. This significant tax burden has the potential to lead to a situation where profits from the sale of GOs are outweighed by the associated procedural costs. As a result, smaller and medium-sized renewable energy producers may find it economically difficult to maintain their share of the GO market. Instead, it may favor the retention of large players and participants that have already entered into long-term power sales contracts bundled with GO, leading to market concentration and limiting the entry of smaller players. Moreover, these regulatory changes may favor foreign suppliers, giving them a competitive advantage and further changing the dynamics of the GO market in the country. These developments underscore the need for a comprehensive assessment of potential disruptions and the impact of regulatory changes on renewable energy markets (Sejm Gov, 2023).

Within this classification, there is also a risk involving force majeure, which refers to the possible consequences of unforeseen and uncontrollable events that may hinder project completion or disrupt energy generation. Such events are beyond the control of the parties and include natural disasters, extreme weather conditions, civil unrest, and exceptional circumstances. Typically, Power Purchase Agreements (PPAs) contain provisions which temporarily relieve the parties from fulfilling their contractual obligations in such situations (Brindley, et al., 2020).

A strategy for dealing with non-market risk may include the inclusion of a clause in the contract to promote good faith renegotiation. This provision states that when a significant change occurs, both the energy consumer and the project owner are obliged to convene a meeting and make a genuine attempt to discuss the modification. The aim is to restore, as far as possible, the initial balance of obligations and benefits for both parties (Shea & Abbott, 2020).

3.10. Summary of PPA risks and mitigation strategies

After outlining and analyzing these basic risks associated with Power Purchase Agreements, it becomes evident that PPAs involve a certain level of uncertainty. However, from an off-taker perspective, some risks can be reduced or eliminated by transferring it to another party, such as the developer of the PPA or electricity supplier. In addition, several strategies reduce multiple risks simultaneously, for example, by reducing profile risk, operational risk, balancing risk, price risk can be addressed as well. Table 2 presents the main mitigation strategies described earlier, showing what risks they reduce.

Table 2. Overview on Risk Mitigation Strategies (Shea & Abbott, 2020).

Risk Mitigation Strategy	Risk Mitigated							
	Price	Shape	Volume	Operational	Balancing	Basis	Credit	Non-Market
Price, Caps & Collars	X							
Multi-technology PPA	X	X	X	X	X			
Multi-location PPA	X	X	X	X	X			
Proxy Gen PPA with VFA	X	X	X	X				
Hub or Load Zone Settlement	X	X	X			X		
Credit Support							X	
Good Faith Renegotiation								X

The above chapter describing the risks associated with a Power Purchase Agreements has demonstrated that entering into such contract is a major risk. However, this uncertainty can be minimized by applying the strategies described. A proactive approach, thorough analysis, and risk assessment before concluding a PPA are key to reducing risks and potential vulnerabilities.

In addition, risk mitigation strategies have a cascading effect, addressing multiple risks simultaneously. For example, by managing the shape risk associated with the unpredictability of renewable energy generation timing, price risk is also mitigated. A more stable and predictable energy supply decreases the need to buy or sell excess energy on the spot market, thereby lowering transaction costs and reducing exposure to volatile spot market prices. The holistic approach to risk management not only minimizes the immediate uncertainty associated with PPAs, but also creates a domino effect, mitigating interrelated risks and increasing overall contract resilience.

The recent energy crisis has amplified some of the risks associated with Power Purchase Agreements and highlighted the key role of effective management strategies in addressing these challenges. Increased volatility and unpredictability in the energy market have significantly affected the dynamics of the PPA sector. The next chapter will focus on changes in PPAs and emerging trends that have materialized in response to the changing energy landscape in 2022.

4. PPA Market Analysis

In 2022, the world experienced its worst energy crisis since the 1970 oil shocks, leading to the highest levels of oil, gas and consequently electricity prices. Energy markets began to tighten as early as 2021 due to the rapid economic rebound after the pandemic resulting in increased energy demand and insufficient supplies. Additionally, Russia began withholding gas supplies to Europe as early as 2021, months before the invasion of Ukraine, leading to low gas storage levels. As has already been mentioned, Russian energy exports are particularly important to Europe, since nearly 30% of total natural gas, more than 20% of oil and about 12% of coal consumed in the EU in 2022 came from Russia. After Russia invaded Ukraine in February 2022, the situation dramatically escalated to a full-scale global energy crisis and ignited chaos. All this led to unprecedentedly high prices and contributed to inflation, poverty and an economic slowdown heading for a severe recession in several countries (Global Energy Crisis, n.d.). Figure 12 depicts the evolution of Cal+1 prices, which is the futures price representing the predicted cost of electricity one year ahead, in several countries between 2020 and 2023 (Carabott, 2023).

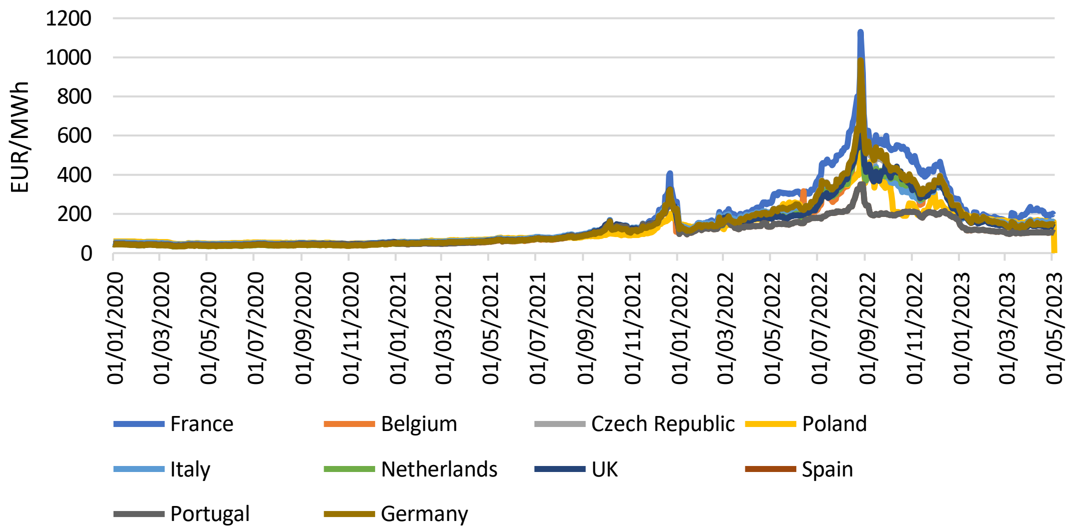


Figure 12. Evolution of Cal+1 prices in selected countries (E&C Consultants, 2023).

The substantial rise in energy costs has profoundly affected multiple sectors, including the PPA market. This surge has resulted in higher contract prices and other associated developments. The upcoming section explores the development of various trends and shifts in PPA markets, focusing in particular on 2022, assessing the direct and immediate impact of the energy crisis on these agreements. Additionally, this chapter provides a more concise analysis of 2023 to gauge how these trends have evolved as energy prices have slightly declined and stabilized.

4.1. PPA Market in 2022

As depicted in Figure 12, in 2022, electricity prices reached extreme levels, entailing several consequences for the PPA market. The following section will analyze PPA prices in 2022, the activity in this market, and the most prominent trends related to balancing costs, backwardation, and cannibalization, among others.

4.1.1. Prices of PPAs

A significant challenge for renewable project developers in 2022 was the raising LCOE (Levelized Cost of Electricity) and higher project costs driven by inflation. LCOE represents the expenses associated with a power generation facility over its lifetime, including both initial capital expenditures (CAPEX) and the present value of ongoing operating expenses (OPEX). Over the past decade, there has been a significant and rapid reduction in the cost of renewables, as assessed by the levelized cost of electricity. The average global LCOE for emerging utility-scale solar PV projects fell by 88% between 2010 and 2021. Similarly, the LCOE for onshore wind fell by 68%, and the LCOE for offshore wind fell by 60% over the same period. This decline in the cost of renewable energy has made PPAs an attractive and compelling choice for corporations looking to reduce their carbon footprint (Steinecke, Moncayo, Palumbo & Schilling, 2023).

Nonetheless, over the past two years, this trend has changed, and the investment costs of new photovoltaic power plants and onshore wind farms have increased by 15% to 25%. This shift has posed challenges for the development of renewable technologies and is reflected in the rising prices of PPAs. The growth in the investment costs can be attributed to several factors (Steinecke, Moncayo, Palumbo & Schilling, 2023).

Firstly, the cost of materials and components required for the construction of renewable assets has seen a significant rise. For example, it is estimated that the prices of essential materials for producing PV panels, such as steel, copper, aluminum, and polysilicon, increased by approximately 300% from 2020 to 2022 (Steinecke, Moncayo, Palumbo & Schilling, 2023).

Secondly, the expenses associated with engineering, procurement, and construction (EPC) contracts for renewable assets have increased. The trend of declining renewable energy costs has been affected by the higher labor and transportation costs (Steinecke, Moncayo, Palumbo & Schilling, 2023).

Thirdly, the rise in interest rates has created greater difficulties in securing financing for renewable projects, with a 2% increase in interest rates in 2022. Additionally, inflation has surged significantly, averaging between 8% and 11% in Europe, which has further elevated the expenses associated with constructing new assets (Steinecke, Moncayo, Palumbo & Schilling, 2023).

Moreover, elevated costs associated with balancing and shaping in recent years contributed to higher PPA prices. Electricity balancing is essential in the case of over- or underproduction from renewable installation. Producing more or less electricity than initially anticipated in the short term, often due to factors such as weather conditions or forecasting inaccuracies. Additionally, there may be a requirement to align the electricity volumes with a consistent baseload pattern. Both of these cost components are intricately connected to the underlying electricity wholesale market and are directly impacted by increased fluctuations in the energy market, leading to an overall increase in PPA prices (Steinecke, Moncayo, Palumbo & Schilling, 2023).

Moreover, growth in PPA prices was also driven by the price of EACs, which was estimated to rise by nearly 500% in Europe over the past two years. This phenomenon can be attributed to demand rising faster than supply. PPA prices in 2022 have been affected by several other factors, such as growing balancing costs, which will be further explained in the following subsections (Steinecke, Moncayo, Palumbo & Schilling, 2023).

Furthermore, previously discussed events such as the economic recovery after the pandemic or Russia's invasion of Ukraine have placed significant pressure on energy markets. Along with the rise in gas and electricity prices, Power Purchase Agreement (PPA) prices have also increased. Figure 13 presents volatility on wholesale energy markets and the effect of it on PPA prices. It compares the Dutch TTF Natural Gas Index, Spanish Cal+1 electricity prices and the average European pay-as-produced PPA price for solar PV as of 07.03.2023 (Steinecke, Moncayo, Palumbo & Schilling, 2023).

Figure 13.Illustration of volatility on the wholesale energy market and effect on solar PPA prices (Steinecke, Moncayo, Palumbo, & Schilling)

Analyzing the chart, it becomes apparent how closely the price of PPA is linked to electricity and gas prices. For this reason, spikes in energy prices in 2022 have driven up the cost of PPAs to levels never seen before. LevelTen, a major PPA platform, estimates that the price of European PPAs increased by more than 50% year-on-year between the third quarters of 2021 and 2022 (Steinecke, Moncayo, Palumbo & Schilling, 2023).

4.1.2. PPA Market Activity

Despite the most turbulent year in recent energy market history, the number and volume of PPAs remained relatively stable. According to Pexapark data, disclosed contract volumes declined by 21% from 10.7 GW in 2021 to 8.4 GW in 2022. However, the number of transactions increased by 4.5% from 154 in 2021 to 161 in 2022. Figure 14 shows a comparison of disclosed PPA volumes and the number of transactions from 2018 to 2022. It can be observed that 2022 saw the highest number of transactions from 2018. In addition, more PPA volumes were disclosed in 2022 than from 2018 to 2020. It is believed that one of the main factors behind these high numbers was hedging against price spikes and volatility (Pedretti & Kanellakopoulou).

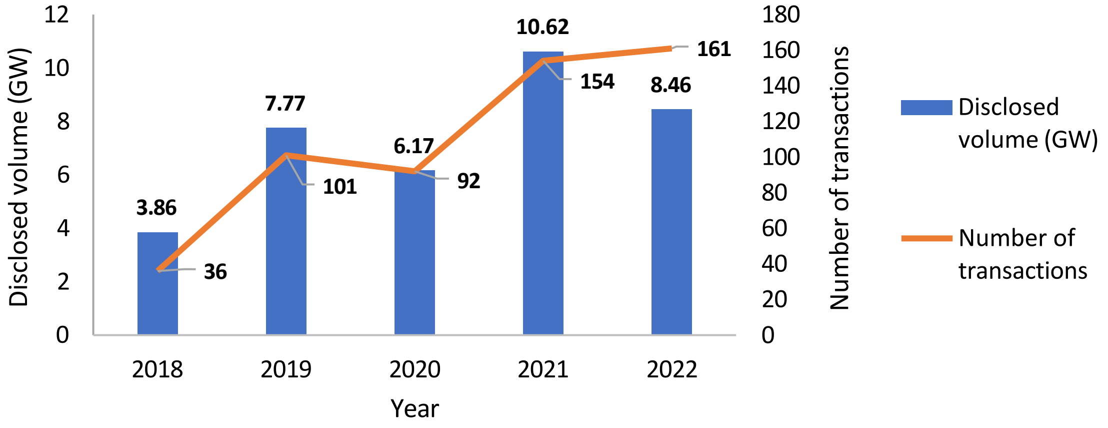


Figure 14. Comparison of disclosed PPA volumes and number of transactions from 2018 to 2022 (Pedretti & Kanellakopoulou).

Moreover, the last quarter of 2022 was characterized by the highest PPA activity, evident in both the number of transactions and volumes of disclosed contracts, as illustrated in Figure 15 and Figure 16. In contrast, the remaining months witnessed stable activity. Even though this pattern of elevated participation in the fourth quarter is a recurring trend that has been observed for years. Market participants tend to accelerate their deal-making efforts during this period to meet their annual targets. Nevertheless, the higher number of transactions and disclosed volumes observed in the fourth quarter signifies a degree of increased confidence and normalization of uncertainty (Pedretti & Kanellakopoulou).

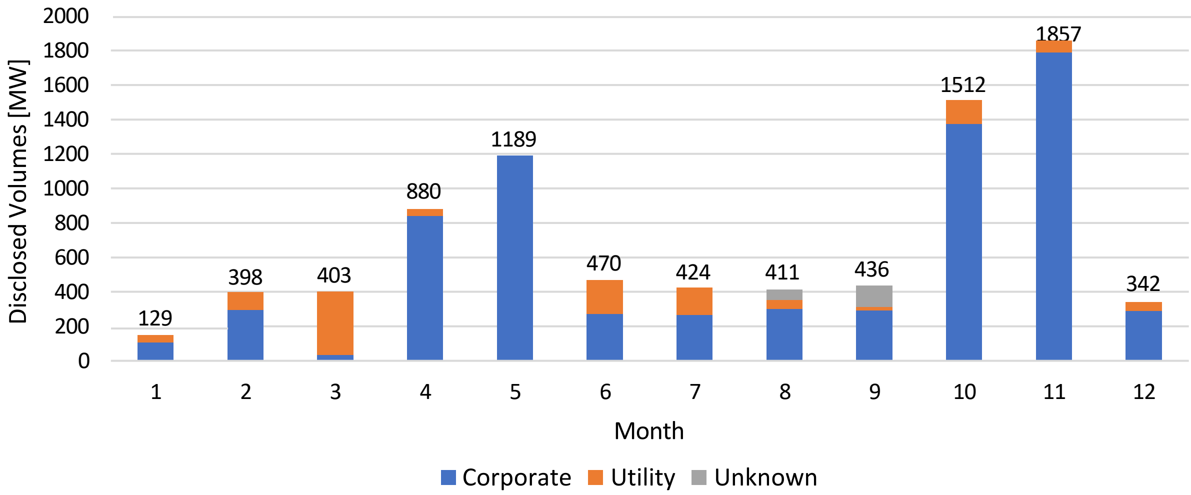


Figure 15. Monthly disclosed PPA volumes in 2022 (Pedretti & Kanellakopoulou).

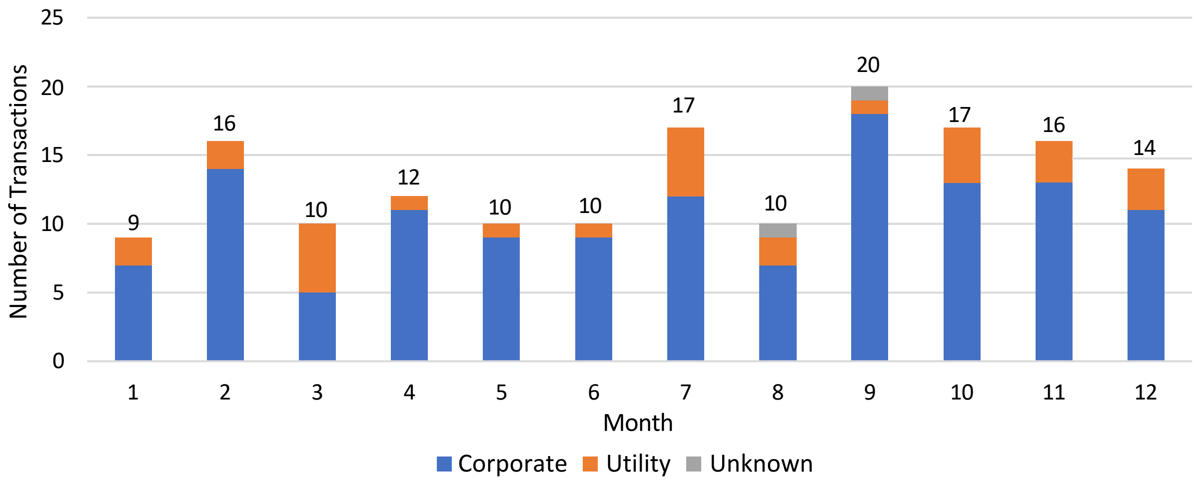


Figure 16. Number of concluded PPAs in 2022 by month (Pedretti & Kanellakopoulou).

The charts above not only show activity among PPAs in 2022, but also divide them into utility Power Purchase Agreements (uPPAs), also known as merchant PPAs, and corporate Power Purchase Agreements (cPPAs), which were not explained earlier. A utility PPA is between an electricity generator and a utility company. A corporate PPA, on the other hand, is concluded between a power generator and an end-user (Pedretti & Kanellakopoulou).

Analyzing the charts above, it is apparent that corporate players had a significant role in driving the European Power Purchase Agreement market. Overall, corporate PPAs accounted for the vast majority, comprising 80% of the total number of transactions and 83% of contracted volumes in 2022. Nonetheless, this is not surprising, as the corporate PPA market has been growing steadily for several years. Figure 17 shows a comparison of disclosed volumes and number of concluded corporate and utility PPAs from 2019 to 2022 (Pedretti & Kanellakopoulou).

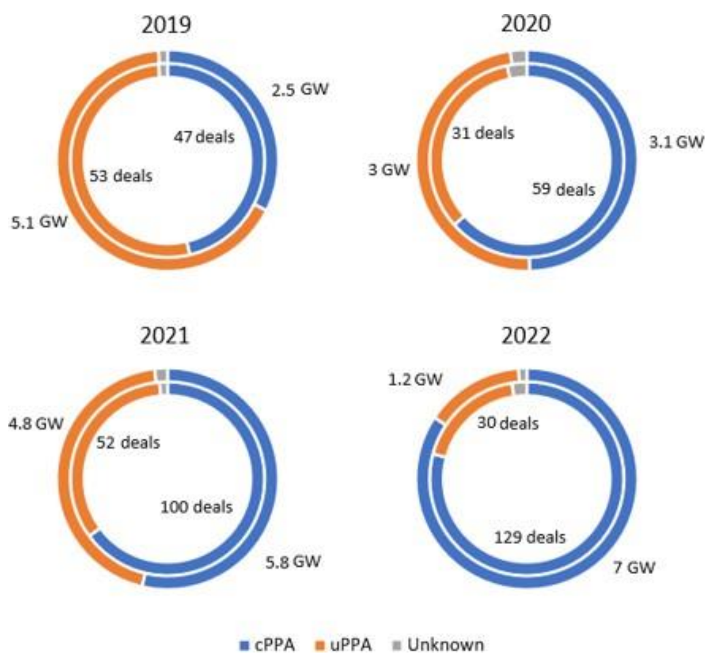


Figure 17. PPA deal flow by off-taker type, deal count and PPA size from 2019 to 2022 (Pedretti & Kanellakopoulou).

As depicted, there was a considerable increase in the number of finalized corporate Power Purchase Agreements from 47 in 2019 to 129 in 2022. During the same period, the number of disclosed volumes increased significantly from 2 GW to 7 GW. In contrast, the number of utility Power Purchase Agreements decreased from 53 transactions in 2019 to 30 in 2022. Similarly, uPPAs disclosed volumes sharply declined from 5.1 GW to 1.2 GW (Pedretti & Kanellakopoulou).

By historical standards, a market characterized by high volatility and price instability is not an ideal environment for contracting. However, activity in the PPA market in 2022 remained high, the main reason being an attempt to mitigate the risks associated with rising and unpredictable prices. Many corporates opted for long-term Power Purchase Agreements instead of securing energy supplies for the near future. Some of the corporations entered into these PPAs as a strategic move to achieve an averaging effect and protect themselves from exorbitant contract prices in the first year. Moreover, the European PPA market continued to transform into a seller's market (Pedretti & Kanellakopoulou).

4.1.3. Balancing costs

As mentioned earlier, the 2022 energy crisis did not result in significant changes to the overall volume or quantity of concluded PPAs. However, it has impacted several other critical aspects of the PPA landscape.

The significant increase in the share of intermittent renewables in the grid mix, coupled with the sharp rise in spot, intraday and balancing electricity prices, has led to a considerable escalation in balancing costs. Over the years, balancing costs have been a relatively secondary issue in the context of PPAs. However, in the aftermath of the energy crisis, they have taken on new importance, exceeding €10 per megawatt hour (MWh) in many markets. Sellers have often faced greater challenges when negotiating balancing agreements compared to conventional PPAs. This transformation highlights the evolving dynamics and priorities within the PPA landscape in response to the energy crisis (Pedretti & Kanellakopoulou).

4.1.4. Alternative pricing mechanisms

Market volatility, elevated price levels and limited liquidity have increased the popularity of alternative PPA pricing mechanisms. Namely, more and more customers have opted for models such as partial fixed price, partial variable price, or inflation-linked PPA. E&C itself was already involved in contracts for a fixed-for-floating price in a certain percentage volume, acting as a contract for difference, and a fixed-price contract with price floor and ceiling in the remaining percentage volume (E&C Consultants, 2023). Such pricing mechanisms indicate that consumers have adopted a proactive strategy to counter market volatility and, by choosing more complex pricing mechanisms, want to protect themselves as much as possible from large price spikes. This is indicative of customers' efforts to ensure relative price stability. The rise in popularity of alternative pricing models also reflects the adaptability required to navigate the current environment of energy market conditions (Pedretti & Kanellakopoulou).

Hybrid pricing structures offer a more balanced approach to risk management and cost monitoring. On the other hand, they allow greater control over how closely the price will be tied to the spot price, the maximum and minimum amount that can be paid for the energy exchanged. This development reflects the industry's response to the challenges posed by a volatile energy market, highlighting the need for flexible strategies to ensure the viability and sustainability of PPAs in this dynamic environment (Pedretti & Kanellakopoulou).

4.1.5. Counterparty & Credit Risk

Another observable trend in the field of Power Purchase Agreements (PPAs) caused by the energy crisis in 2022 is the significant escalation of counterparty risk and credit risk. Counterparty risk has emerged as a key contributor to the collapse of many PPAs in 2022, mainly attributed to challenges in reaching consensus on adequate credit support (Pedretti & Kanellakopoulou).

Greater emphasis on counterparty risk has highlighted the importance of a thorough assessment of the financial stability and creditworthiness of parties involved in PPA negotiations. The changing landscape in 2022 has underscored the industry's recognition of the critical role that credit risk plays in the success and sustainability of PPAs. In addition, it has become apparent that comprehensive risk management strategies are required to protect the integrity of PPAs in an increasingly uncertain energy market (Pedretti & Kanellakopoulou).

4.1.6. Backwardation

Energy price spikes in 2022 have also caused an increase in backwardation, a price phenomenon in which the futures price of a commodity is lower than the expected spot price at the time of delivery. For traders and investors, backwardation is a signal that the current price is too high, and the spot price is expected to eventually fall as the futures contract approaches expiration. The backwardation curve is very important for Power Purchase Agreements because it affects its duration and price (Pedretti & Kanellakopoulou). Figure 18 shows future prices for several countries as of June 1, 2022, showing significant backwardation.

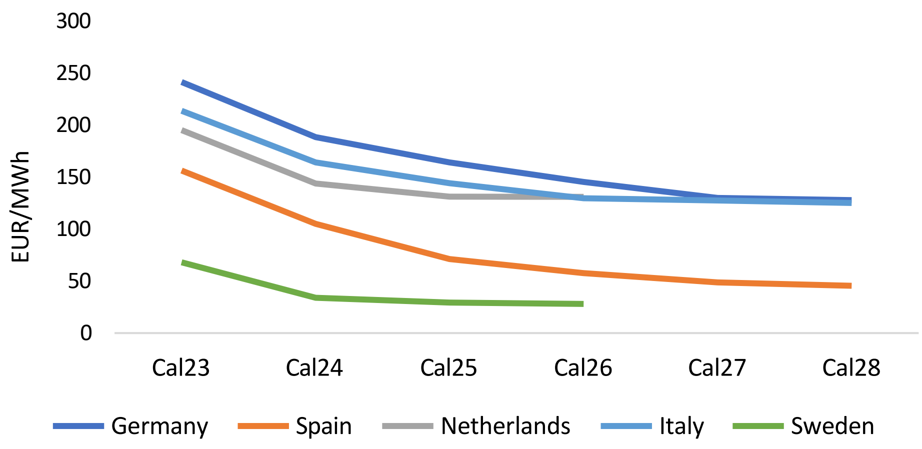


Figure 18. Future prices in selected countries on June 1st, 2022 (E&C Consultants, 2023).

Furthermore, recently substantial backwardation led to a price divergence between short- and long-term PPAs. Short-term supply contracts began to be priced significantly higher than long-term ones. This phenomenon resulted in a high level of interest among power producers in choosing short-term hedges over the usually high-demanded long-term PPAs (Pedretti & Kanellakopoulou).

4.1.7. Cannibalization

With the increase in intermittent renewable generation and limited grid flexibility, the phenomenon explained in the previous chapter, called cannibalization, has become even more profound. In addition, the problem of lower capture prices for renewable energy producers has intensified in 2022. As a result of unexpected deviations from production forecasts, renewable energy producers were often forced to buy energy on the spot market at very high prices, when production from environmentally friendly sources was limited, so energy came mainly from extremely expensive fossil fuels. On the other hand, they had to resell their energy at a lower price when there was an abundance of wind and solar power. As a result, capture factors were very low, which meant that profits from excess energy production sold on spot markets were insufficient to offset the cost of buying energy shortages. These developments imposed an extra and substantial burden on renewable initiatives.

Figure 19 shows a chart from Pexapark of a 20 MW baseload hedge for a 50 MW onshore wind farm in Finland in November. The asset produced 7,337 MWh less than committed, and additional volumes needed to be purchased, which resulted in a cost of 1,704,524 €. In November, the average monthly capture factor for onshore wind in Finland reached a record low of 0.53 (Pedretti & Kanellakopoulou).

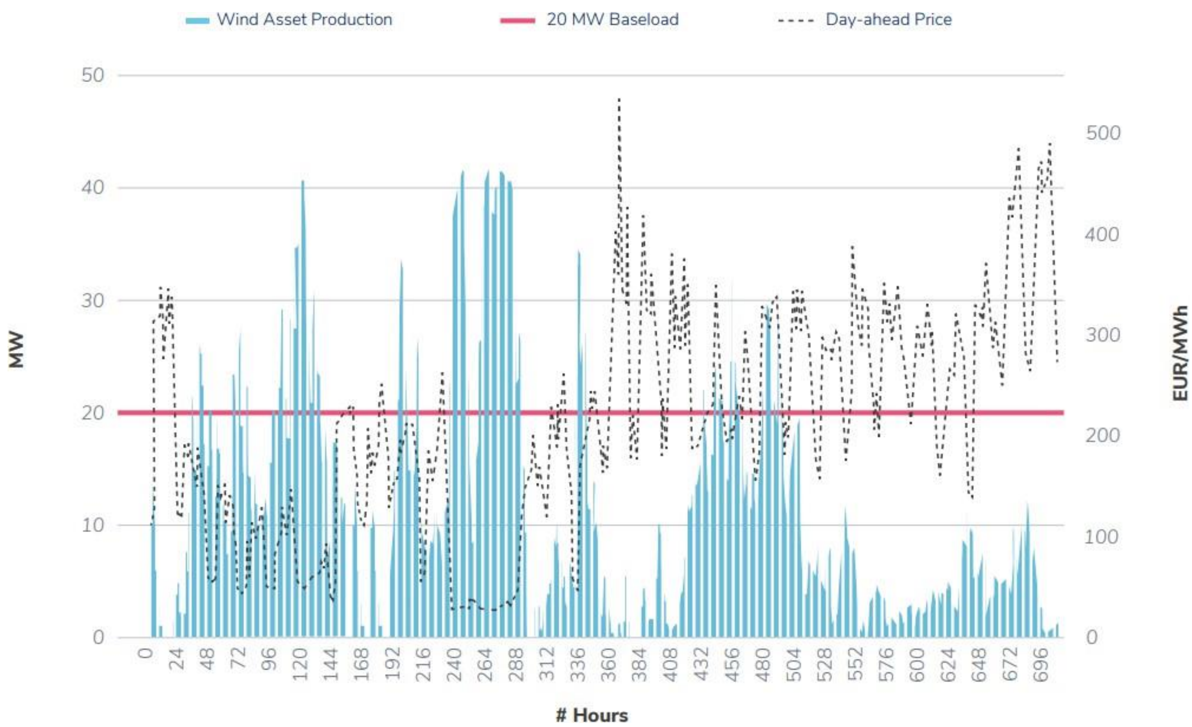


Figure 19. 20 MW Baseload hedge for a 50MW onshore wind asset, November 2022 (Pedretti & Kanellakopoulou).

Figure 19 shows a comparison of the 20 MW baseload hedge for an onshore wind power plant and its actual production. The capacity block hedge for 20 MW is the amount of energy contracted to be delivered over the entire PPA period. Analyzing the chart, it is apparent that production from renewable sources is much lower than the previously defined 20 MW for the majority of time. This means that a large amount of energy had to be purchased on the spot market at very high prices. In this situation, despite having a PPA, the exposure to market prices was still significant. Such a scenario entailed a high price and profile risk for the power producer.

4.1.8. Regulatory Risk

Elevated market volatility has also increased the level of regulatory risk associated with new regulations designed to shield consumers from sudden price spikes. One example of such regulations is the EU-wide revenue cap of 180 €/MWh introduced by the European Commission in September 2022. The cap was intended to recoup excess revenues from electricity generators using technologies with lower marginal costs, including renewables, nuclear power and lignite (Store, 2022)

By setting a uniform EU-wide cap of 180 €/MWh on electricity generated, the Commission's goal was to mitigate the impact of expensive marginal energy sources, such as coal and gas, on the final price of electricity, while ensuring a reasonable return on investment in the technologies covered by the cap. The cap was to be in effect until March 31, 2023 (Store, 2022).

Nevertheless, this regulatory change has raised numerous concerns about its potential impact on Power Purchase Agreement revenues and investors' expected returns on investment. Within the PPA market, the prevailing view is that these regulatory changes could potentially reduce incentives for green energy suppliers to engage in such contractual arrangements. Paula Abreu Marques, who heads the unit at the European Commission's Directorate-General for Energy, highlighted this issue at the start of the RE-Source 2022 conference in Amsterdam, stressing the absolute need for more PPAs to accelerate the development of renewables as a sustainable response to the energy crisis (Gordon, 2022).

4.2. PPA Market in 2023

In 2023, energy prices in Europe experienced a decrease and relatively stabilized. The following part will analyze the changes in offered PPA prices during this period, examining whether they remained as high as in 2022. Additionally, it will explore the prevalence of these contracts in 2022 and the key trends observed.

4.2.1. Prices of PPAs

In 2023, PPA prices saw a decline in selected countries, as previously demonstrated by Figure 13 and now substantiated by LevelTen's data. LevelTen monitors fluctuations in clean energy prices across 20 European countries and publishes a 25th percentile (P25) index, representing that 25% of the PPA prices fall below this threshold, with the remaining 75% being higher, based on PPA proposals submitted to the LevelTen Energy Marketplace. In the first quarter of 2023, the 25th percentile (P25) index for solar energy indicated a 4.7% decrease to 73.20 €/MWh on a quarterly basis. This decrease marked a significant deviation from the sharp price surges observed in the solar energy sector over the previous two years. Nevertheless, this value remained 47% higher than that of the first quarter of 2022 and 76% higher than that of the first quarter of 2021. In contrast, wind energy prices continued to rise, driven by challenges in obtaining permits and rising costs, leading to a 35% increase in prices over the last six months (Solar PPA Prices Drop in Europe for First Time in Two Years According to New LevelTen Energy Report, 2023).

Figure 20 depicts the changes in the median PPA price across various European countries and the overall EU PPA price index (Casey, 2023).

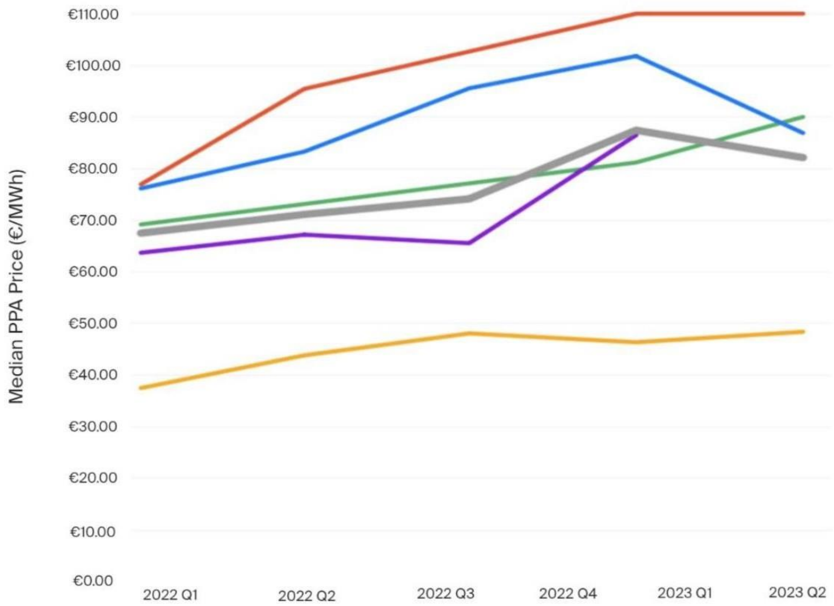


Figure 20. Median PPA prices in Europe from 2022 to 2023: Poland (red), the Netherlands (green), Germany (blue), Italy (purple), the EU PPA price index (grey) and Spain (yellow) (Casey, 2023).

Examining the data for 2023, the EU's PPA price index decreased from roughly 88 €/MWh in the first quarter to about 82 €/MWh in the second quarter. Among the selected countries, Poland maintained the highest average PPA price at 110 €/MWh throughout 2023. Spain observed a marginal price increase, with its average PPA price remaining around €49/MWh, the lowest among the other selected countries. Notably, the Netherlands experienced a significant rise, with the average PPA price increasing from 81 €/MWh to 90 €/MWh, surpassing the EU PPA price index for the first time since the third quarter of 2022. In contrast, Germany witnessed a considerable decline in 2023, dropping from roughly 100 €/MWh to less than 90 €/MWh (Casey, 2023).

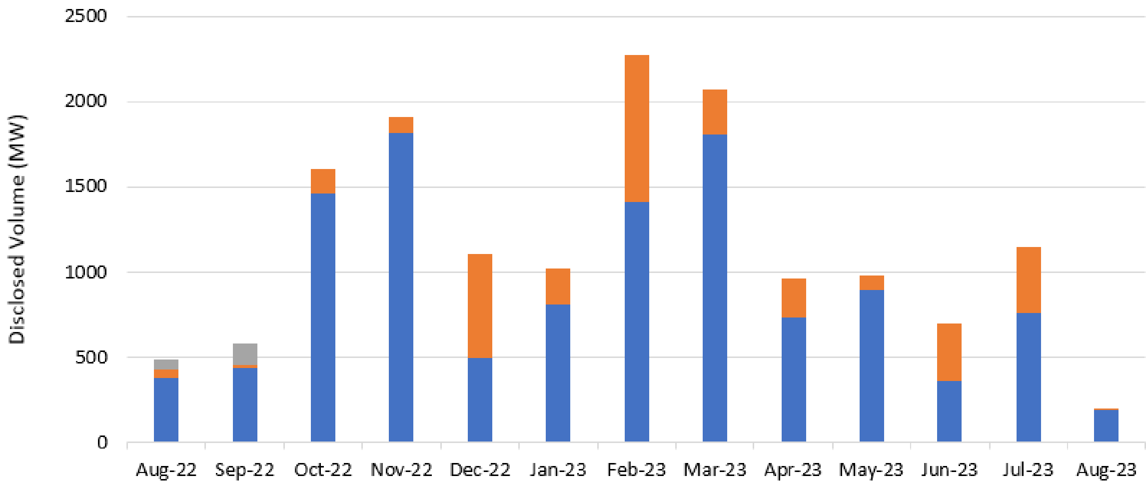
4.2.2. PPA Market Activity

Analyzing the Power Purchase Agreement activity in 2023, there was no sign of slowdown compared to 2022. In February 2023, 29 agreements were announced in Europe, setting a record for the highest number of transactions in a single month. In addition, Spain was a leader with eight PPA deals, establishing a new country-specific record. Most of the agreements made in February were of smaller or medium scale, with 16 deals involving less than 50 MW of capacity and only seven exceeding 100 MW. Additionally, the new capacity secured under these contracts increased by 66%, reaching a total of 2.17 GW. In March 2023, yet another PPA record was broken, with a disclosed capacity exceeding 2.5 GW. It was reported to be the highest disclosed volume ever recorded in a single month, representing a 14% increase from the previous month of February (Hough & Ljubic, 2023).

Moreover, this month, a significant electricity market reform was introduced by the European Commission, holding the potential for a highly positive impact on the PPA market. It was estimated that the proposed measures were to unlock 1000 terawatt-hours (TWh) of corporate demand. An important aspect of this proposal was its preservation of the existing market structure, which offered market participants long-term certainty. Announced adjustments rested on two main pillars. The first pillar involved structuring all public support schemes as bilateral contracts for difference (CfDs). The goal of it was to prevent investors under CfDs from exploiting excessive profits from price volatility fluctuations. The second pillar focused on the introduction of credit support mechanisms, which involved the implementation of guaranteed schemes addressing settlement and replacement risk. This approach can be established in a fully market-based manner, as evidenced by the Norwegian Export Credit Guarantee Agency (GIEK), which provides credit coverage for PPAs in exchange for risk-adjusted premiums. Credit constraints have posed a considerable obstacle to the conclusion of many PPAs, and these reforms aimed to alleviate this challenge (Pedretti, The Coming of The Golden PPA Age, 2023).

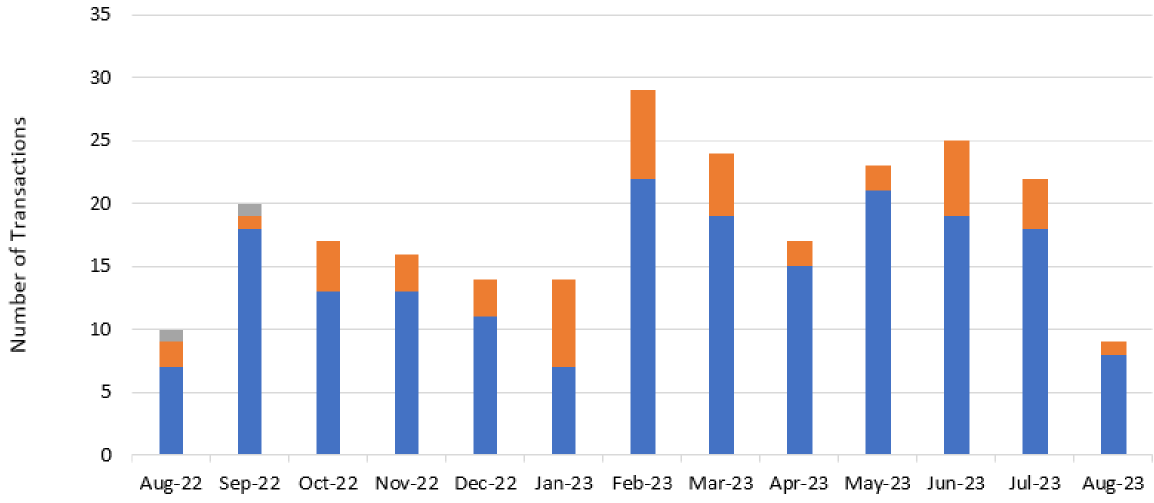
However, despite a solid first quarter in 2023 and high expectations following regulatory changes, the second quarter of the year saw a significant decline in overall PPA activity. April experienced a 55% drop in announced PPA volumes and a 33% drop in the number of transactions. The situation improved slightly in May, but the overall output of monthly deals remained relatively low. Moreover, in June the lowest PPA volume since September 2022 was concluded (Hough & Ljubic, 2023).

In the third quarter of the year, the market rebounded, witnessing a 64% surge in newly revealed PPA volumes in comparison to June. In August PPA activity decreased by 84%, however, this decline can be ascribed to the holiday season, as it is a relatively typical occurrence for transaction activity to diminish during this period. Figure 21 and Figure 22 below provide a comparison of disclosed volumes and the number of PPA transactions from 2022 to the most recent date (Hough & Ljubic, 2023).



	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23	Apr-23	May-23	Jun-23	Jul-23	Aug-23
Unknown	59	123	0	0	0	0	0	0	0	0	0	0	0
Utility	50	21	136	97	606	212	866	263	232	84	342	388	4
Corporate	376	436	1464	1815	498	807	1406	1809	731	898	357	757	189

Figure 21. Overview of PPA disclosed volumes from August 2022 to August 2023 (Hough & Ljubic, 2023)



	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23	Apr-23	May-23	Jun-23	Jul-23	Aug-23
Unknown	1	1	0	0	0	0	0	0	0	0	0	0	0
Utility	2	1	4	3	3	7	7	5	2	2	6	4	1
Corporate	7	18	13	13	11	7	22	19	15	21	19	18	8

Figure 22. Overview of number of PPA transactions from August 2022 to August 2023 (Hough & Ljubic, 2023)

By the end of August, signed volumes have reached 9.5 GW in 166 deals, surpassing last year figure of 162. This number may indicate a potential new record, especially given the expected increase in activity during the last quarter of the year when many contracts rush to conclusion before year-end. Moreover, as can be seen from the charts above, the PPA market is predominantly oriented toward corporate demand. Corporate PPAs significantly outnumber utility-PPAs in 2022 and 2023 (Kanellakopoulou M., A data-driven preview of 2023's PPA landscape, 2023).

4.2.3. Overview of PPA trends

In 2023, some of the dominant trends include concerns about the risks associated with starting commercial operations. This is partly attributed to financing issues due to rising costs, as well as regulatory uncertainty (Kanellakopoulou M., A data-driven preview of 2023's PPA landscape, 2023).

Moreover, hedging against market volatility and securing below-market rates through green PPAs remains the primary motivation for many participants to enter into PPAs, as was the case in 2022. This represents a shift away from the initial focus on ESG (environmental, social and governance) objectives that initially drove the growth of the European PPA market (Kanellakopoulou M., A data-driven preview of 2023's PPA landscape, 2023).

A notable development is the increasing involvement of corporate entities in vendor-led tenders, a trend that has emerged relatively recently, in less than 18 months (Kanellakopoulou M., A data-driven preview of 2023's PPA landscape, 2023).

5. Risk Assessment

The importance of risk assessment is emphasized by the magnitude of volatility in energy markets, as shown in Figure 23, which compares energy price volatility with other asset classes. In that case, volatility is quantified by the standard deviation of historical annual returns, which measures the extent to which values deviate from the average. Returns, on the other hand, represent the financial gains or losses made on investments over a designated period (Werner, 2020).

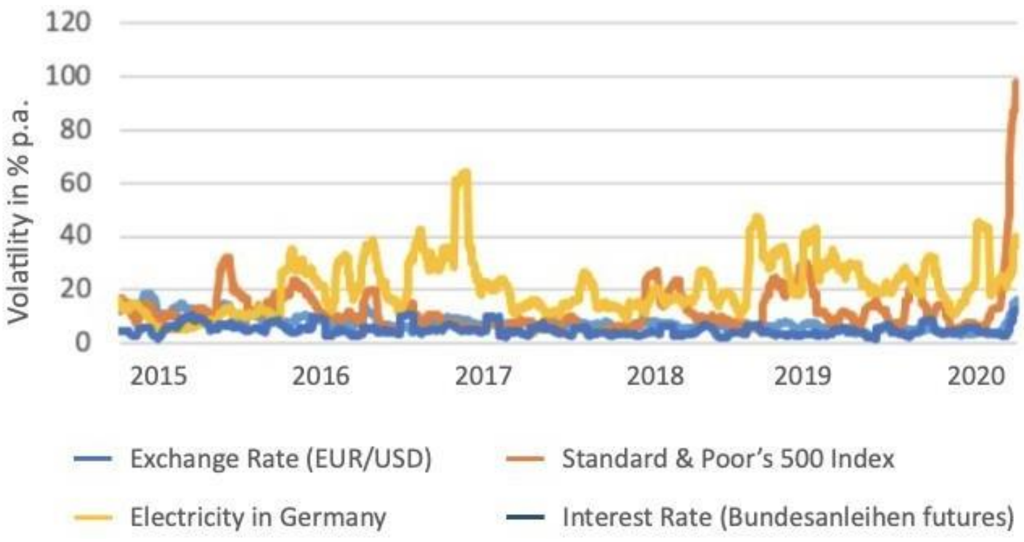


Figure 23. Historical volatilities for various asset classes (Werner, 2020)

As shown in Figure 23, energy markets show much higher volatility compared to exchange rates (such as the EUR/USD), interest rates (as seen in German Bundesanleihen futures) and equities (such as the Standard & Poor's 500 index). While these other financial indices typically experience volatility in the 10% to 15% range, energy prices show muchŚ higher levels. This significant degree of uncertainty demonstrates the importance of conducting a meticulous risk assessment and applying effective risk management tools, especially for long-term electricity sales contracts (Werner, 2020).

Based on the analysis of the chart above and the points elaborated in the previous sections, it becomes evident how crucial effective risk management is. This is especially pertinent during times of uncertainty in energy markets, instilling concerns among consumers about their ability to maintain their energy budgets. For this reason, the following section conducts an extensive risk assessment of PPAs, considering PPA prices before and after the energy crisis, as well as the historically high electricity prices observed in 2022. E&C Consultants' Monte Carlo simulation tool is used to conduct this examination.

For the risk assessment, two distinct markets have been selected: Germany and Spain. These countries differ in terms of the composition of their energy mix, dependence on Russian fossil resources, advances in renewable energy technologies and maturity of PPA markets. This choice was made to provide a comprehensive perspective on the impact of the energy crisis on the different European countries.

The subsequent section provides a comprehensive analysis of the electricity and Power Purchase Agreement markets in Germany and Spain. This is followed by an evaluation, using the Pexapark tool What, to examine volatility in these markets. The following segment provides a detailed definition of the Monte Carlo method, outlining its basic assumptions and objectives. Next, the methodology used in the simulations conducted for this study, covering its basic principles, input parameters and all underlying presumptions, is explained. The chapter concludes with a presentation and summary of the results of the study.

5.1. Analysis of German and Spanish markets

This chapter begins with an in-depth study of the German and Spanish energy markets, including a comprehensive analysis of the country´s electricity mix and PPA market. The goal of this preliminary examination is to lay the groundwork for a more detailed understanding of the results obtained in subsequent simulations. For example, a country's degree of dependence on Russian fossil fuels significantly affected its electricity prices in 2022, which in turn had an impact on the offered PPA prices. For example, Pexapark reported a record high short-term PPA rate in Germany, reaching 380 €/MWh.

This was followed by a study of the PPA market in selected countries, including an analysis of the number of finalized contracts and disclosed volumes over the years. In addition, the position of these countries in the European context was assessed, considering the level of development and maturity of their PPA markets, along with the prices offered.

Next, an analysis of market volatility in Germany and Spain is presented, employing Pexapark tool based on historical energy prices. This study contributes to a more comprehensive understanding of the potential consequences and uncertainties faced by customers seeking to enter into long-term contracts in these markets.

5.1.1. Electricity market

German and Spanish markets were selected because of some similarities and differences they show in terms of interconnection development, renewable generation in the electricity mix, supply dependence, but also the maturity of the PPA market or different weather conditions. This subsection aims to delve deeper into the selected electricity markets, enabling a comprehensive understanding of the further risk assessment simulations performed.

Figure 24 represents total energy supply (TES) by source in Germany and Figure 26 in Spain from 2010 to 2021. Total energy supply (TES) is the sum of production and imports subtracting exports and storage (World Energy Balances 2022, n.d.).

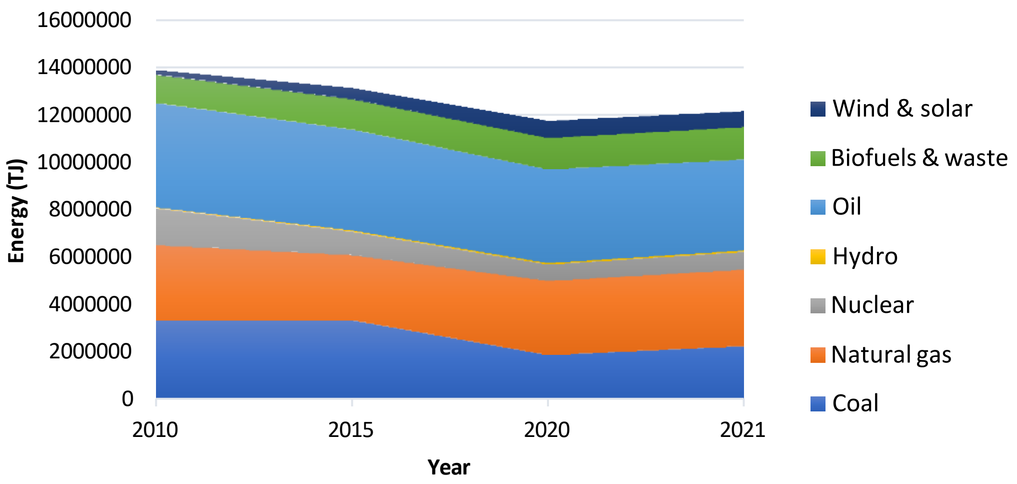


Figure 24. Total energy supply (TES) by source in Germany from 2010 to 2021 (World Energy Balances 2022, n.d.)

From 2010 to 2021, Germany's principal energy sources were mainly coal, oil and natural gas. However, consumption of both coal and oil has declined over time, while natural gas consumption has remained relatively stable. In addition, Germany has been phasing out nuclear power since 2011 after the Fukushima disaster, which has led to a decline in nuclear power consumption with some steady trends recently. The share of hydropower in Germany's energy mix is limited. Nevertheless, Germany is investing extensively in renewable energy, particularly wind and solar power. In addition, Germany has significant biomass power plant capacity (World Energy Balances 2022, n.d.).

As depicted in the chart, Germany has a substantial dependence on fossil fuel resources, especially coal and natural gas. In the past, Germany derived much of its energy from coal mined in regions such as North Rhine-Westphalia and Saarland. However, by December 2018, Germany had ceased all domestic coal mining operations. While the country still has a considerable reserve of hard coal, estimated at 83 billion tons, only about 36 million tons are considered potentially mineable. The extreme depth and complex geological conditions of these deposits make mining too expensive for the global market. Similarly, in the context of lignite mining, Germany once held the title of the world's leading producer. However, they were significantly overtaken by China, and as a result, starting in 2021. Germany began to import a significant portion of its consumed coal from various sources. The largest share came from Russia (50%), followed by the United States (17%), Australia (13%) and Colombia (6%). Additional imports came from Poland, Canada and South Africa (Appunn, 2023).

Furthermore, Germany is one of the world's largest importers of natural gas, with about 95 percent of its consumption coming from abroad. In 2021, Germany imported 142 billion cubic meters (bcm) of gas, mostly coming via pipeline from Russia. Figure 25 shows German gas supply in 2021 by source.

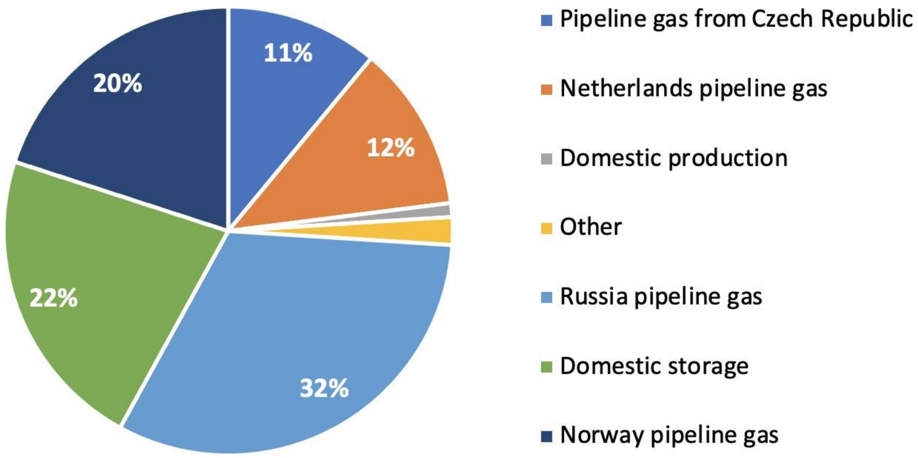


Figure 25. German gas supply in 2021 by source (Eckert & Kate, 2022).

In addition, until the end of 2022 Germany was solely dependent on natural gas imports via pipelines. The country had no liquefied natural gas (LNG) regasification terminals of its own, forcing them to import LNG via facilities located in neighboring countries, particularly Belgium and the Netherlands. In addition, part of Germany's LNG supply was transported overland. For a long time, there was a perception that Germany did not have an economic justification for directly importing LNG, due to its extensive network of pipeline connections and Europe's substantial but untapped LNG import capacity. However, the landscape underwent a remarkable transformation after Russia's invasion of Ukraine. In response to this geopolitical event, Germany quickly intensified efforts to improve its gas import infrastructure, inaugurating a temporary floating terminal in December 2022 (Eckert & Kate, 2022).

As evidenced, Germany was heavily reliant on Russian fuel imports. Therefore, the energy crisis in 2022 had a significant impact on this country. As natural gas prices are closely linked to electricity prices, in the second half of 2022, the average wholesale electricity price in Germany reached almost €330/MWh. In Spain, on the other hand, average prices were much lower during the same period, at around €130/MWh due to the price ceiling. For this reason, Germany delayed the planned closure of its three remaining nuclear reactors, and delayed the shutdown or reactivated a fossil fuel-fired power plants. As a result, Germany still accounts for most of the additional coal-fired capacity, with nearly 10 GW for the winter of 2022/2023 (Electricity Market Report 2023).

Figure 26 below examines total energy supply by sources in Spain from 2020 to 2021, indicates similar trends as in Germany.

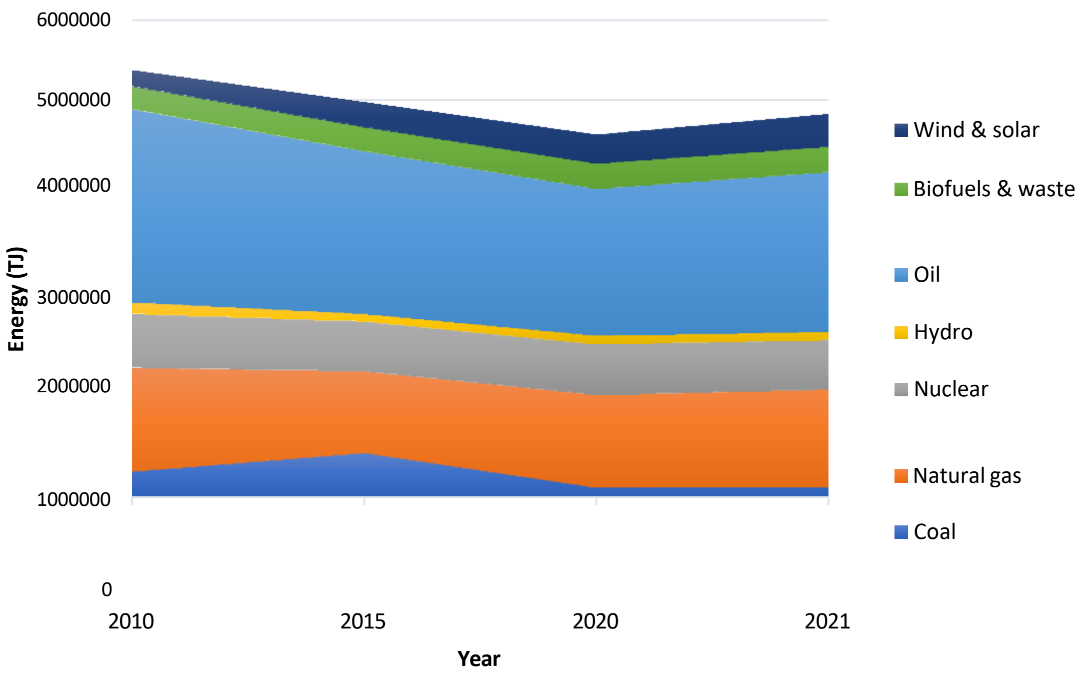


Figure 26. Total energy supply (TES) by source in Spain from 2010 to 2021 (World Energy Balances 2022, n.d.)

As depicted, Spain's coal and oil supply has gradually declined over the years, while natural gas supply has remained relatively stable. Spain has several nuclear power plants that contribute substantially to its energy mix. Nonetheless, nuclear supply has declined over the period. Due to its favorable geographic location, the country has a considerable hydropower potential, with an observed increase between 2010 and 2021. Spain has also made significant progress in renewable energy, particularly wind and solar power. Moreover, the use of biofuels and waste as energy sources is on an upward trend (Electricity Market Report 2023).

Spain, located in the southwestern part of Europe, is less dependent on Russian fossil fuel imports. According to Eurostat, energy imports from Russia in 2020 amounted to just 7.5%, significantly less than the EU average of 24.4%. From this share, gas imports accounted for 10.5% compared to the EU average of 41.1%, while oil and coal accounted for 8.8% and 43.2%, respectively. The Iberian Peninsula is considered an energy island with limited energy transportation infrastructure - connections between Spain and France account for only 3% of electricity and include only two pipelines. These pipelines are connected to the Algerian gas hub at Hassi R'Mel - one directly from Algeria and the other via Morocco. Moreover, Spain has the largest regasification capacity in Europe. Its milder climate compared to northern European countries meant that household heating demand accounted for only 40% of total household demand, as opposed to the EU average of 62%. This combination of a diversified energy infrastructure and limited dependence on Russian gas meant that Spain never faced the risk of a gas shortage. Nevertheless, the tension in the gas market has had several consequences, most notably a sudden increase in electricity prices, which in turn has contributed to inflation (Pérez, 2023).

Additionally, in June 2022, the Commission approved a strategy to reduce the cost of electricity generated by fossil fuel-fired power plants in Spain and Portugal. As part of this initiative, electricity producers received direct financial support to offset part of their fuel expenses. The payment was calculated daily based on the difference between the market price of natural gas and the price set by the initiative. From June to December 2022, the cap was 40 €/MWh, increasing by €5 per month thereafter. Funding for the program came from two sources:

congestion income, that is, income generated by cross-border electricity trade between France and Spain, and the cost of the adjustment imposed by Spain and Portugal on program beneficiaries. The mechanism gradually lowered wholesale electricity prices, benefiting consumers. It is estimated that the total net savings, after adjustment costs, amounted to about €5 billion for consumers in both countries from June 2022 to January 2023 (State aid: Commission approves prolonged and amended Spanish and Portuguese measure to lower electricity prices amid energy crisis, 2023).

Figure 27 illustrates the SPOT electricity prices in Germany and Spain from 2020 through July 2023, highlighting the influence of the energy crisis. Spot prices reflect current market conditions and represent the prices at which electricity is sold for immediate delivery, usually within the same day or in the near future. They are determined by real-time supply and demand dynamics, weather conditions, generation mix and other short-term factors. They are therefore the best indicator of the state of the market at any given time.

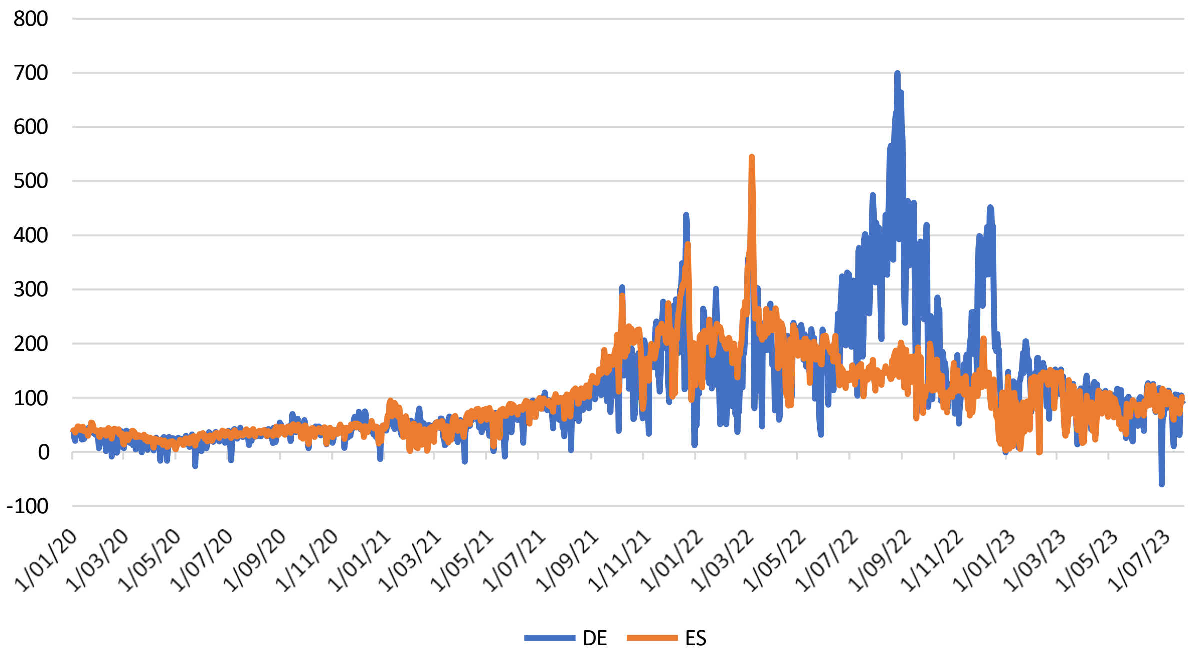


Figure 27. SPOT prices in Germany and Spain from 01.2020 to 07.2023 (OMIP, 2023; German Power Market Data, n.d.; E&C Consultants, 2023).

As depicted in the data, both countries experienced a gradual increase in prices starting from the third quarter of 2021, but in 2022, they escalated to unprecedented heights. Notably, the impact of the Iberian implemented in Spain is evident as electricity prices saw a substantial decrease in the latter half of 2022. In contrast, during the same period, the German market witnessed historically high price levels. In 2023, prices in both countries have already begun to fall and stabilize. However, the repercussions of the exceptionally high prices experienced in the past continue to reverberate and have a lasting impact to this day.

Figure 28 shows future Cal+1 prices in Germany and Spain, representing market expectations for future electricity prices. These prices are influenced by factors such as long-term supply contracts, expectations of changes in generation capacity, fuel prices, regulatory changes, and economic conditions. Comparing spot prices with Cal+1 prices allow market participants to assess whether the market anticipates significant changes in electricity prices in the near future.

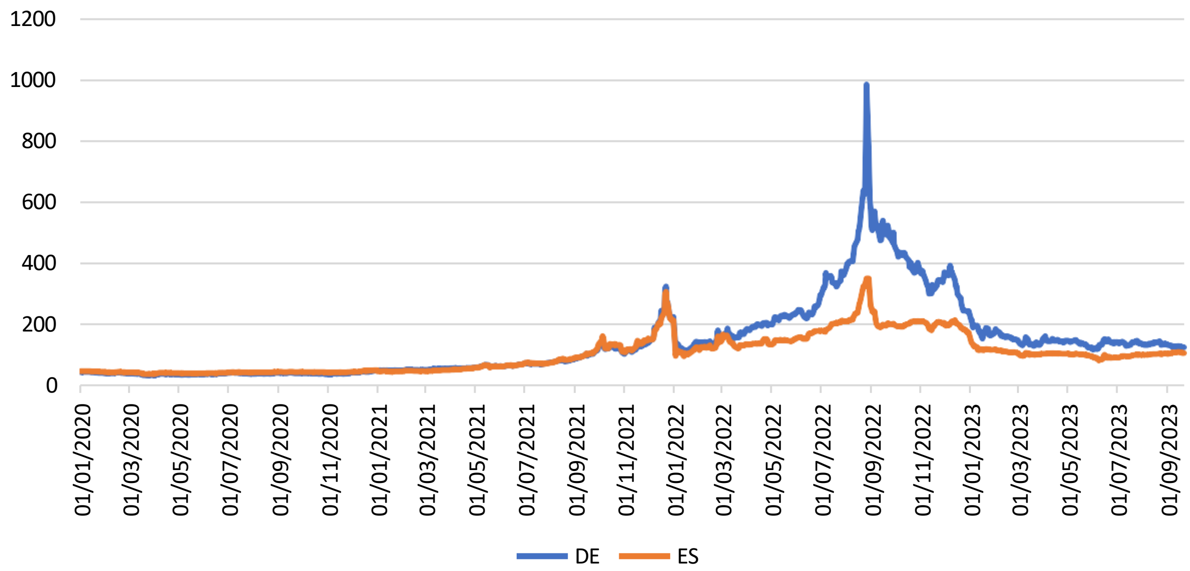


Figure 28. Cal+1 prices in Germany and Spain from 01.2020 to 09.2023 (OMIP, 2023; German Power Market Data, n.d.; E&C Consultants, 2023).

During the reviewed period, both German and Spanish Cal+1 electricity prices showed a steady upward trajectory, with German prices significantly exceeding those in Spain. However, there was a shift in the last quarter of 2022, as both countries experienced a decline in these prices. This trend indicates a potential easing of previously observed price pressures and a return to more stable and manageable electricity price dynamics.

Electricity prices play a key role in shaping the dynamics of PPAs. When electricity prices are high, PPA prices tend to reflect these higher market rates, potentially leading to higher costs for buyers. Conversely, during periods of lower electricity prices, PPAs often offer more favorable terms as sellers seek to attract customers with competitive prices. Consequently, fluctuations in electricity prices have a direct impact on the financial benefits and risks associated with long-term PPAs. The next section of this chapter will examine the PPA market in more detail in selected countries.

5.1.2. PPA market

The PPA markets in Germany and Spain exhibit distinct differences influenced by their unique energy mixes, regulatory frameworks, market maturity, and energy dependence. These variations significantly shape how PPAs are structured and utilised in each country. Following section explores the contrasting features of the German and Spanish PPA markets, highlighting their impact on energy procurement and renewable energy adoption.

Spain is a frontrunner in the global market when it comes to the number of Power Purchase Agreement (PPAs) signed. According to Pexapark, in 2021, Europe concluded approximately 11.1 GW of PPAs, with Spain accounting for nearly 4 GW of that total. It is worth noting that Alcoa played a significant role in this achievement with two significant PPAs. The initial contract with Greenalia covered 924 MW of onshore wind capacity, followed by a further contract covering the delivery of 131 MW of baseload capacity. Moreover, the largest PPAs, not only in Spain but also in the whole of Europe, were baseload PPAs (Pedretti & Kanellakopoulou).

Figure 29 presents the 10 countries in the EU with the highest disclosed capacity in 2022. As illustrated, Spain is the undisputed leader, surpassing Ireland, the second country, by more than 3 times and Germany, the third country in the ranking, by more than 4 times (Pedretti & Kanellakopoulou).

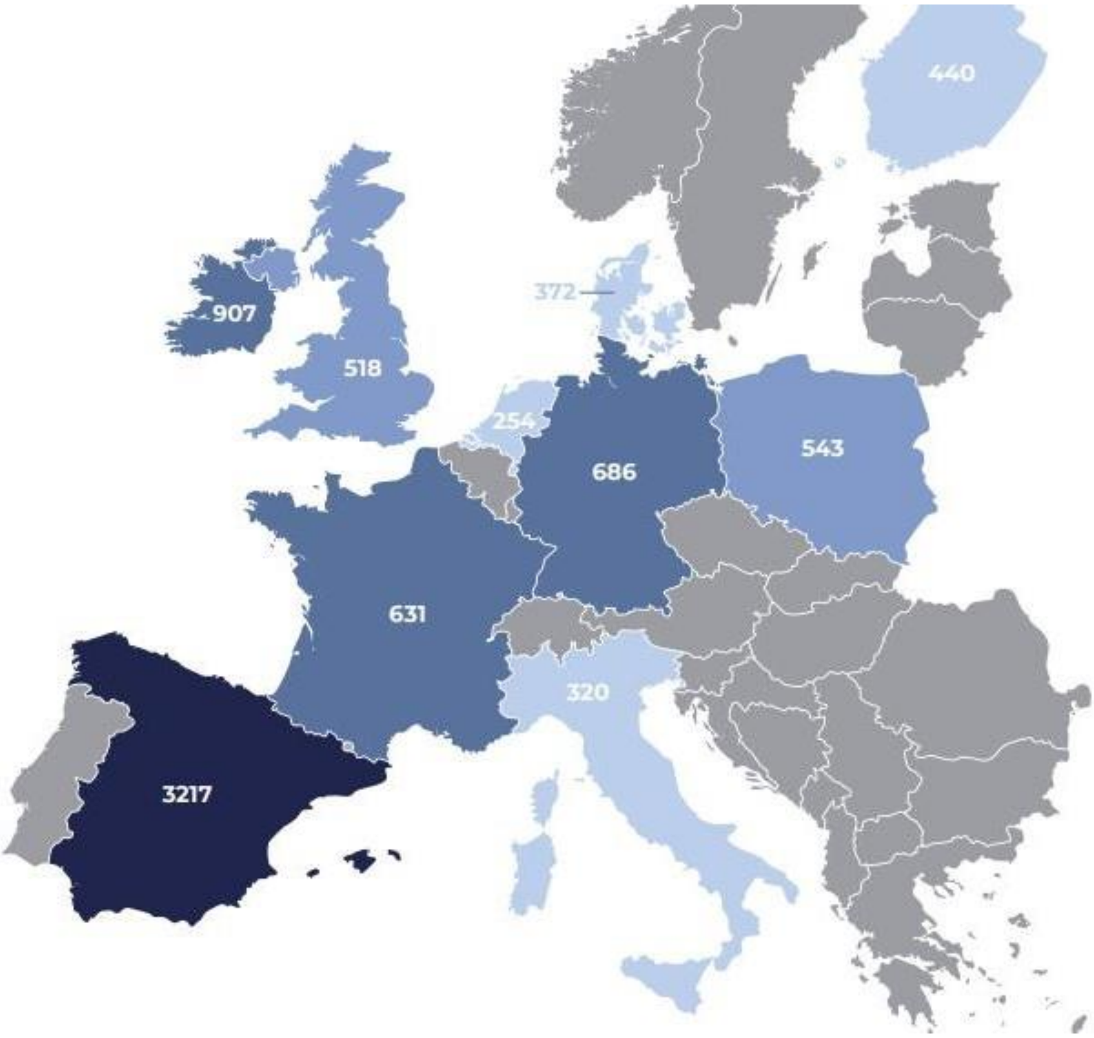


Figure 29. Ten countries with the highest disclosed contracted capacity in MW as of 2022 (Pedretti & Kanellakopoulou).

In terms of the number of transactions in 2022, Spain continued to lead the way with a total of 31 transactions. Germany, on the other hand, advanced to second place, recording a total of 23 deals. Nevertheless, the increase in deal volume in this country was not proportional to the number of deals, mainly due to the fact that the PPAs concluded were for smaller-scale projects, usually in the range of 5 to 10 MW. Additionally, some of the PPAs were concluded for a period of less than 5 years, and these types of short-term PPAs are not included in Pexapark's statistics. Looking at German PPAs in more detail, the country experienced a decrease in the share of offshore PPAs compared to the 2021 data. On the other hand, there has been a clear increase in activity centered around solar projects. Table 3 presents a comparison of PPA activity in 2021 and 2022 among the top 10 countries with the highest number of transactions (Pedretti & Kanellakopoulou).

Table 3. Comparison of PPA activity in 2021-2022 among the 10 countries with the highest number of transactions (Pedretti & Kanellakopoulou).

Country	Transactions in 2021	Country	Transactions in 2022
Spain	**35**	**Spain**	**31**
Sweden	16	**Germany**	**23**
Germany	**15**	Great Britain	15
Finland	14	Poland	13
Great Britain	12	Denmark	12
Poland	11	Finland	12
France	10	Italy	9
Denmark	8	Sweden	7
Netherlands	8	France	6
Italy	8	Norway	5

It is worth noting that the Operador del Mercado Ibérico de Energía (OMIP), which acts as the regulator of the Iberian energy market in Spain, currently monitors PPA prices. This tracking mechanism ensures that customers are well informed of the latest PPA price dynamics and related trends. Unfortunately, the website does not offer data from 2022. Analysis of the 2023 information shows a decrease in the prices offered under PPAs from around 64 €/MWh on 2 January 2023 to 58.50 €/MWh on 12 August 2023, as shown in Figure 30 (OMIP, 2023).

Figure 30. Overview of PPA prices in Spain in 2023 at 11.08.2021 (OMIP, 2023).

There is no equivalent PPA price monitoring tool in Germany. However, based on LevelTen´s PPA Price index, the price during the third quarter of 2022 was recorded at 90 €/MWh. LevelTen Marketplace offers the world's largest collection of PPA price quotations, covering

21 countries in North America and Europe. Each quarter, the LevelTen Energy PPA Price Index is published, which shows the prices offered by wind and solar project developers for Power Purchase Agreements. Importantly, LevelTen's indexes use the 10% most competitive bids in a selected market to determine its index (Level Ten´s PPA Price Index, 2023).

In previous sections of this chapter, the German and Spanish electricity and Power Purchase Agreement markets were examined. The assessment included a detailed study of electricity price trends during the 2022 energy crisis, a comparative examination of the countries' dependence on Russian fossil fuel imports, and an assessment of the maturity levels of the PPA markets. Subsequently, the following sections will use statistical tools, using a historical electricity price approach, to assess the risks associated with long-term contracts in both the German and Spanish markets. This approach will facilitate the assessment of market volatility, serving as a valuable resource for stakeholders considering concluding PPA in these regions.

5.1.3. Volatility analysis using historical approach

In this section of the report, an analysis of market volatility within the German and Spanish electricity markets is undertaken using a statistical tool provided by Pexapark. This tool employs a simulation approach to evaluate market risk, primarily relying on historical price data. Log-returns, which represent the natural logarithms of price indexes between specific dates, are utilized to compute fundamental risk metrics such as standard deviation and value at risk (VaR) (Werner, 2020).

For the calculations, Cal+2 product prices were used to examine future trends, gaining insight into the potential risk and volatility associated with electricity prices over a two-year supply period. Cal+2 product is a futures price, that indicates the prediction of a price two year ahead. A 5-day interval was used in the calculations, as suggested by Pexapark (Werner, 2020).

Firstly, logarithmic returns and standard deviation were calculated. Calculating log-returns over a 5-day interval for prices in Germany and Spain provides insight into the percentage rate of change and volatility of electricity prices during that period. Positive logarithmic returns indicate rising prices, while negative logarithmic returns indicate falling prices. Analysis of logarithmic returns helps to understand short-term price dynamics, assess potential risks associated with price fluctuations, and make informed decisions related to risk management strategies and energy market investment planning. The chart below shows the distribution of logarithmic returns in Germany and Spain (Werner, 2020).

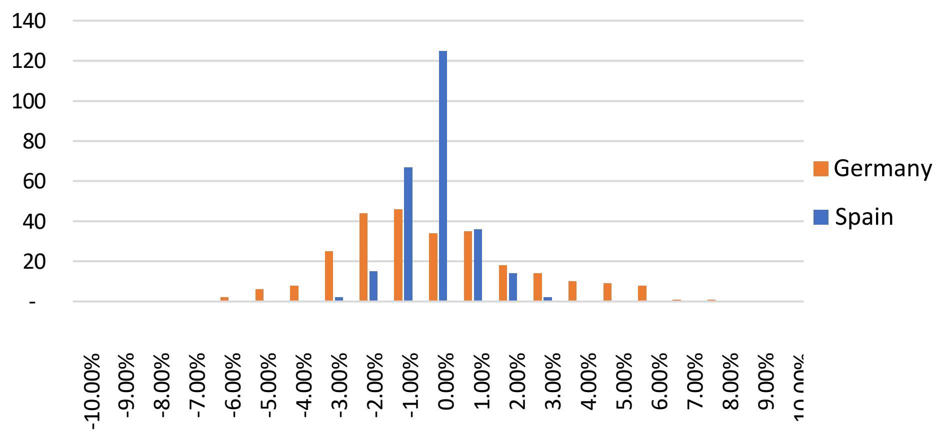


Figure 31. Distribution of log-returns in 2019 in Germany and Spain.

Figure 31 illustrates the distribution of logarithmic returns within a range of +/- 0.005% from selected values from -10% to +10%. Analysis of 2019 prices shows that Spain has a higher number of logarithmic returns centered around 0, indicating a more stable price environment than Germany. This is supported by the fact that Germany shows a wider distribution of logarithmic returns, from negative values starting at around -6% to positive values reaching up to +8%. In addition, both Germany and Spain show mostly negative log-returns, suggesting a general downward trend in electricity prices.

Subsequently, the standard deviation was calculated for each country, providing insight into the range of volatility in Cal+2 electricity prices over a 5-day period. A higher standard deviation indicates a higher level of market volatility, while a lower standard deviation suggests lower volatility. The results of these calculations are displayed in Table 4 (Werner, 2020).

Table 4. Calculated standard deviations of Cal21 product in Germany and Spain from 2019.

Country	Germany	Spain
Year	2019	
Standard deviation	2.67%	0.94%

The calculation of standard deviations reinforces the findings from the analysis of log-returns, confirming that the German market is characterized by a higher degree of fluctuations compared to the Spanish market. This is evidenced by the calculated standard deviation of 2.67% for Germany and 0.94% for Spain.

To further examine volatility in the German market, which showed much higher variability, the standard deviation of Cal+2 prices from 2018 to 2022 was also calculated. This analysis provided a comprehensive assessment of market volatility over a broader time frame, offering valuable insight into the stability and fluctuation of electricity prices over the years. The values of calculated standard deviations are presented in Table 5 (Werner, 2020).

Table 5. Calculated standard deviations of Cal+2 product in Germany from 2018 to 2022.

Country	Germany				
Year	2018	2019	2020	2021	2022
Standard deviation for Cal+2	3.32%	2.64%	3.46%	4.85%	10.53%

Analysis of standard deviations for German Cal+2 prices from 2018 to 2022 reveals significant changes in market volatility over the selected period. In 2018, the standard deviation was 3.32%, indicating a moderate level of volatility. The following year, 2019, saw a slight decrease in volatility with a standard deviation of 2.64%. Interestingly, in 2020 the market experienced a similar level of volatility compared to 2018. It is worth noting that 2020 was the year of the largest lockdown in Germany due to the COVID-19 pandemic. In 2021, market volatility increased further, reaching a standard deviation of 4.85%. The most significant increase occurred in 2022, reaching 10.53%, which can be attributed to various factors, including increased uncertainty and economic disruption caused by geopolitical events, such as the outbreak of Russia's war with Ukraine. While it is known that energy prices are influenced by many factors, including supply and demand dynamics, political changes, climatic conditions and geopolitical events, the analysis conducted provides interesting insights into noticeable price changes during periods of significant events in previous years (Werner, 2020).

In the next step of the analysis, Value at Risk (VaR) was calculated for Germany and Spain in 2019. VaR, known as the "new science of risk management," is a statistical measure used to estimate potential losses on investments or portfolios over a specified time frame and confidence level. The term "loss" refers to a decline of the price and a positive price change is considered a "gain" or "return". For instance, 5d-P90 VaR means that there is a 90% probability that the price difference over the 5-day period will be less than 10%. In this analysis, VaR was calculated for German and Spanish Cal+2 prices in 2019, given a time horizon of 5 days and a confidence level of 90%. The results are summarized in Table 6 (Werner, 2020).

Table 6. Value at Risk calculated for Cal+2 electricity prices in 2019 in Germany and Spain with a 5-day interval and a 90% probability level (Werner, 2020).

Country	Germany	Spain
VaR (5d-90%)	-5.12 %	-1.20 %

Germany has a 90% probability that losses will remain below 5.12% over a 5-day period, with a 10% chance of exceeding that threshold. In the Spanish market, on the other hand, the VaR indicates a 90% confidence level that losses will not exceed 1.20%. The German market exhibits greater price volatility, as evidenced by the higher negative VaR. Consequently, the Cal+2 electricity price risk in Germany is higher, indicating a higher probability of higher losses compared to the Spanish market (Werner, 2020).

The historical approach, utilizing calculations of standard deviation, log-returns, and Value at Risk, provides valuable insights into price volatility within a specific market. Through the analysis of past prices, the extent of market fluctuations over time can be determined, and potential risks associated with investment and entry into a PPA can be identified. Taking these factors into account, investors can assess the magnitude of risk in the market and make informed decisions about the feasibility of engaging in a PPA (Werner, 2020).

5.2. Monte Carlo simulation

Risk assessment of the off-site PPA project was conducted using Monte Carlo analysis, which is a multivariate modelling technique that uses multiple variables to predict possible outcomes. This statistical tool is used to generate probability distributions or to assess the risk of an investment or event. Since PPAs are long-term contracts with a high degree of uncertainty, Monte Carlo analysis is commonly used in the decision-making process to perform risk-benefit assessments (Kenton, 2023).

5.2.1. Methodology

The Monte Carlo simulation tool uses historical price data for a specific market and, by performing a selected number of iterations, checks the probability of the Power Purchase Agreement price more expensive than market price.

To analyze the impact of the energy crisis on PPA risk, three sets of simulations were conducted. The first simulation focused on assessing the risk of PPAs in the fourth quarter of 2020, before the price fluctuations caused by the pandemic and then Russia's war with Ukraine. The second simulation assessed PPA risk in the fourth quarter of 2022, when the impact of the energy crisis was more apparent. A third set of simulations was run for 2023 to examine how the risk changed as energy prices gradually declined and relatively stabilized. These 3 series of simulations were performed to examine changes in PPA risk over the period 2020-2023 in a changing market environment.

Prior starting the Monte Carlo simulation, the following input data had to be defined:

1. Hourly power output from renewable installation for a year at the selected location.
2. Hourly energy consumption of a hypothetical client for one year.
3. Energy market information for the selected country.
4. PPA price offered in Germany and Spain in 2020, 2022 and 2023.

To obtain the first required set of inputs - the hourly power output from the renewable installation for one year - it was assumed that the energy was produced by a photovoltaic (PV) installation. Subsequently, the European Commission's Geographical Information System was used, which is an interactive tool that collects hourly radiation and photovoltaic power production data from 2005 to 2020 for European countries. Using this tool, two locations - one in Germany and one in Spain - were selected by specifying the longitude and latitude, and then the hourly energy production from PV panels was collected for these specified sites for 2018-2020. A span of three years was selected for the examination since this duration would allow the creation of an average energy production profile for the region. The data was generated for the optimal conditions of PV modules, such as azimuth and tilt. The specifications that are adopted by the EU interactive tool and the assumptions made in the methodology are presented in Table 7.

Table 7. Parameters of PV installation in Germany and Spain (Comission, 2023)

General specifications	
Radiation database	PVGIS-SARAH2
PV technology	Crystalline silicone
Installed peak PV power (kWp)	1
System loss	14%
Germany	
Latitude	52.726°
Longitude	11.417°
Elevation	29 m
Slope	41° (optimum)
Azimuth	-6° (optimum)
Spain	
Latitude	40.281°
Longitude	-3.630°

Elevation	590 m
Slope	36° (optimum)
Azimuth	-5° (optimum)

In the next step, based on the E&C Consultants' expertise, it was assumed that the PV installation would produce 30 GWh per year. Then, the hourly production of the PV plant was calculated as a multiplication of hourly profile for a specific location and determined power output of 30 GWh. Figure 32 shows the hourly PV production in Spain and Germany.

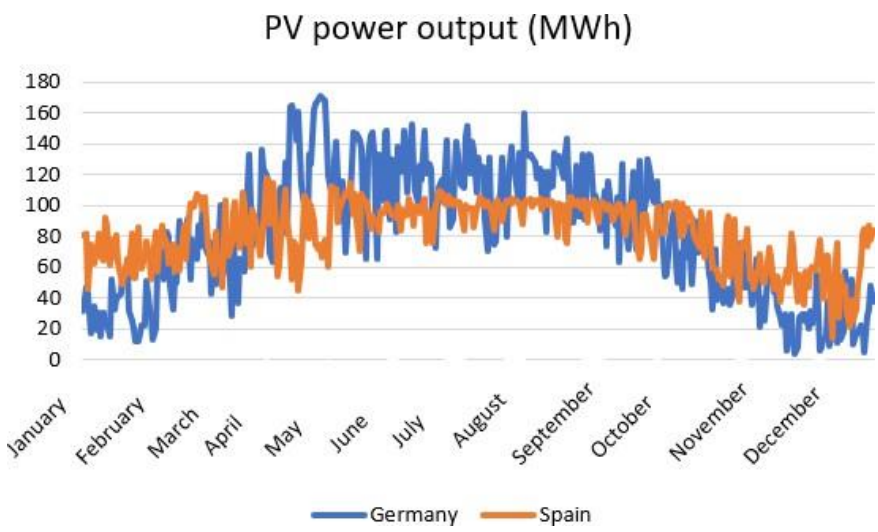


Figure 32. Annual power output of PV installation in Germany and Spain.

After obtaining hourly production data from PV installations in Spain and Germany, the consumption pattern of a hypothetical customer had to be developed. For this purpose, it was assumed that 50% of the customer's energy consumption would be met by energy generated by the PPA plant, resulting in a consumption of 60 GWh. This percentage was determined through internal discussions with E&C Consultants.

Once hourly PV production and customer consumption data had been collected, historical energy prices had to be extracted. For this reason, market data was sourced from the European Energy Exchange (EEX), a prominent energy trading platform for the German market in Europe, and OMIP, the entity in the Iberian energy market in Spain, known as "Operador del Mercado Ibérico de Energía - Polo Español, S.A.".

Finally, a PPA price in Germany and Spain had to be defined. The analyses were carried out for three reference periods to examine the risks associated with PPA before, during and after the energy crisis. Therefore, prices from the fourth quarter of 2020 and 2022, and the second quarter of 2023 were considered. The LevelTen PPA Price Index was used as a source for the PPA prices. As mentioned, LevelTen takes into account the 10% most competitive bids in a given market to determine its index.

At this point, it is important to emphasize that in the simulation performed by the PPA tool, the profiles of photovoltaic production and customer energy consumption are constant. This means that in each iteration these two profiles remain unchanged. In contrast, the data set that varies in each iteration is the price profile.

The price profile is generated in two stages. Firstly, the simulation uses one year of future calendar prices quotes to create an average future price and calculate its standard deviation. Depending on the selected market, the interactive tool creates an average price based on available futures traded products. For instance, the tool takes predicted futures prices from the day of the analysis for years 2024, 2025, 2026, namely Cal24, Cal25, Cal26 products. The tool then generates an hourly price profile for a period of one year, based on the historical SPOT prices and the previously obtained Gaussian future price distribution. This profile is generated for each iteration and finally, after a fixed number of iterations, the most probable profile and price is obtained.

The next section of this chapter will examine the specific cases in Germany and Spain. For both countries, the risks associated with Power Purchase Agreements within the period 2020-2023 will be analyzed.

5.2.2. Monte Carlo simulation- Germany

The initial set of simulations was aimed to assess the PPA risks in 2020, 2022 and 2023 in the German market. Based on the generated production profile for previously defined location, a baseload PPA model was generated, as illustrated in Figure 33.

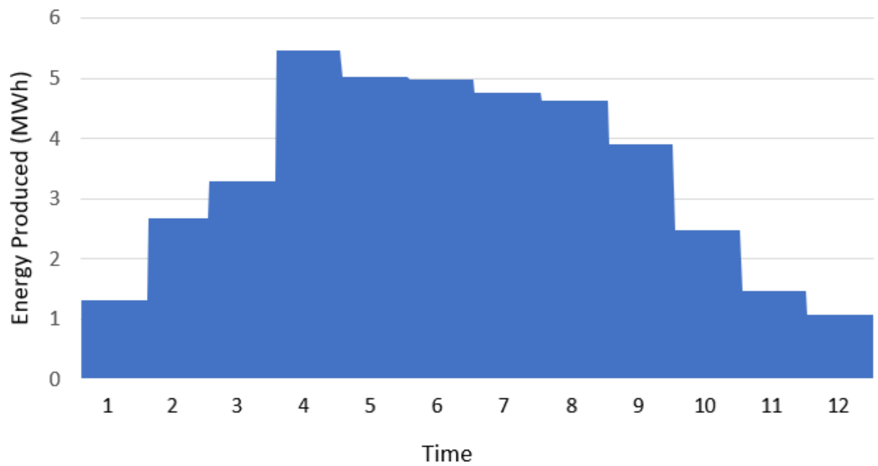


Figure 33. Baseload PPA model in Germany.

The consumption profile of a hypothetical customer, shown in Figure 34, was the same for Germany and Spain. Analyzing this graph, a consistent trend can be observed each day - an increase in energy consumption at midday and a decrease at night.

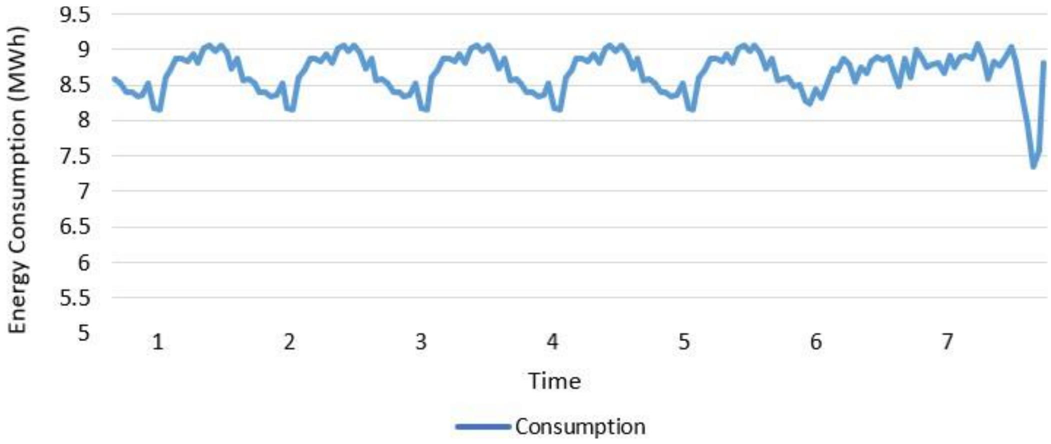


Figure 34. Energy consumption profile of a hypothetical client for 7 days.

In the simulations, three reference periods were used, namely the fourth quarter of 2020 and 2022 and the second quarter of 2023. For this reason, the starting dates of the respective quarters - 01/10/2020, 01/10/2022 and 01/04/2023 - were chosen and each simulation referred to historical SPOT prices and future Cal prices in relation to these three selected dates. PPA prices used in the analysis were obtained from PPA Price Index Report of LevelTen Energy, as presented in Table 8 (PPA Price Index Reports).

Table 8. PPA prices in in Q4-20, Q4-22 and Q2-23 in Germany (PPA Price Index Reports).

Q4-20	Q4-22	Q2-23
49 €/MWh	90 €/MWh	75 €/MWh

Another factor adjusted for each simulation was the balancing cost. As mentioned earlier, balancing costs are determined by the TSO due to the imbalance between the hourly e-program, which represents expected consumption for the next day, and actual volumes at 15-minute intervals. Detailed balancing costs are difficult to obtain. To determine balancing costs for each simulation, assumptions were made based on several factors:

- The greater the share of an asset in the system imbalance, the higher the balancing cost (Cyriel, 2021; WBCSD).
- Increasing capacity of renewable energy sources with intermittent generation causes a raise in the balancing costs (Cyriel, 2021; WBCSD).
- Balancing costs in 2020 were in a range of 1.00-5.00 €/MWh (de Jong & Kovaleva, 2021; ACER Market Monitoring Report 2020 – Electricity Wholesale Market Volume, 2021)
- According to daily balancing cost reports from National Grid ESO, which is the electricity system operator in the UK, average monthly balancing costs were approximately: 3 €/MWh in October 2020, 15 €/MWh in October 2022 and 15 €/MWh in February 2023 (Daily Balancing Cost Report ESO, 2023).
- In 2023 balancing costs were ranging 15 €/MWh (Franke, 2023)

- Electricity markets in 2022 were characterized by much higher volatility level as evidenced by calculation of standard deviation from section 0 (3.46% in 2020 and 10.53% in 2022). Higher volatility involves increased balancing requirements.

Based on the factors mentioned above, it was assumed that the balancing cost in 2020 would be 2.5 €/MWh, falling within the range of 1 to 5 €/MWh. For the years 2022 and 2023, it was projected that balancing costs would amount to 15 €/MWh. Although there was lower variability in 2022 compared to 2023, the penetration of renewable energy sources increased. The assumed balancing costs in 2020, 2022 and 2023 are shown in Table 9.

Table 9. Balancing costs in 2020, 2022 and 2023 adopted for the simulation in Germany.

Q4-20	Q4-22	Q2-23
2.50 €/MWh	15 €/MWh	15 €/MWh

After collecting all the necessary input data and determining the balancing costs, three simulations were conducted, each consisting of 500 iterations. The results of this analysis are presented in Table 10.

Table 10. Monte Carlo simulation results for the German market.

	Analysis from 01/10/2020	Analysis from 01/10/2022	Analysis from 01/04/2023
Price with PPA	77.54 €/MWh	124.03 €/MWh	114.14 €/MWh
Price without PPA	100.71 €/MWh	139.24 €/MWh	134.59 €/MWh
PPA Cost	1 545 000 €	3 150 000 €	2 700 000 €
Cost of exchange with the grid	3 115 419 €	4 304 362 €	4 159 678 €
Net Cost	4 660 419 €	7 454 362 €	6 859 678 €
Cost without PPA	6 052 457 €	8 368 506 €	8 088 761 €
Revenue of having PPA	1 392 038 € **23.00 %**	914 144 € **10.92%**	1 229 083 € **15.19%**
Risk of PPA ¨going out of the money¨	**23.20%**	**33.40%**	**14.40%**

Table 10 provides an overview of the key results obtained from the first Monte Carlo simulations. The first row of the table shows the average PPA price paid per MWh depending on a certain point in time.

When

$$PPA\ generation > client\ consumption$$

Client must pay the following price.

$$\frac{(PPA\,price + balancing\ cost) \cdot client\ consumption + SPOT \cdot (client\ consumption - PPA\ generation)}{client\ consumption}$$

When

$$PPA\ generation < client\ consumption$$

The client must pay the following PPA price.

$$\frac{(PPA\,price + balancing\ cost) \cdot PPA\ generation + SPOT \cdot (client\ consumption - PPA\ generation)}{client\ consumption}$$

The next row in Table 10 shows the price without PPA, which is derived from the Monte Carlo simulation and represents the probable price deduced from historical data and expected future prices. Then the cost of the PPA is displayed, which is calculated as the PPA price multiplied by the total volume delivered under the PPA. Subsequently, the total cost of reselling or purchasing energy to the grid is presented. These costs are substantial for two reasons. Firstly, only 50% of the customer's needs are met by the energy produced under the PPA, and the rest is the residual energy that must be purchased in addition. Secondly, the discrepancy between the customer's consumption profile and the production profile of the PV plant leads to the requirement of imbalances settlement in the SPOT market. The simulation analyzes baseload PPA contracts, which specify the energy supply in the capacity blocks. For this reason, these contracts require a significant amount of energy to be traded on the SPOT market and involve greater exposure to energy price volatility. Baseload PPAs were explained in section 2.2.

Table 10 also provides information on the net cost of PPAs compared to the total cost without them, showing how much the client has saved by entering into this agreement. In the last row of the table a probability of the PPA ¨going out of the money¨ is presented, showing the likelihood of the market price being lower than the PPA price.

Conducted analysis tracks the evolution of risks related to Power Purchase Agreements from 2020 to 2023. Examining this time span seeks to assess the influence of the energy crisis on the PPA market. To achieve this, the study first examines the landscape in 2020 before the pandemic and the Russia-Ukraine conflict, then delves into the energy crisis in 2022, and finally evaluates the recent developments in 2023 to assess the current situation as markets are relatively stabilized.

Examining the results in Table 10, the main considerations were two key factors: customer savings from having a Power Purchase Agreement, and the risk associated with the PPA price being above the market price at a particular time. A review of these two factors for the period 2020-2023 can demonstrate the effectiveness of the PPA in protecting against energy price spikes.

Looking at the first factor in the analysis for Germany, it is apparent, the benefit of having a PPA is highest in 2020. With a PPA price of 49 €/MWh and balancing costs of 2.50 €/MWh, the savings amounted to 1 392 028 €/MWh, equivalent to 23% of the total savings. In 2022, when the PPA price rises to 90 €/MWh and balancing costs to 15 €/MWh, the gains decisively decrease to 10.92%. Then, in 2023, with the same value of balancing costs as in 2022, but with a 15 €/MWh lower PPA price, the benefits of this contract increase to 15.19%.

Profits generated from a Power Purchase Agreement are highest when the difference between the PPA price and the market price is the greatest. The final PPA price includes the proposed rate based on LevelTen data, balancing costs, and the average price of energy exchange with the grid. Therefore, optimizing profitability under PPA ownership includes minimizing these cost components and maximizing the market price.

The greater the energy price and the lower the PPA price, the more savings the customer can achieve. To assess this factor, it is important to understand how the price profile is generated. As mentioned in the methodology section, the price profile is created for the date of analysis and considers historical spot prices and one last year of futures prices relative to that day. Therefore, an analysis conducted in the fourth quarter of 2022 and 2023 likely resulted in a higher and more variable price profile than the one in 2020, as it incorporated energy price spikes from 2022. As evidenced by Figure 27 in previous sections, depicting SPOT prices from 2020 to 2023, these prices were significantly lower and more stable in the past.

Nonetheless, the higher and more volatile price profile in 2022 was accompanied by a higher PPA price as well. Consequently, the gap between the market price and the PPA price was narrower, leading to lower profits from the PPA. When the PPA price dropped in 2023, these profits automatically increased.

On the other hand, analyzing the balancing cost, it was at its lowest in 2020, thus creating the most favorable conditions for cost savings generated through PPAs. At this time, the profits from having a PPA amounted to 23%. In 2022 and 2023, balancing costs increase 6-fold to 15 €/MWh and remain unchanged in both years. This resulted in a substantial decrease in profits of PPA. These results confirm the findings of the 2022 PPA market study that the higher the balancing costs, the worse the benefits of holding a PPA and the greater the associated risks. Increasing balancing costs in 2022 created an additional challenge for renewable project developers. Nonetheless, in 2023 with balancing costs still at the same high level, the benefits of having a PPA increased compared to 2022. This can be attributed to a 15 €/MWh lower PPA basis price in 2023, which contributed to a greater price difference.

When evaluating the expense associated with grid electricity exchange, it's crucial to note that the customer's energy consumption pattern and PV production pattern remained consistent across all years. Additionally, the contract under consideration was a baseload Power Purchase Agreement. Therefore, the client had the same amount of energy to sell and buy from the grid each year. In general, these costs are well balanced. However, in years when the market exhibited higher prices and greater volatility, such as in 2022, these transactions could potentially cause an increase on the overall PPA price. The client might have been compelled to purchase energy at very high SPOT prices in the situation of not sufficient production from renewable installation.

When examining the second selected factor, which is the risk of the PPA "going out of the money", an intriguing trend emerges. As shown in previous sections, electricity prices in Germany remained relatively low and stable before 2020. The standard deviation, calculated in Section 5.3 and shown in Table 5, was below 3.5% until 2020. Consequently, the risk that electricity prices would be lower than the PPA price was the lowest at 23.20%.

In 2022, electricity prices experienced a drastic and significant increase, accompanied by heightened volatility with a standard deviation of 10.53% shown in Section 5.3. However, the PPA price also rose from 49 €/MWh to 90 €/MWh, and balancing costs escalated from 2.50 €/MWh to 15 €/MWh. This scenario resulted in a sharp growth in the risk level, reaching 33.40%.

An interesting pattern emerges in 2023. Despite still elevated balancing costs, but a lower PPA price, the risk that the PPA price would be higher than the market price was the lowest. This year, the PPA price fell from 90 €/MWh to 75 €/MWh. In addition, the generated price profile incorporated historical SPOT prices from 2022, showing the effects of the energy crisis, resulting in increased volatility and price growth. In such a case, the lower PPA price by 15 €/MWh acted as a buffer and protection against the threat of PPA "going out of money." With a reduced PPA price in 2023 and energy prices still partially affected by the energy crisis, the risk to customers was lowest.

The conducted simulation implies that the greatest benefits of a Power Purchase Agreement compared to conventional grid energy procurement would have been generated in the market environment of 2020. Conversely, the lowest risk associated with a Power Purchase Agreement occurred in the most recent times, specifically in 2023.

After analyzing the results of the simulations, several conclusions emerge. Firstly, the challenging market situation in 2022 led to a decrease in generated savings from PPAs and an increase in associated risks, thus confirming the statement that the energy crisis had a negative impact on PPA-related risks.

Secondly, even in the difficult energy landscape in 2022, which created the least favorable conditions for PPAs, the risk that their prices would exceed market prices remained relatively low, accounting for about one-third of the scenarios. Furthermore, engaging in PPAs continued to yield significant cost savings compared to conventional grid power purchases.

Furthermore, while evaluating the profitability of PPA, it is crucial to consider the situation when the savings from having a PPA in the first few years can offset higher prices in the future. Then, taking the entire PPA energy budget into account, it may be lower than buying energy from the grid for the entire period.

In addition, Germany, as highlighted in previous sections, exhibited a strong dependence on Russian fossil fuels imports, leading to significant price volatility and elevated energy and PPA prices. Value at Risk (VaR) calculated in section 5.3 and presented in Table 6 was at the level -5.12% indicating a higher probability of losses at this market. Nevertheless, even under these less advantageous market conditions in Germany, PPAs have proven to be protective against price spikes. In the same part, the same analyses are conducted for Spain.

5.2.3. Monte Carlo Simulation- Spain

The subsequent round of the simulations followed the same methodology, but this time using data for Spanish market. Figure 35 shows the baseload Power Purchase Agreement model in Spain, derived from the generated production curve.

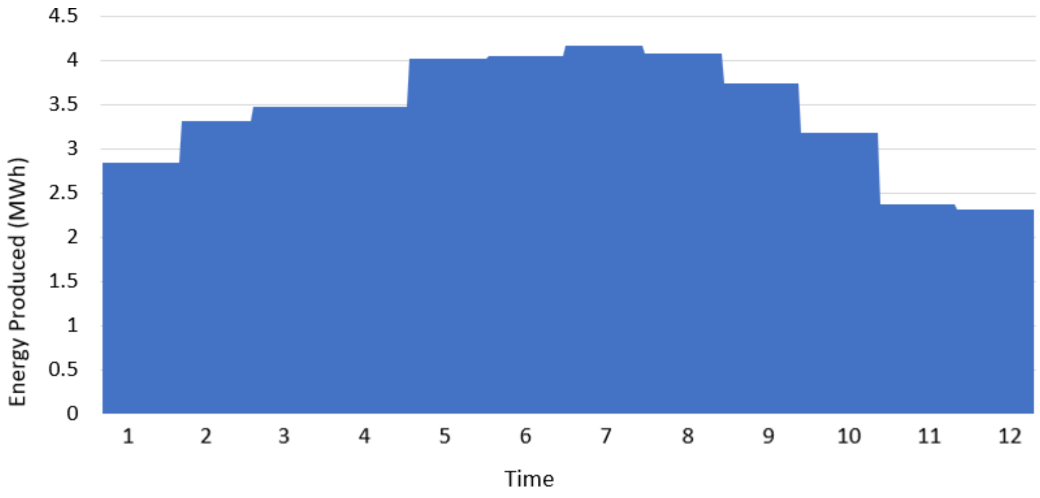


Figure 35. Average PPA profile in Spain.

As already mentioned, the consumption profile of the hypothetical customer was the same for Germany and Spain. Historical price data, as well as future prices for the traded Cal products, were obtained for the Spanish market for the same dates - 01.10.2020, 01.10.2022 and 01.04.2023. In addition, the PPA prices were taken from the LevelTen Energy Report, as shown in Table 11 (PPA Price Index Reports). It can be observed that PPA prices in Spain, the PPA leader in Europe, are much lower than in Germany.

Table 11. PPA prices in in Q4-20, Q4-22 and Q2-23 in Spain.

Q4-20	Q4-22	Q2-23
34 €/MWh	46 €/MWh	46 €/MWh

The same balancing costs were adopted for simulation in Spain, as the one in Germany, as shown in Table 12.

Table 12. Balancing costs in 2020, 2022 and 2023 adopted for the simulation in Spain.

Q4-20	Q4-22	Q2-23
2.50 €/MWh	15 €/MWh	15 €/MWh

After collecting all the necessary data, 500 iterations were run, as in the previous round of simulations. Table 13 presents the results obtained from the analysis.

Table 13. Monte Carlo simulation results for Q4-20, Q4-22 and Q3-23 for the Spanish market.

	Analysis from 01/10/2020	Analysis from 01/10/2022	Analysis from 01/04/2023
Price with PPA	50.51 €	70.11 €	67.37 €
Price without PPA	63.71 €	78.37 €	72.90 €
PPA Cost	1 095 000 €	1 830 000 €	1 830 000 €

Cost/Revenue of exchange with the grid	1 940 693 €	2 383 807 €	2 218 882 €
Net Cost	3 035 693 €	4 213 807 €	4 048 882 €
Cost without PPA	3 828 726 €	4 709 887 €	4 381 433 €
Revenue of having PPA	793 033 € **20.71%**	496 080 € **10.53%**	32 552 € **7.59%**
Risk of PPA ¨going out of the money¨	**21.00%**	**35.20%**	**34.20%**

Table 13, similarly as in the previous case, provides a comprehensive overview of the results obtained from the simulations, offering insight into the financial implications of PPAs in 2020, 2022 and 2023.

Examining the first key factor, which is the savings generated by Power Purchase Agreements, a pattern slightly different than in Germany emerges. The highest savings occur in 2020, constituting 20.71% of the total savings. This is primarily due to the favorable price difference between PPAs and market rates during that period. These savings declined in 2022 during the energy crisis, mirroring the German experience. As explained in the case of Germany, increased PPA price, raising balancing costs and more volatile electricity prices contributed to that decline.

An interesting phenomenon is seen in 2023, where the savings decreased from 10.53% to 7.59%, unlike the situation in Germany. It's crucial to note that the PPA price in Spain remained consistent in the fourth quarter of 2022 and the second quarter of 2023 at 46 €/MWh. Balancing costs also were the same in both scenarios. The only variable that changed was the range of historical spot prices and futures prices considered. The potential explanation for this shift lies in how the Monte Carlo simulation constructs a price profile. Given that the introduction of a price cap in Spain led to a decrease in prices and their stabilization, as evidenced in Figure 27 in previous sections, a lower and less volatile energy price profile was generated based on historical prices from April 1, 2023. In this scenario, the relatively higher PPA price at that time and the lower market price could have reduced the client's benefit from having a PPA compared to purchasing electricity from the grid.

In the context of the risk associated with PPA "going out of the money," the energy crisis significantly increased this risk, rising from 21% in 2020 to 35.20% in 2022. The escalating balancing costs, coupled with a more unpredictable market and a higher PPA price, made it more likely that the market price would fall below the PPA price.

Interestingly, the risk only slightly decreased in 2023, remaining at an elevated level. This may be attributed to the aforementioned price cap, which resulted in a relative decline and stabilization of prices in Spain from the third quarter of 2022 onward. This suggests that the higher PPA price, set at 46 €/MWh in both 2022 and 2023, could have been associated with a similar level of risk, that the market price would be lower than the PPA price.

It is also worth to note that a calculated example of Value at Risk (VaR) calculated from section 5.3 was much lower for Spanish market than German one and amounted only -1.20%. This indicated lower probability of loses in Spain.

In general, similar to the analysis of the German energy market, the results from the Spanish energy sector depict the resilience of Power Purchase Agreements even in difficult times. During the energy crisis, the risk of PPA prices exceeding market prices was relatively low, settling around one-third. This finding underscores the reliability of PPAs as a protective mechanism against price spikes, shielding energy consumers from the severe market volatility that occurred during the energy crisis. Despite the market turmoil, the risk that PPAs would cease to be profitable remained relatively stable, suggesting that PPAs retained their value and continued to offer consumers some level of security.

5.2.4. Summary of the Results & Discussion

Results obtained using Monte Carlo simulations of how PPA risk has changed over the 2020-2023 period reveal intriguing insights. In the discussion, the focus will be on previously selected two factors: the potential savings generated through PPA and risk of PPAs ¨going out of the money¨.

As previously mentioned, entering into Power Purchase Agreements (PPAs) in both Germany and Spain within all the considered timeframe resulted in considerable cost savings compared to the conventional method of purchasing electricity from the grid. The results of the simulations are summarized in Table 14.

Table 14. Savings generated by PPA in Germany and Spain in 2020, 2022 and 2023.

	Analysis from 01/10/2020	Analysis from 01/10/2022	Analysis from 01/04/2023
Germany	23.00 %	10.92%	15.19%
Spain	20.71%	10.53%	7.59%

When examining the numbers, it becomes clear that both Germany and Spain have recorded the greatest potential for savings in 2020. This phenomenon can be attributed to lower PPA basis price and balancing costs, which created beneficial difference between market price and PPA price.

In 2022, during the energy crisis, there was a significant decrease in potential cost savings, both in Germany and Spain. Several factors contributed to this change. Firstly, the analysis incorporated notably high balancing costs, which led to an increase in the PPA price. Secondly, the PPA price itself was considerably higher compared to two years prior. Considering all these factors, this narrowed the gap between the market price and the PPA price.

An intriguing situation emerged in 2023, when Germany experienced an increase in PPA savings, while Spain saw a decrease. It should be noted that the level of balancing costs in both years was the same at 15 €/MWh in both countries. However, Germany's PPA price dropped from 90 €/MWh in 2022 to 75 €/MWh in 2023. Spain, on the other hand, kept its PPA price steady at 46 €/MWh. This phenomenon may indicate the potential impact of the introduction of a price cap in Spain, which stabilized and reduced electricity prices in the country. These measures could result in market price being closer to PPA priced, thus reducing the benefits of it. Nevertheless, PPAs continued to offer consumers a reasonable financial choice, even in the face of market fluctuations and uncertainty, as evidenced by the positive values obtained in the assessment.

Another significant outcome revealed in the simulation is the value of the risk associated with the possibility of Power Purchase Agreements "going out of the money." The results obtained in each simulation are presented in Table 15.

Table 15. Summary of the "going out of money" risk values for PPA from 2020 to 2023.

	Analysis from 01/10/2020	Analysis from 01/10/2022	Analysis from 01/04/2023
Germany	23.20%	33.40%	14.40%
Spain	21.00%	35.20%	34.20%

One notable finding is that the risk levels in both chosen countries were similar in 2020 and 2022. Despite the earlier pointed out distinctions in their reliance on Russian fossil fuel imports and the progress of the PPA market, the changes in risk show a parallel pattern. The risk of PPA price exceeding the market price was 23.30% in Germany and 21% in Spain in 2020.

Risk of PPAs “going out of money” substantially increased in 2022 during the energy crisis. Notably, it rise more for Spain than for Germany. At the same time, the price of PPA in Spain increased by 12 €/MWh from 34 €/MWh to 46 €/MWh, and in Germany it almost doubled, from 49 €/MWh to 90 €/MWh. Such an increase for Spanish market could be caused by the introduction of a price cap, that lowered and stabilized energy prices, increasing the risk that a higher PPA price would surpass the market price.

Looking at 2023, different trends for Germany and Spain emerge. In the case of the first selected country, risk significantly decreased and reached the lowest level from all simulations. The higher and more volatile market prices, coupled with a lower PPA price, provided a significant protective buffer, ensuring a favorable PPA price compared to the market price. On the other hand, the risk of PPAs becoming financially unviable in 2023 stayed relatively constant in Spain compared to the previous year. It is important to highlight that the proposed PPA price and balancing costs remained unchanged between 2022 and 2023. Additionally, the previously mentioned price cap impacted the market price already 2022, thus creating a similar market environment. The maximum level of risk that the PPA price would exceed the market price was 35%, indicating relatively positive results.

The conducted analyses confirm the effectiveness of Power Purchase Agreements as a means of safeguarding against energy price spikes. This is evident from the fact that, in all the examined scenarios, positive benefits were observed as a result of having a PPA in place. Moreover, even in challenging market conditions characterized by frequent and dynamic fluctuations in electricity prices and market instability, PPAs have proven to be highly resilient and profitable mechanisms.

The risk associated with the PPA price being higher than the market price remained at relatively low levels, reaching a maximum of approximately one-third in the most unfavorable scenarios. These findings clearly emphasize that this risk was reasonably controlled and manageable during the periods under examination.

Nevertheless, It should be noted that the results of the conducted simulations are obtained for specific assumptions, such as the profile of photovoltaic plant production, customer consumption profile, and PPA price. Changing any of these parameters can significantly alter the risk associated with these agreements. For example, the PPA price for the simulations was taken from LevelTen index, which publishes its price based on the 10% most competitive offers. A higher PPA price offered to the selected customer could increase the risk of this transaction. Additionally, the customer in analyzed scenario had relatively steady consumption throughout the week. If the customer had highly variable consumption or the plant operated intermittently, such as five days a week, this would also impact the parameters related to the PPA contracts. According to previous findings from E&C Consultants, a well-aligned correlation between consumption and generation patterns within a PPA, where consumption typically corresponds to PPA generation and decreases during non-generation periods like at night, alongside a PPA price lower than the average forward market price, suggests the PPA's profitability. Conversely, an opposite correlation, indicates an increased risk exposure, resulting in a higher probability of a PPA becoming economically unfeasible.

Moreover, Monte Carlo simulation does not consider the historical relationship between future prices for consecutive periods, such as one, two, and three years ahead, and the final spot prices occurring in those corresponding years. For instance, the simulation process might ascertain an expected price of 50 €/MWh derived from the futures prices, incorporating the most recent year's quotations for 2024, 2025, and so forth. However, subsequent investigation in 2024, 2025 could reveal an average spot price 45 €/MWh, indicating that the initial estimation had an added component of 5 €/MWh to account for the market's uncertainty. Monte Carlo simulation used in this Master’s Thesis does not consider this correlations, what must be taken into account while analyzing the results obtained.

In general, entering into an energy purchase agreement is a lengthy process that involves a thorough risk assessment and identification of potential threats and benefits. Moreover, it is important to consider the company's risk appetite, which can be defined as the amount and type of risk that the organization is willing to take to achieve its strategic objectives. Organizations have varying risk appetites depending on the sector, culture, and goals, which may change over time. Understanding the company's risk aversion is key to finding the best type of PPA. Nevertheless, both the results of the conducted analysis and the continuous growth of activity in the PPA market in 2022 and 2023 testify to the effectiveness of PPAs as a mechanism to protect customers from price spikes. Furthermore, PPAs also contribute to the achievement of ESG (Environmental, Social, and Governance) goals, which play a significant role in the development and promotion of sustainable energy technologies. Through PPA agreements, companies can significantly save on carbon taxes, which is an additional advantage of these contracts (Risk Appetite Framework, 2018).

6. Conclusion

In 2022, global energy markets experienced an unprecedented surge in prices. This increase was initially driven by low gas reserves and economic recovery after the pandemic. However, it was further intensified by the Russian invasion of Ukraine. High energy prices had a significant impact on various aspects, including inflation, energy poverty, food security, and recession. The unstable energy market exerted pressure on all sectors of the economy, including the Power Purchase Agreement (PPA) market in Europe.

The aim of this Master's Thesis was to examine the impact of the energy crisis on Power Purchase Agreements. The report explored how PPA prices changed in 2022 and how this affected the use of these contracts. It analyzed various trends and characteristics that emerged in response to energy price spikes. Additionally, a series of simulations were conducted to assess how the risk associated with PPA evolved in this modified environment in the years 2020-2023.

In 2022, renewable energy project developers faced significant challenges, partly driven by the increase in the Levelized Cost of Electricity (LCOE) and rising project costs due to inflation. For instance, capital expenditures for new photovoltaic power plants and onshore wind farms surged by 15% to 25%. This escalation could have been attributed, in part, to the escalating costs of materials and the expenses linked to engineering, procurement, and construction of renewable projects. This shift presented a hurdle for the advancement of renewable technologies and manifested itself in higher PPA prices.

Another factor contributing to the elevated pricing of PPAs was the heightened costs associated with balancing and shaping the energy profiles within PPAs. This challenge was exacerbated by the intermittent nature of energy generation from renewable sources and the limited flexibility of the grid. Consequently, negotiations related to balancing costs became a pivotal aspect of the PPA agreement process, whereas in the past they played a more marginal role.

Moreover, this growth of renewables and the lack of grid flexibility has led to another phenomenon known as cannibalization. Renewables have begun to cannibalize their own profits, putting additional strain on renewable projects and PPAs.

The environment in 2022 was also filled with uncertainties and concerns related to anticipated regulatory changes. Governments, to protect consumers from extreme energy prices, introduced various measures, including price caps. In September 2022, the European Commission announced a European-wide revenue cap set at 180 €/MWh. This regulatory change raised numerous concerns regarding its potential impact on revenue from PPAs and the expected returns on investments. There were fears that such regulatory changes could potentially reduce incentives for green energy providers to engage in PPAs.

Adjustments in legislation were also a contributing factor to the shift in the supply and demand dynamics of EACs (Energy Attribute Certificates), resulting in a drastic price increase of nearly 500% in Europe over the past two years. An example of such a change was the implementation of a 97% tax on income derived from the sale of Guarantees of Origin (GO) for renewable energy producers in Poland. This substantial tax burden has the potential to create a situation where the profits from selling Guarantees of Origin are overshadowed by the associated procedural costs. As a result, some certificate producers may choose to stop their sales, potentially reducing their availability and subsequently causing an increase in PPA prices.

Additionally, the energy crisis played a role in driving up backwardation, a pricing phenomenon where the futures price of a commodity is lower than the expected spot price at the time of delivery. Backwardation signals that the current price is too high and will eventually decrease as the futures contract nears its expiration date. The backwardation curve is crucial for determining PPA prices and contract durations. The significant backwardation in 2022 led to price disparities between short-term and long-term PPAs, with short-term contracts being valued considerably higher than their typically more expensive long-term counterparts. This situation generated significant interest among energy producers in choosing short-term deals.

Moreover, in 2022, credit risk became a more significant challenge in the context of higher interest rates. Investors encountered greater difficulty in securing financing for renewable projects.

All the aforementioned developments, which led to rising prices and increased PPA risks, cast doubts on the long-term profitability of Power Purchase Agreements. As the costs of these contracts continued to climb, investors, businesses, and institutions began to analyze thoroughly the long-term advantages associated with such agreements.

By historical standards, a market characterized by significant volatility and price instability is not an ideal environment for contracting. Nevertheless, despite this turbulent period, there was no decline in the number or volume of Power Purchase Agreements, and activity in this sector remained consistently high. The main reason for this phenomenon was companies' proactive approach to hedging against fluctuations in energy prices. Many corporations opted for long-term PPAs instead of securing energy supplies for the near future. Some of these companies entered into these PPAs as a strategic move to achieve an averaging effect and protect themselves from excessive contract prices in the first year. This higher activity in 2022 was mainly driven by corporate players, who accounted for 80% of the total number of deals and 83% of contracted volumes in 2022.

The continuing popularity of PPAs can be attributed to the increased adoption of more flexible PPA models and applied strategies to mitigate the associated risks. Both parties involved in PPAs have taken measures to protect themselves from adverse scenarios through various mechanisms.

One solution that gained popularity in 2022 were alternative pricing mechanisms, such as inflation-linked prices, price floors, collars or hybrid systems. These mechanisms were designed to guard against both very high and very low energy prices, ensuring that the PPA price remains more closely aligned with market dynamics.

Furthermore, in 2022, multi-technology or multi-location PPAs became increasingly popular. By opting for a PPA that covers multiple technologies or locations, customers could reduce their energy procurement commitments while concurrently limiting their exposure to market volatility. This approach partially helped diversify their risk across volume, price, and profile.

Moreover, new types of agreements were introduced, including Proxy-Gen PPAs with Volume Firming Agreements. In Proxy-Gen VPPAs, the contract size is determined based on the energy the renewable plant can deliver to the grid at maximum equipment efficiency and optimal operating conditions. This incentivizes renewable plant owners to maximize their performance. These Proxy Generation VPPAs could be complemented with Volume Firming Agreements, shifting risk management responsibilities to third parties, such as insurance companies. Despite the higher costs, this solution effectively mitigates various types of risks, including price, shape, volume, and operational risks.

To assess how the risk associated with Power Purchase Agreements changed in response to the energy crisis, this Master's Thesis analyzed two examples: the Spanish market, a leader in PPAs, and the German market, which had fewer PPAs and a different market characteristic. The analysis involved conducting Monte Carlo simulations for three periods: before the energy crisis in 2020, during the crisis in 2022, and in 2023.

After studying the simulation results, it was demonstrated, firstly, that the challenging market conditions in 2022 led to a decrease in cost savings generated from PPAs and an increase in associated risks. This confirmed the statement that the energy crisis had a negative impact on the risks associated with PPAs.

However, even in the difficult energy landscape of 2022, which created the least favorable conditions for contracting, the risk of PPAs prices exceeding market prices remained relatively low, accounting for about one-third of scenarios. Furthermore, engaging in PPAs still resulted in significant cost savings compared to conventional energy purchases from the grid.

Additionally, when assessing the profitability of Power Purchase Agreements, it is crucial to consider a scenario in which the savings from having PPAs in the first few years can offset higher prices in the future. In such cases, considering the entire PPA energy budget, it may be lower than purchasing energy from the grid over the entire period.

Very importantly, PPAs also contribute to the development of sustainable technologies and can bring significant savings to a company through the purchase of Energy Attribute Certificates and carbon tax reductions.

These findings demonstrate why PPA activity did not decrease in 2022, and even increased, with these trends continuing into 2023. By the end of August 2023, the signed volumes have reached 9.5 GW in 166 deals, surpassing last year's figure of 162. This is a clear indicator of a potential new record in 2023, especially considering the expected increase in activity during the last quarter of the year when many contracts rush to conclusion before year-end.

Despite market volatility, the study highlighted the effectiveness of PPAs in mitigating energy price spikes. Positive benefits were consistently observed with PPAs in all scenarios, even in challenging market conditions with frequent price fluctuations. The risk of PPA prices exceeding market prices remained relatively low and manageable, emphasizing their controlled nature during the periods examined.

Despite the challenges posed by rising PPA prices and the associated risks stemming from the energy crisis, this study has demonstrated that Power Purchase Agreements remain compelling instruments for ensuring stability and predictability in long-term energy costs. These agreements have proven their effectiveness in shielding against energy price fluctuations, facilitating price stabilization, enabling budget planning, and actively supporting the adoption of sustainable technologies. The events of 2022 underscored the importance of conducting thorough risk assessments prior to entering into PPAs and selecting the PPA type that aligns with the company’s risk appetite. Nevertheless, the surge in PPA activity witnessed in 2023 serves as further testament to their enduring value and resilience in the evolving energy landscape. PPAs continue to play a pivotal role in shaping the future of sustainable energy solutions.

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