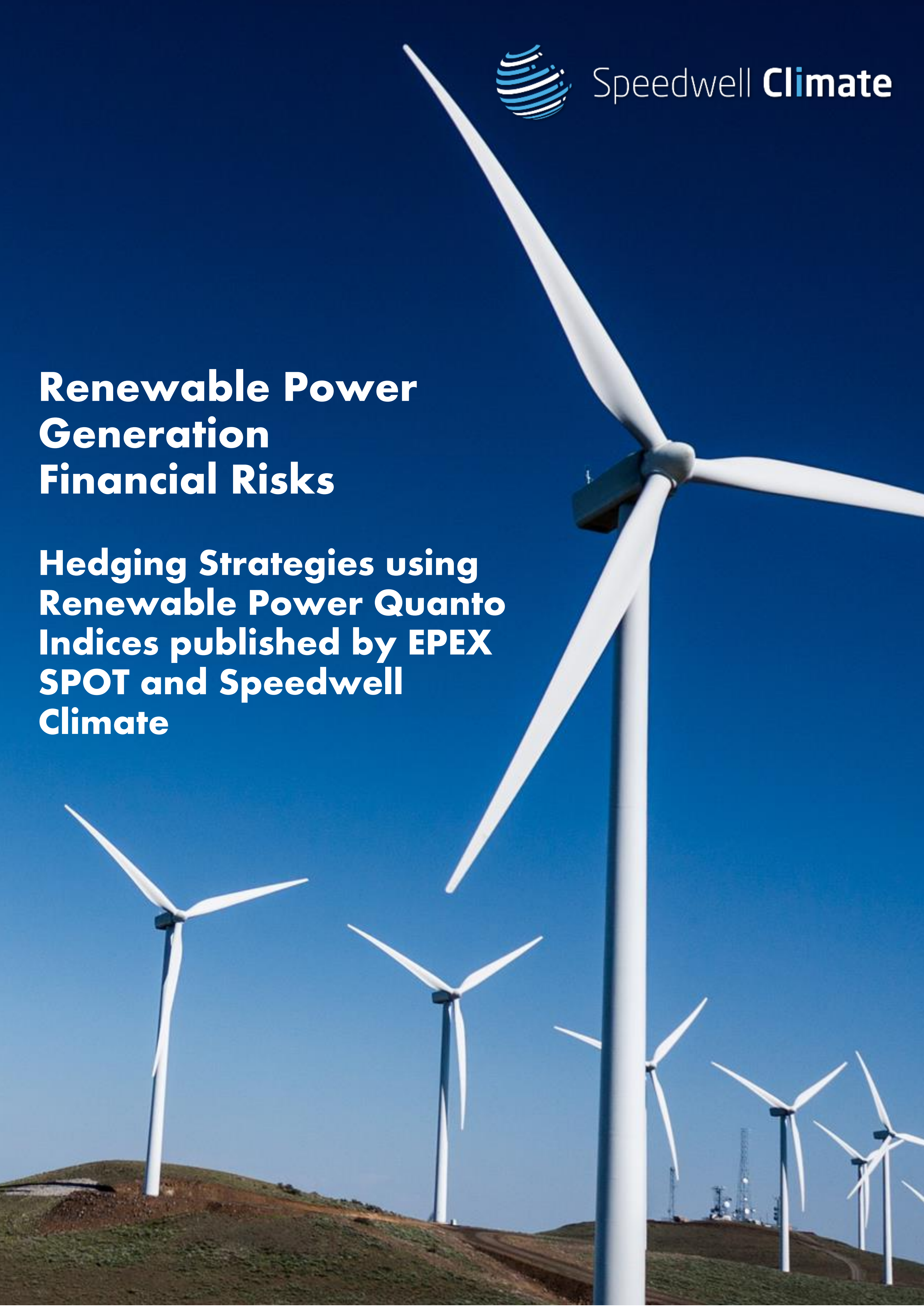


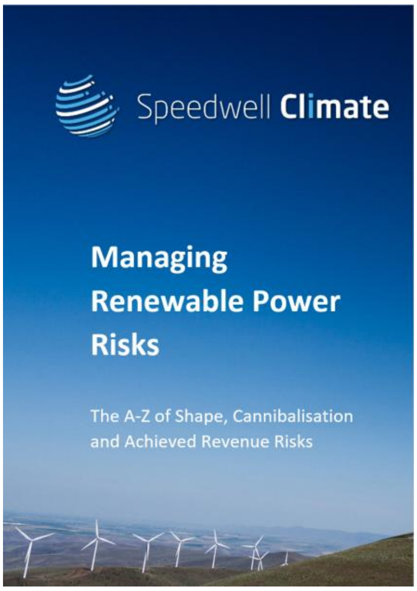
Speedwell Climate

Renewable Power Generation Financial Risks

Hedging Strategies using Renewable Power Quanto Indices published by EPEX SPOT and Speedwell Climate

Renewable Power Generation Financial Risks Hedging Strategies

In this whitepaper, we propose to review how a renewable energy asset manager or a PPA portfolio manager may hedge financial risks using the Renewable Power Quanto Indices published by EPEX SPOT and Speedwell Climate.



This whitepaper follows a previous introductory article in which renewable power generations risks (Shape and Cannibalisation) are presented in greater detail and which introduce the Renewable Power Quanto EPEX SPOT/Speedwell Climate indices.

Please feel free to contact us to access this whitepaper.

The reader already familiar with the Renewable Power Quanto EPEX SPOT / Speedwell Climate Indices may safely jump to the section: Hedging Strategy using the Achieved Revenue Swap.

Acknowledgements

I would like to express my thanks to Arnault Martin from EPEX SPOT, whose invaluable insights and guidance greatly contributed to the development of this article. His deep understanding of the subject matter and expertise in renewable energy finance provided the foundation for exploring the intricacies of hedging strategies for Wind and Solar Power financial risks.

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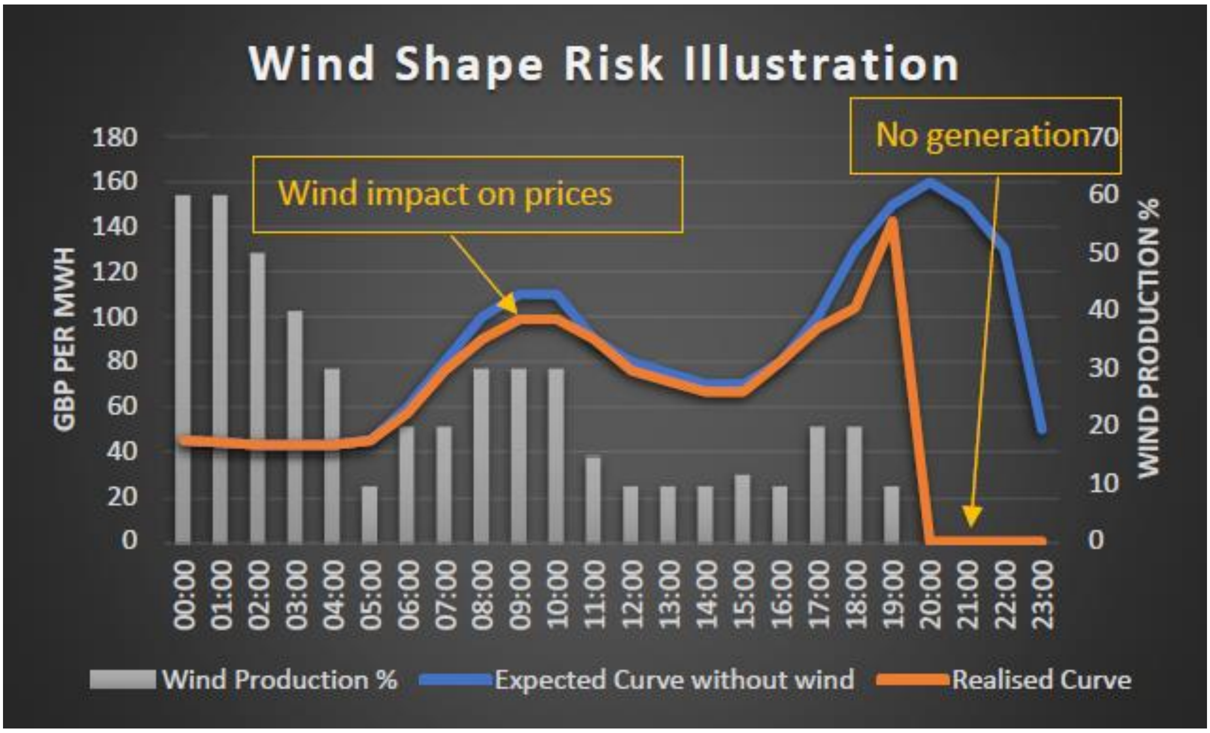
General Introduction and Problem Definition

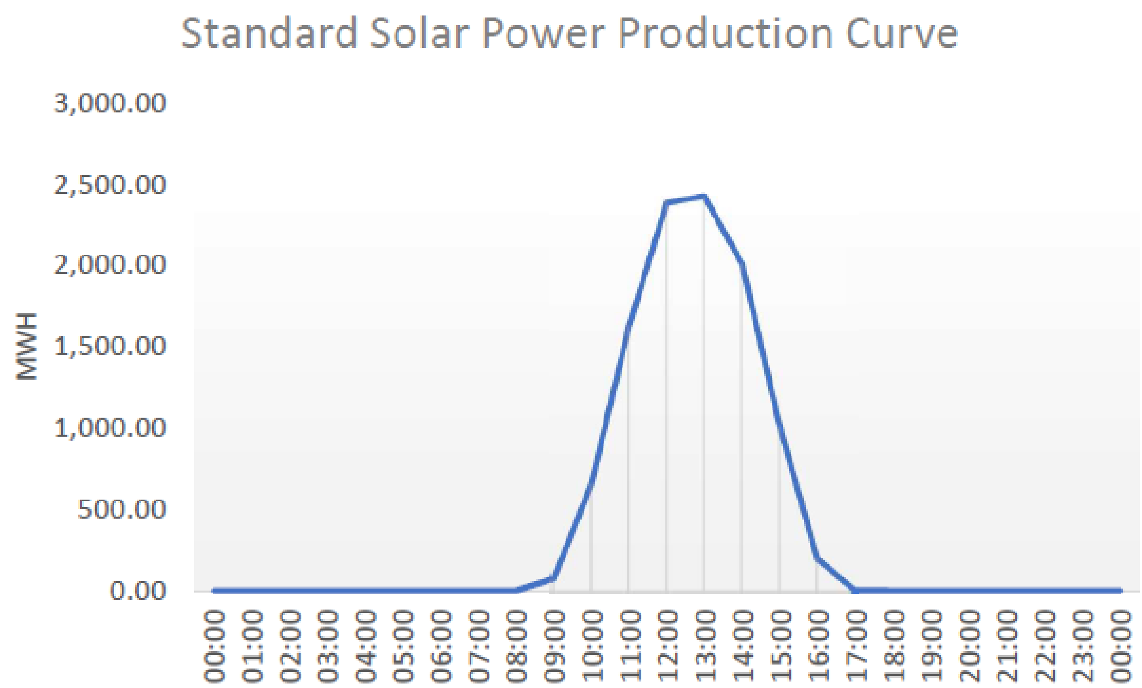
A Power Purchase Agreement (PPA) is a legal contract between a power producer and a power purchaser. The agreement typically outlines the terms of the sale of power, including pricing, delivery, and payment. PPAs are commonly used in the renewable energy industry to facilitate the development and financing of renewable energy projects, such as wind and solar farms.

When entering into a “Pay-as-Produced” Power Purchase Agreement (PPA), an offtaker, such as a utility company or large consumer, may need to manage certain risks associated with the variable nature of the power generation and pricing. Wind and Solar power plants produce energy according to the weather at particular times and locations, not according to demand. Renewable energy generation companies are therefore exposed to what is known as the **Shape Risk**. This risk results from the time disconnect between supply and demand and the impact of the generation on the shape of the day-ahead price curve. In addition, with no fuel to burn when producing power, renewable energy companies can offer low auction prices. This competition can drive prices down and lead to a **cannibalisation of revenues**.

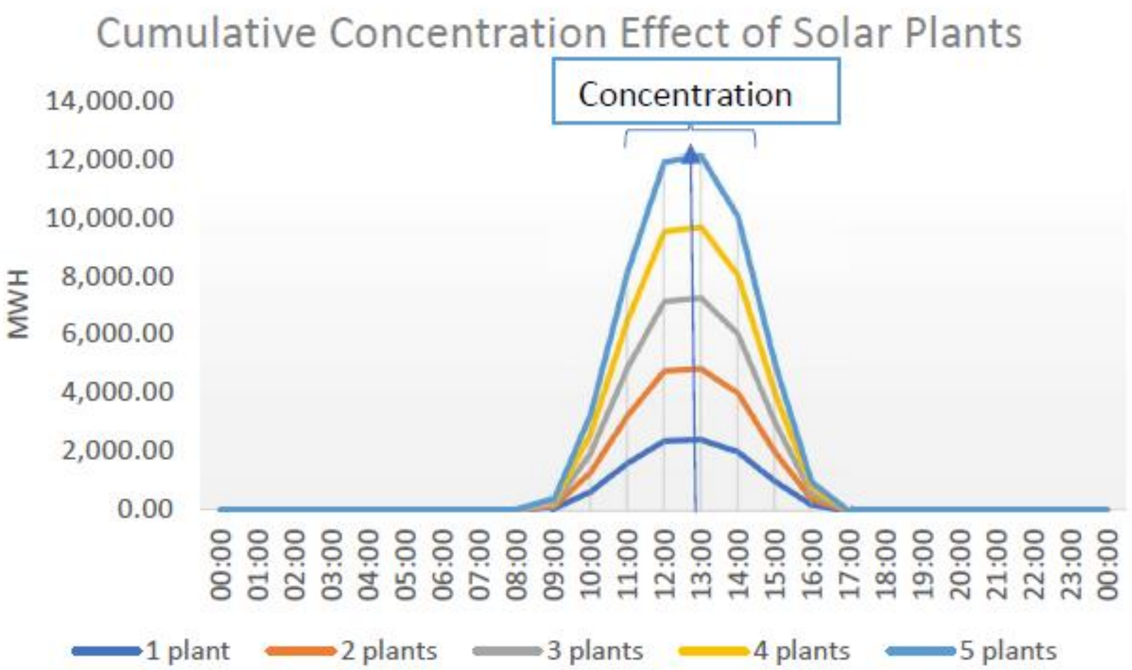
Renewable energy producers may hope to generate revenues according to an estimated day-ahead hourly price curve per MWh (see the blue curve below – derived by modelling price in the absence of wind power). However, in practice their own output is intermittent and modifies the revenue curve per MWh (price per MWh * 1 if there is production and 0 otherwise). This is illustrated on the graph below:



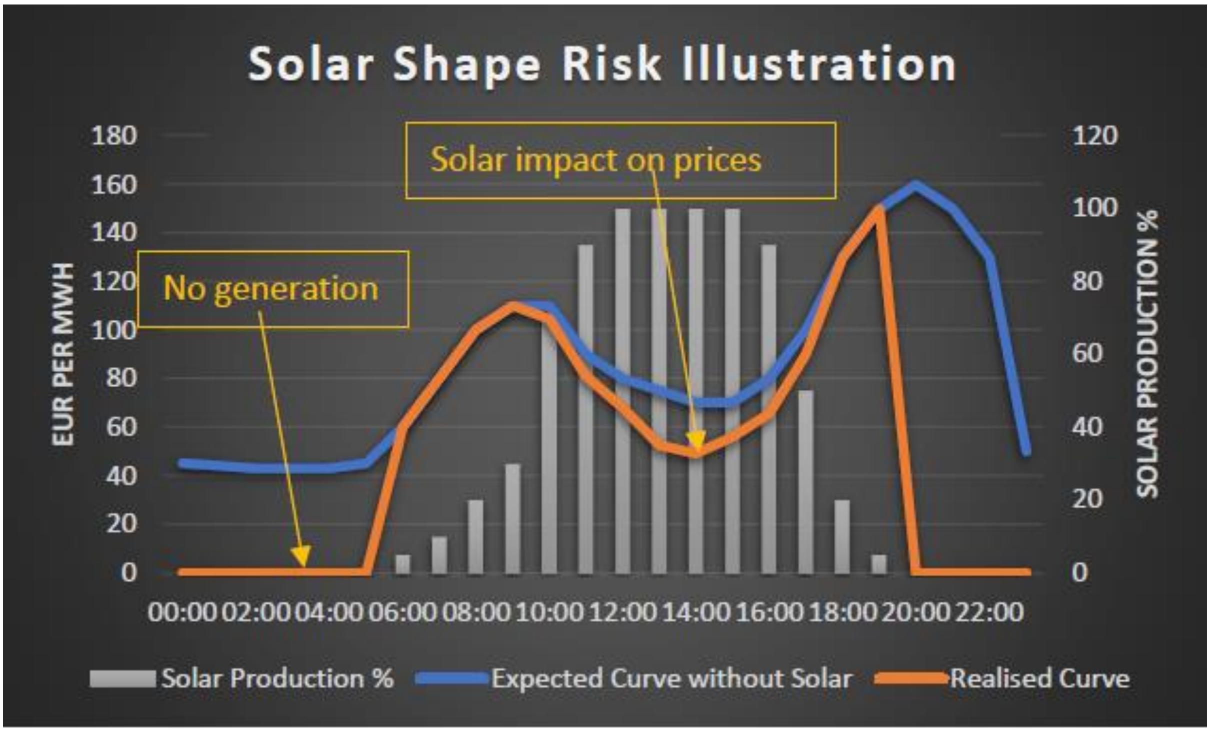
The Shape Risk for solar is perhaps more predictable than for wind but it is also more concentrated. To understand this let us assume for simplicity that all solar plants of a region produce energy as per this curve:



Then, as more and more solar plants are commissioned, the cumulative curves become:



This concentration effect, which results from the high correlation between energy production at different solar plants, will increasingly impact the achieved clearing prices especially during the hours between 10:00 and 16:00 thereby modifying the shape of the price curve. The solar Shape Risk is illustrated on the graph below:



We now go on to introduce the indices that have been created to address the renewable risks described above and how they may be used.

Tradeable Indices – Background

The three variants of the Renewable Power EPEX SPOT/Speedwell Climate Quanto indices are Achieved Revenue, Achieved Price and Quality Factor. All three are derived by combining wind/solar production ("volume") *and* physical spot price over a period of time (day, month, season, etc.). By combining both volume risk and price risks in different ways, these three indices can then be used to implement risk management strategies that increase revenue stability. This may help optimise financing and development of assets in the renewables market.

All variants are currently designed to be used for financial risk-transfer in the OTC market. This means that a historical dataset of each index is available allowing the user to make an informed assessment of trends and therefore inform the opinion of fair-value for a particular structure (eg swap, put, etc.) that can then be based on it. It also means that up-to-date data is available to enable the user who has open transactions to monitor valuations and then to settle the transaction within 5 working days.

…more about the Volume Risk Part

The power production part is derived using the Speedwell Wind/Solar Benchmarks which address pure volume risk. The Speedwell Wind/Solar Benchmarks have been used in the OTC market for wind and solar volume risk-transfer for over 5 years. These are based on modelled *theoretical* output rather than metered data. They are derived using physical modelling combining documented renewable capacity frozen on a specific date and gridded wind data from the ERA5[1] dataset. These indices are regularly updated to reflect the changes in asset base with previous "vintages" being maintained in parallel as long as is necessary to allow any existing risk-transfer contracts based on them to expire.

The advantage of using modelled data for production is that it is possible to derive a synthetic history using the frozen asset base back in time (usually to 1979), that problems relating to errors or changes in reported metered data are avoided and that the "moving target" problem of using actual production is avoided. In the following text all reference to Volume (e.g. "V(h)") should be understood to mean *modelled* production.

The underlying Speedwell volume indices for wind/solar power are available for a number of standard countries and regions worldwide (see later section). The Renewable Power Quanto EPEX SPOT/Speedwell Climate indices are currently for a number of European countries and generation regions. Note that it is also possible to produce all variants for specific assets relevant to a particular generator or portfolio manager. In the examples below, wind indices are discussed. However, the examples are relevant to both wind and solar production.

…more about the Price Risk Part

The prices used are derived from the EPEX SPOT Day-Ahead Power Market. This is a physical market which allows market participants to buy and sell power for delivery the following day. Day-ahead

[1] The ERA5 data set is an historical gridded data set based on "reanalysis data" provided by the European Centre for Medium-Range Weather Forecasts (ECMWF)

power prices, also known as spot prices, are the market-clearing prices determined through the auction process on the EPEX SPOT Day-Ahead Power Market.

Note on the Hedging Strategy Examples to follow

The implementation of hedges based on the Renewable Power Quanto Indices currently requires the execution of bilateral transactions in the over-the-counter market. One of the features of this market is that, generally, transaction payoffs are capped. This practice owes its origin to the early days of the climate risk transfer market where companies hedging temperature, rainfall (etc.) risks would generally transact with insurance counterparties or with specialist funds for whom a theoretically open-ended liability would attract excessive risk premium. In the examples below and for reasons of simplicity, this is ignored.

Renewable Power Quanto Indices – Definition

The three variants of the Renewable Power EPEX SPOT/Speedwell Climate Quanto indices are defined below and hedging examples are shown for each.

Achieved Revenue Index

The first Renewable Power Quanto index is the Achieved Revenue Index, which is:

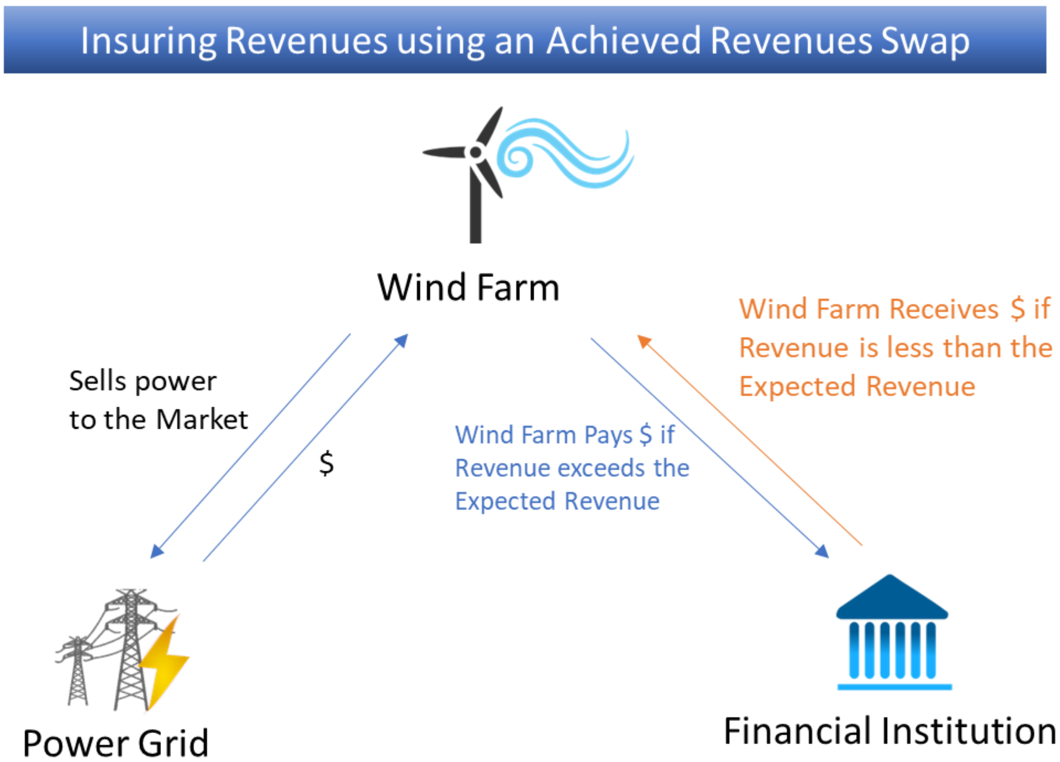
$$Revenue_{Achieved} = \frac{1}{Constant} \sum\nolimits_{h=1}^{N} V(h) \times \mathrm{P}(h)$$

Where N is the number of hours in the period

V(h) is the generated volume for the hour h

P(h) is the day-ahead auction price

An Achieved Revenue swap is a financial contract designed to mitigate revenue risks associated with wind power generation as represented by this index. It can be used to provide protection to wind farm operators or investors against fluctuations in power prices and/or wind resource availability, thereby offering a more predictable revenue stream.



In a wind power Achieved Revenue swap, two parties typically enter into an agreement that forms an over-the-counter (OTC) risk-transfer contract generally documented under ISDA[2] documentation: the

[2] International Swap and Derivatives Association

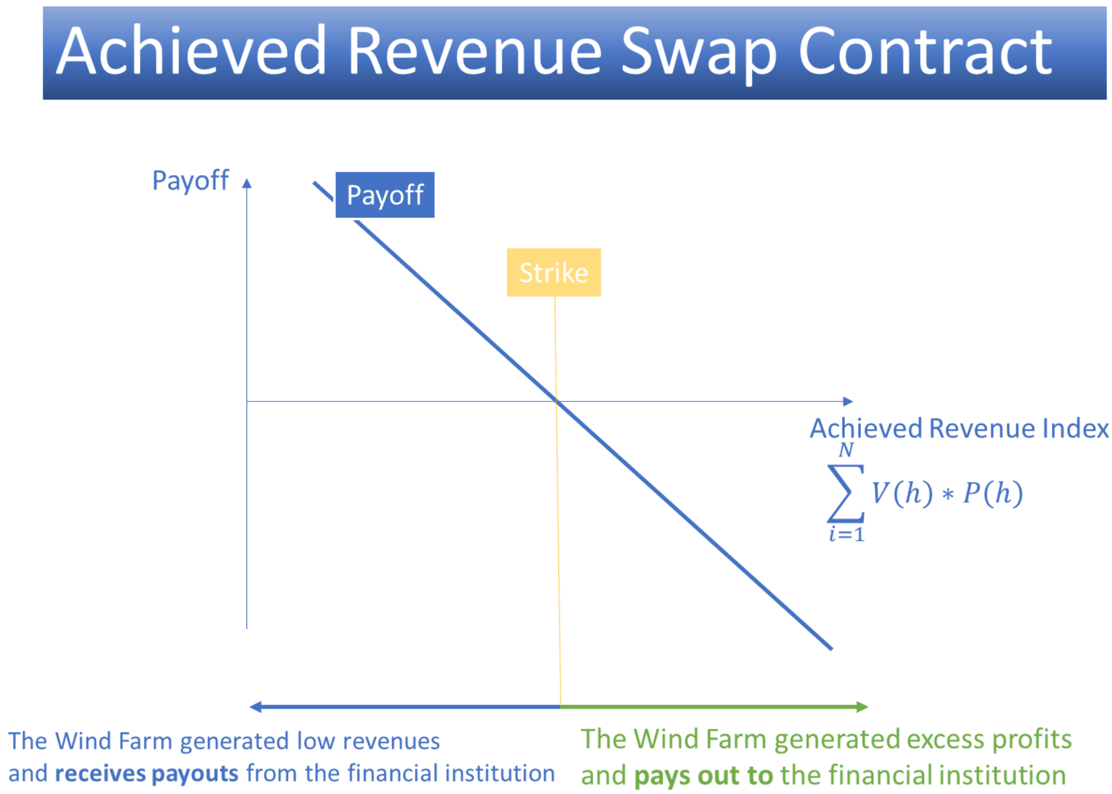
wind farm operator (or generator) and a counterparty (often a financial institution or an insurance company or an energy company with opposite risk profile). The contract is structured based on the Achieved Revenues index, which serves as a proxy for the wind farm's expected revenue.

The key elements of an Achieved Revenue swap include:

1. The chosen Achieved Revenue Index: The contract defines the Achieved Revenue index that serves as a proxy for the wind farm's actual revenue. This could be a standard index if the relationship between the asset base and the standard index is sufficiently close, or a user-tailored index based on a specific asset base.
2. The financial institution agrees to make payments to the wind farm operator based on the predetermined revenue index if the farm modelled revenue is below a certain strike value. These payments are intended to compensate the operator for any shortfall in actual revenue compared to the expected revenue defined by the index.
3. Conversely, if the wind farm's actual revenue exceeds the expected revenue, the wind farm operator is required to make variable payments to the counterparty. These payments act as a form of deductible or excess sharing mechanism, aligning the interests of both parties.
4. Contract Term: The contract typically has a predetermined term during which the revenue swap is in effect. This term is agreed upon by both parties and can vary based on the specific needs and circumstances of the wind farm project.

Typically, the fixed and variable payments are merged into a contract for difference (swap) as illustrated below:

Hedging Strategy using Achieved Revenue Swap



The trading strategy would be:

1. OPERATION 1 – Sell the actual wind portfolio generation on the day-ahead market with physical delivery every day.

2. OPERATION 2 – Sell an Achieved Revenues swap with the following characteristics:
    - Risk Period: January
    - Number of Contracts: 1
    - Strike = Expected Revenues

The following table shows the detail for one day:

Hour	Expected Volume	Expected Price	Expected Volume * Expected Price	Realised Volume	Realised Price	Realised Volume * Realised Price
1	8,500	50	425,000	8,244	47	387,468
2	10,489	50	524,450	10,526	49	515,774
3	8,361	50	418,050	7,928	47	372,616
4	5,695	50	284,750	5,689	49	278,761
5	6,888	50	344,400	7,178	45	323,010
6	8,759	50	437,950	8,769	54	473,526
7	6,259	60	375,540	6,196	60	371,760
8	5,997	75	449,775	6,223	75	466,725
9	9,363	85	795,855	9,540	88	839,520
10	5,956	85	506,260	5,863	84	492,492
11	9,130	83	757,790	9,328	78	727,584
12	11,495	75	862,125	11,689	80	935,120
13	8,673	70	607,110	8,648	75	648,600
14	5,670	72	408,240	5,480	69	378,120
15	9,340	72	672,480	9,143	67	612,581
16	10,913	75	818,475	11,379	75	853,425
17	10,479	80	838,320	10,293	82	844,026
18	10,738	90	966,420	10,646	92	979,432
19	10,817	100	1,081,700	11,080	96	1,063,680
20	10,866	110	1,195,260	11,022	113	1,245,486
21	6,198	100	619,800	5,864	104	609,856
22	5,651	80	452,080	6,063	79	478,977
23	10,874	70	761,180	11,320	73	826,360
24	8,673	50	433,650	8,806	49	431,494
Average	8,574	72	626,528	8,622	72	631,516
Sum			15,036,660			15,156,393

Swap Strike	15,036,660	
Swap Payoff	-119,733	
Realised Revenues	15,156,393	
Swap Payoff + Realised Revenues	15,036,660	matches the Expected Revenues! ...the revenues were locked in.

By selling a wind power Achieved Revenue swap, wind farm operators can reduce their exposure to revenue uncertainties caused by fluctuations in power prices *and* wind resource availability. This type of risk management tool can provide greater financial stability, help attract investment, and facilitate the financing of wind energy projects.

This index can easily be accommodated to cover other scenarios. For example, the seller of a Pay-as-Produced PPA may fix the price in the formula and sell an OTC swap based on the following index to hedge its revenues:

$$Revenue_{Achieved} = \frac{1}{Constant} \sum_{h=1}^{N} V(h) \times P_{fixed}$$

Where P_{fixed} is the fixed price of power agreed in the PPA and the Constant is simply a factor to hedge the desired fraction of the risk.

On its side, a Pay-as-Produced PPA offtaker who resells the power to the market is exposed to this risk:

$$Revenue_{Achieved} = \frac{1}{Constant} \sum_{h=1}^{N} V(h) \times \left(P(h) - P_{fixed}\right)$$

Which reads as: the sum of the hourly volume multiplied by the difference between price the offtaker sells the power in the market at and the price it is buying it from the producer.

Achieved Price Index

The second index is the Achieved Price Index which is a measure of the actual price received on a weighted basis per MWh:

$$P_{Achieved} = \frac{1}{N} \sum_{h=1}^{N} \frac{V(h)}{\bar{V}} \times \mathrm{P}(h)$$

Where N is the number of hours in the period

V(h) is the generated volume for the hour h

P(h) is the day-ahead auction price

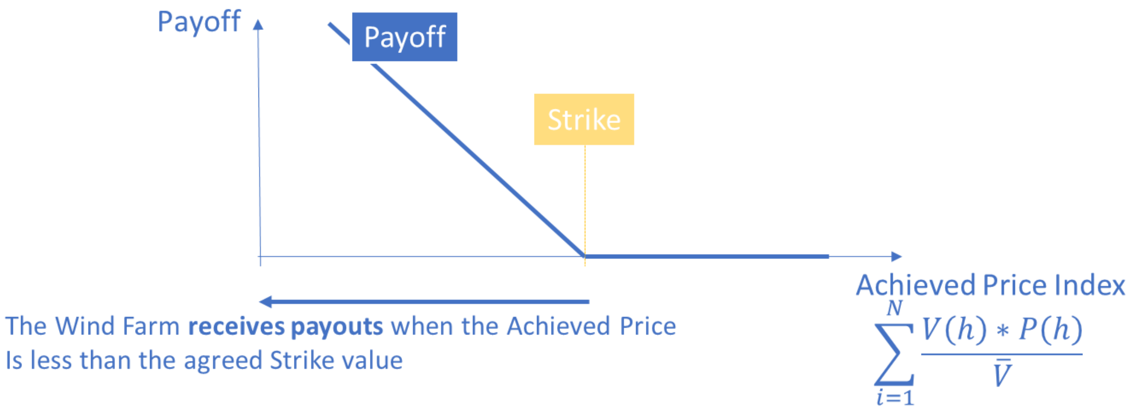
$\bar{V}$ is the average volume over the period

This index may be used to assess the comparative economic performance or value generation of a number of different wind power projects in a portfolio or for hedging purposes.

The wind power Achieved Price refers to the average price at which a wind power generator sells its power output in the market. It represents the revenue earned per unit of power produced by the wind farm. This Achieved Price can vary depending on various factors, including power market prices, contractual agreements, subsidies, and grid integration costs.

A trader may sell a swap, as discussed above, or buy put options on an Achieved Price index to guarantee a minimum achieved price. The example below illustrates the benefit of buying a put option:

Achieved Price Put Option



The trading strategy would be:

1. OPERATION 1 – Sell the actual wind portfolio generation on the day-ahead market with physical delivery every day.

2. OPERATION 2 – Buy Achieved Price Put options with the following characteristics:
   - Risk Period: January
   - Number of Contracts: Expected Volume
   - Strike = a percentage of the Expected Price

The following Table shows the detail for one day:

Hour	Expected Volume	Expected Price	Expected Volume * Expected Price	Realised Volume	Realised Price	Realised Volume * Realised Price
1	8,500	50	425,000	8,883	40	355,320
2	10,489	50	524,450	10,867	40	434,680
3	8,361	50	418,050	8,527	40	341,080
4	5,695	50	284,750	5,629	40	225,160
5	6,888	50	344,400	7,030	40	281,200
6	8,759	50	437,950	8,723	40	348,920
7	6,259	60	375,540	5,909	50	295,450
8	5,997	75	449,775	6,425	65	417,625
9	9,363	85	795,855	9,016	75	676,200

10	5,956	85	506,260	5,494	75	412,050
11	9,130	83	757,790	9,045	73	660,285
12	11,495	75	862,125	11,963	65	777,595
13	8,673	70	607,110	8,758	60	525,480
14	5,670	72	408,240	6,085	62	377,270
15	9,340	72	672,480	8,952	62	555,024
16	10,913	75	818,475	10,707	65	695,955
17	10,479	80	838,320	10,069	70	704,830
18	10,738	90	966,420	10,454	80	836,320
19	10,817	100	1,081,700	10,743	90	966,870
20	10,866	110	1,195,260	10,566	100	1,056,600
21	6,198	100	619,800	6,559	90	590,310
22	5,651	80	452,080	5,194	70	363,580
23	10,874	70	761,180	11,163	60	669,780
24	8,673	50	433,650	8,397	40	335,880
Average	8,574	72.17	626,528	8,548	62.17	537,644
Sum	205,784		15,036,660	205,158		12,903,464

Expected Achieved Price per MWh	73.07	
Number of Put Options	205,784	
Put Strike	65	
Sum Put Payoffs	583,055[3]	
Realised Revenues	12,903,464	
Total Put Payoff + Realised Revenues	**13,486,519**	The put options served their purpose and hedged the revenues

Conclusion: The Achieved Price put option has protected some of the losses as intended. It is, however, not as "perfect" a hedging strategy as selling a swap on the Achieved Revenues index.

[3] Ie (65-62.17)*205,784

Quality Factor Index

The third and final index is the Quality Factor (QF) Index which is a measure of the Achieved Price divided by the Baseload Price. It is sometimes described as the Capture Rate:

$$QF = \frac{1}{N}\sum_{h=1}^{N} \frac{V(h) \times \mathrm{P}(h)}{\bar{V} \times \bar{P}}$$

Where N is the number of hours in the period

V(h) is the generated volume for the hour h

P(h) is the day-ahead auction price

$\bar{V}$ is the average volume over the period

$\bar{P}$ is the average price over the period, also known as the baseload price

This index is, by definition, a measure of price cannibalisation. Renewable power price cannibalisation refers to a phenomenon that occurs when the increasing deployment of renewable energy sources, particularly intermittent sources like wind and solar, leads to a decline in power prices that can negatively impact the revenue and profitability of existing renewable energy projects.

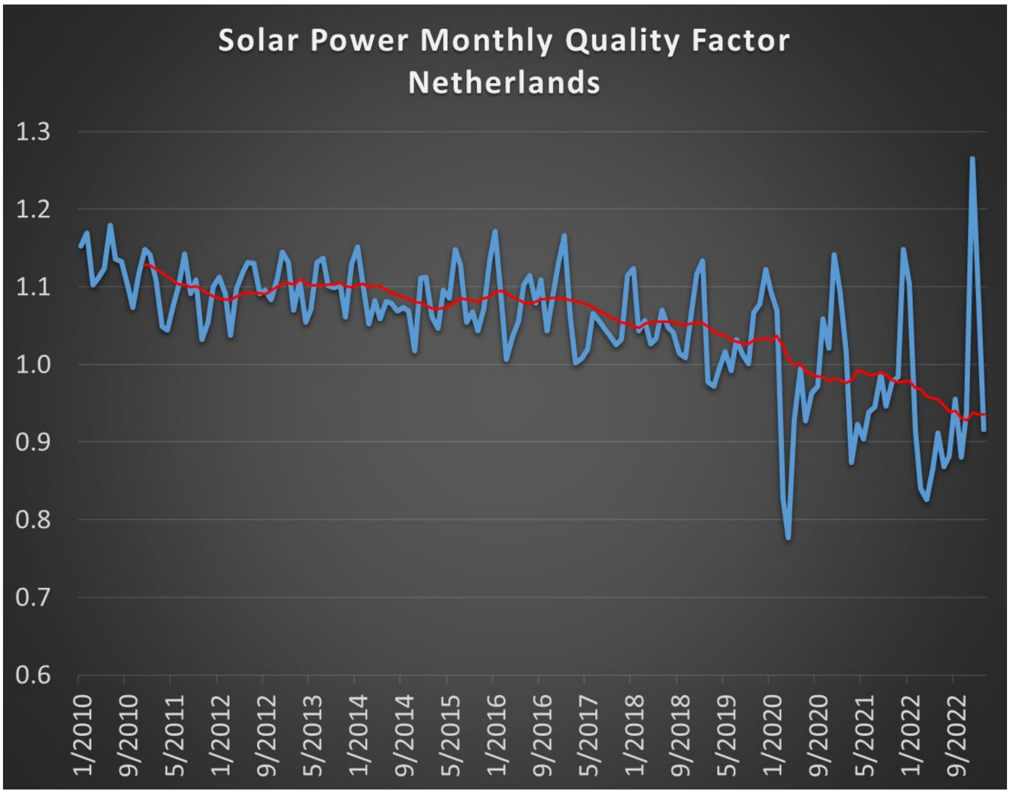
The key concept behind renewable power price cannibalisation is the interaction between supply and demand dynamics in the power market. As more renewable energy projects are added to the grid, their intermittent generation patterns can result in periods of high renewable energy supply, leading to an excess of power generation compared to demand. During these periods, renewable energy sources may bid their power output into the market at very low or even negative prices in order to ensure dispatch, gain from guarantee of origin certificates[4], and avoid curtailment.

In simple terms, the higher the QF value the better the situation is for a renewable energy generator or offtaker selling its power to the market.

In most countries and regions, we see the QF value in a long-term downward trend as shown on this graph representing the monthly QF values for Solar Power Generation in the Netherlands:

[4] A Guarantee of Origin (GO) is a tradable commodity that represents a claim to the environmental benefits associated with renewable power generation. GOs are traded electronically in the voluntary market for renewable energy certificates and are not tied to the physical delivery of electricity.

A GO indicates the generation of one megawatt hour (MWh) of electricity from an eligible source of renewable power. Each GO denotes the underlying generation source, location of generation, and year of generation (a.k.a. “vintage”). The trading market in Europe includes GOs from wind, hydropower, solar PV, geothermal and biomass sources for now.



Let us consider a scenario where a trader manages a wind generation portfolio with the following characteristics:

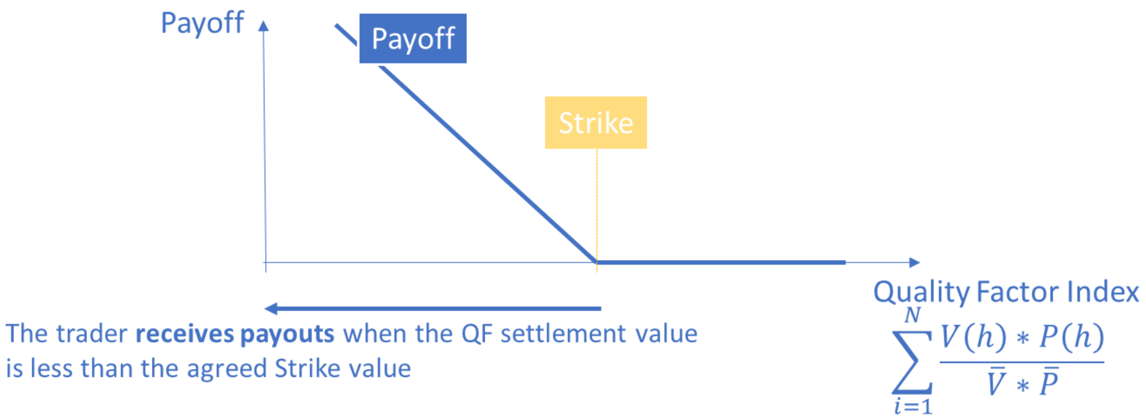
- For the first quarter of the year, the expected generation is 300,000 MWh.
- The Expected QF Value over the quarter is 0.9
- Based on listed futures contracts, the anticipated average EPEX SPOT baseload price for the quarter is EUR 60 per MWh.

Hedging Strategy, Addressing Price Cannibalisation using a Quality Factor Put Option

The trader sells the power to the market on a daily basis and is concerned that the Quality Factor may degrade below a "pain threshold" of 0.85. To hedge this risk, the trader buys QF Put options where the payout is linked to the Baseload Price*:

- Number of Put options: 300,000 * Expected Baseload Price
- Strike: 0.85

Quality Factor Put Option



For simplicity, let us assume that there is no volume and no baseload price risk, but that the Quality Factor degraded and settled at 0.8.

Then, instead of achieving a revenue equal to:

Expected Generation * Expected QF * Price per MWh = 300,000 * 0.9 * 60 = EUR 16,200,000

The trader's realised revenues are notably lower:

Realised Generation * Realised QF * Realised Baseload Price[5]

= 300,000 * 0.8 * 60 = EUR 14,400,000

The trader however gains from the purchased Put options:

= Number of Put options * (Strike – Realised QF) * Expected Baseload Price

= 300,000 * (0.85 – 0.8) * 60

= EUR 900,000

Hence, the total hedged revenues that combine the daily sell of the power to the market and the purchase of the Put options are: EUR 14,400,000 + EUR 900,000 = EUR 15,300,000

***Conclusion**: the trader has hedged its position against a low realised Quality Factor. A similar strategy based on selling a QF swap can be envisaged.*

[5] In this example as we have stated there is no baseload price risk, Realised and Expected Baseload price are the same

Possible Hedging Strategies using the Quality Factor Index – A step by step use case

The previously illustrated strategies work well and are easy to set up. However, in this section, alternative strategies are explored to better understand the various risks and see how to mix and combine hedges to achieve different level of protections. In particular, we will see how a renewable energy company may further build its hedging strategy around its existing baseload power future price position.

Let us consider a scenario where a trader manages a wind generation portfolio with the following characteristics:

- The wind portfolio has an installed capacity of 1000 MW.
- The long-term average load factor for the month of January is 25%.
- The expected generation for January is calculated as

  January Expected Generation = 1000 MW * 0.25 * 24 * 31

  = 186,000 MWh

- The wind farms are located in Germany and are geographically well-distributed. It is assumed that there is no difference in the Quality Factor (QF), Achieved Price (AP), or Achieved Revenue (AR) between the portfolio and the German market (i.e. perfect correlation).
- January Expected QF Value = 0.9
- Based on listed futures EEX contracts, the anticipated average EPEX SPOT baseload price for January is EUR 38.888 per MWh.

At the start of the month, without any hedge in place, the Expected Revenue is:

$$=\sum_{i=i}^{N} V(h) \times P(h)$$

$$=\bar{V} \times \bar{P} \times \sum_{i=i}^{N} \frac{V(h)\times P(h)}{\bar{V}\times\bar{P}}$$

$$=\boldsymbol{\bar{V} \times \bar{P} \times QF}$$

Which reads as:

= Expected Generation * Expected Baseload Price * Expected QF

= 186,000 * 38.888 * 0.9

= EUR 6,509,851

During the month of January, the trader may simply sell all the wind generation forecasts on EPEX SPOT day-ahead German auctions. This crude strategy relies on good fortune when it comes to the timing and the volume of the generated power and the matching day-ahead prices for each hour. Hence, the trader may prefer to reduce the volatility of its earnings and secure its revenues.

Scenario 1: WITH Price risk, NO Volume Risk, and NO QF Risk - Using only Power Futures

Let us review the case where the trader hedges their position using only EEX Power Futures.

To do so, the trader enters into the following two strategies:

1. OPERATION 1 - Sell the actual wind portfolio generation on the German day-ahead market with physical delivery every day.

2. OPERATION 2 - Sell "German Power Futures" with the following characteristics:
   - Risk Period: January
   - Traded Volume: Expected Generation x QF
     = 186,000 * 0.9
     = 167,400 MWh[6]
   - Expected Price = Contract price = EUR 38.888 per MWh

     Please note that the expected Achieved Price at which the expected generation is sold is:

     Expected Achieved Price = Expected Baseload Price * QF = 38.888 * 0.9 = EUR 35 per MWh

In this first scenario, we assume there is price risk, but there is neither Volume nor QF risk.

- The realised EPEX SPOT DAM average baseload price (Realised Price) is EUR 40 per MWh
- There is no QF Risk, so Settlement QF Value = Expected QF Value = 0.9
- There is no Volume risk, so Realised wind power generation = Expected generation = 186,000 MWh

The total revenues are calculated as the sum of:

Revenues from the sales on the EPEX SPOT day-ahead market

- Realised QF * Realised Generation * Realised price
- = 0.9 * 186,000 * 40
- = EUR 6,696,000

Revenues from the Financial Power Future

- Traded Volume * (Expected EPEX SPOT DAM average baseload price - Realised price)
- = 167,400 MWh * (38.888 - 40)
- = EUR -186,149

Total Revenue = 6,696,000 – 186,149 = EUR 6,509,851

The total revenues amount to EUR 6,509,851, which matches the expected Revenue. Thus, the price risk has been effectively managed with this strategy when there is neither volume nor QF risk.

[6] 167,400 MWh for the month of January is equivalent to 167400/31/24 = 225 1MW January Future Contracts

Scenario 2: WITH Price risk, NO Volume Risk, and WITH QF Risk Using Only Power Futures

In this second scenario, we assume there are both price and QF risks but that there is still no volume risk. The hedging strategy is the same as Scenario 1

- The realised EPEX SPOT Day Ahead Market average baseload price is EUR 40 per MWh
- The realised QF settles at: 0.75
- There is no Volume risk => Realised wind power generation = Expected generation = 186,000 MWh

The total revenues are calculated as the sum of:

Revenues from the sales on the EPEX SPOT day-ahead market

- Realised QF * Realised Generation * Realised Price
- = 0.75 * 186,000 * 40
- = EUR 5,580,000

Revenues from the Financial Power Future

- Traded Volume * (Expected EPEX SPOT DAM average baseload price - Realised Price)
- = 167,400 MWh * (38.888 - 40)
- = EUR -186,149

Total Revenue = 5,580,000 – 186,149 = EUR 5,393,851

The total revenues amount to EUR 5,393,851, which is less than the expected revenue and corresponds to only EUR 29 per MWh. This example shows that a combination of EEX baseload financial futures and selling on the day-ahead market can hedge the price risk but not the QF risk.

Scenario 3: WITH Price risk, NO Volume Risk, and WITH QF Risk using Power Futures and QF Contracts

In this third scenario we assume, as per scenario 2, that there are both price and QF risks but that there is still no volume risk.

Using a risk-transfer contract that uses QF as the underlying asset, the trader performs the following three operations:

As before

1. OPERATION 1 - Sell the actual wind portfolio generation on the German day-ahead market with physical delivery every day.

2. OPERATION 2 - Sell "German Power Futures" with the following characteristics:
   - Risk Period: January
   - Traded Volume: Expected Generation x Expected QF
     = 186,000 * 0.9
     = 167,400 MWh
   - Contract price: EUR 38.888 per MWh

     Please note that the Expected Achieved Price at which the expected generation is sold is:

     Achieved Price = Baseload Price * QF = 38.888 * 0.9 = EUR 35 per MWh
3. OPERATION 3 - Sell an OTC German QF swap with the following characteristics:
   - Risk Period: January
   - Number of QF units: Expected generation of the portfolio
     = 186,000
   - Expected QF = QF Strike = 0.9
   - Payoff Formula = Expected Generation * (QF Strike – Realised QF) * Realised Baseload Price

- The realised EPEX SPOT DAM average baseload price is EUR 40 per MWh
- The realised QF settles at: 0.75
- There is no Volume risk => Realised wind power generation = Expected generation = 186,000 MWh

The total revenues are calculated as the sum of:

Revenues from the sales on the EPEX SPOT day-ahead market

- Realised QF * Realised Generation * Realised Price
- = 0.75 * 186,000 * 40
- = EUR 5,580,000

Revenues from the Financial Power Future

- Traded Volume * (Expected EPEX SPOT DAM average baseload price - Realised Price)
- = 167,400 MWh * (38.888 - 40)
- = EUR -186,149

Revenues from the QF OTC Swap

- Number of QF Contracts * (QF Strike - Realised QF) * Realised Price
- = 186,000 MWh * (0.9 - 0.75) * 40
- = EUR 1,116,000

Total Revenue = 5,580,000 – 186,149 + 1,116,000 = EUR 6,509,851

*The total revenues amount to EUR 6,509,851, which matches the expected revenue, despite the realised QF being different from the expected QF. By combining these three operations, and assuming there is no volume risk, the trader can lock in a revenue equal to the number of German Power futures multiplied by the DE Power Financial Future price (167,400 * 38.888 = EUR 6,510,000, equivalent to EUR 35 per MWh).*

Scenario 4: WITH Price risk, WITH Volume Risk, and WITH QF Risk - Using Power Futures and QF Contracts

In this fourth scenario, there is price, volume and QF risk. The hedging strategy is the same as Scenario 3

- The realised EPEX SPOT DAM average baseload price is EUR 40 per MWh
- The realised QF settles at: 0.75
- The Realised wind power generation = 170,000 MWh

The total revenues are calculated as the sum of:

Revenues from the sales on the EPEX SPOT day-ahead market

- Realised QF * Realised Generation * Realised price
- = 0.75 * 170,000 * 40
- = EUR 5,100,000

Revenues from the Financial Power Future

- Traded Volume * (Expected EPEX SPOT DAM average baseload price - Realised price)
- = 167,400 MWh * (38.888 - 40)
- = EUR -186,149

Revenues from the QF OTC Swap

- Number of QF Contracts * (QF Strike - Realised QF) * Realised Price
- = 186,000 MWh * (0.9 - 0.75) * 40
- = EUR 1,116,000

Total Revenue = 5,100,000 – 186,149 + 1,116,000 = EUR 6,029,851

The total revenues amount to EUR 6,029,851

This is less than the expected EUR 6.5Mln due to the volume risk.

Scenario 5: WITH Price risk, WITH Volume Risk, and WITH QF Risk - Using Power Futures, QF Contracts and Wind Power Volume Swap

In this fifth scenario we replay the situation of Scenario 4 but with a different hedging strategy.

This time, the trader performs the following four operations:

As before

1. OPERATION 1 - Sell the actual wind portfolio generation on the German day-ahead market with physical delivery every day.

2. OPERATION 2 - Sell "German Financial Power Futures" with the following characteristics:
   - Risk Period: January
   - Traded Volume: Expected Generation x QF = 186,000 * 0.9 = 167,400 MWh
   - Contract price: EUR 38.888 per MWh

   Please note that the Achieved Price at which the expected generation is sold is:

   Achieved Price = Baseload Price * QF = 38.888 * 0.9 = EUR 35 per MWh

3. OPERATION 3 - Sell an OTC "German QF Swap" with the following characteristics:
   - Risk Period: January
   - Number of QF units: expected generation of the portfolio = 186,000 contracts
   - QF Strike: 0.9
   - Payoff Function= Expected Generation * (QF Strike – Realised QF) * Realised Baseload Price

4. OPERATION 4 - Sell a Germany Speedwell Climate Wind Power Volume OTC Swap with the following characteristics:
   - Risk Period: January
   - The Settlement Index value is defined as the ratio between the Speedwell index calculated over the period and the expected generation (186,000MWh)
   - Strike: 1
   - Payoff Formula: (Strike – Realised Settlement Index Value) * Realised Baseload Price * Expected generation * Realised QF

- The realised EPEX SPOT DAM average baseload price is EUR 40 per MWh
- The realised QF settles at: 0.75
- The Realised wind power generation index value = 170,000 MWh
- Assuming a perfect correlation between the portfolio and the Speedwell German Volume Index this means the Swap settlement index value = 170,000/186,000 = 0.9140

The total revenues are calculated as the sum of:

Revenues from the sales on the EPEX SPOT day-ahead market

- Realised QF * Realised Generation * Realised price
- = 0.75 * 170,000 * 40
- = EUR 5,100,000

Revenues from the Financial Power Future

- Traded Volume * (Expected EPEX SPOT DAM average baseload price - Realised price)
- = 167,400 MWh * (38.888 - 40)
- = EUR -186,149

Revenues from the QF OTC Swap

- Number of QF Contracts * (QF Strike - Realised QF) * Realised Price
- = 186,000 MWh * (0.9 - 0.75) * 40
- = EUR 1,116,000

Revenues from the Wind Power Volume Swap

- (Strike - Index) * Realised Baseload Price * Expected generation * Realised QF
- =(1-0.9140) * 40 * 186,000 * 0.75
- =EUR 479,880

Total Revenue = 5,100,000 – 186,149 + 1,116,000 + 479,880 = EUR 6,509,731

The total revenues amount to EUR 6,509,731.

This strategy achieves a perfect hedge!

Please note that if the Speedwell Wind Power Volume OTC Swap payoff formula had been based on the expected rather than the realised QF value, this would have led to:

Revenues from the sales on the EPEX SPOT day-ahead market

- Realised QF * Realised Generation * Realised price
- = 0.75 * 170,000 * 40
- = EUR 5,100,000

Revenues from the Financial Power Future

- Traded Volume * (Expected EPEX SPOT DAM average baseload price - Realised price)
- = 167,400 MWh * (38.888 - 40)
- = EUR -186,149

Revenues from the DE QF Financial Future

- Number of QF Contracts * (QF Strike - Realised QF) * Realised Price
- = 186,000 MWh * 38.888 * (0.9 - 0.75) * 40
- = EUR 1,116,000

Revenues from the Wind Power Volume Swap

- (Strike - Index) * Realised Baseload Price * Expected generation * Expected QF
- =(1-0.9140) * 38.888 * 186,000 * 0.9
- =EUR 559,847

Total Revenue now= 5,100,000 – 186,149 + 1,116,000 + 559,847 = EUR 6,589,698

The hedge is then imperfect. However, given the QF value is fixed before the trade happens, it might be easier to find a counterparty for it.

Conclusion

Managing a portfolio of Power Purchase Agreements (PPAs) presents several challenges, including volume risk, Quality Factor risk, baseload price risk, and more. These risks need to be carefully addressed to ensure effective portfolio management.

Volume risk refers to the uncertainty surrounding the actual output of the power generation facilities covered by the PPAs. The Quality Factor risk relates to the ability to sell the contracted energy at favourable prices in the market. Market conditions, demand-supply dynamics, and competition can influence the Quality Factor, which may deviate from the expected value.

Baseload price risk pertains to the exposure to fluctuations in the prices of baseload power, which serves as the foundation of energy markets. Variations in fuel costs, regulatory changes, and shifts in market dynamics can impact the price of baseload power. Effective risk management strategies, such as diversification and hedging mechanisms, can assist in mitigating this risk.

Managing these risks requires a comprehensive and adaptive approach, including ongoing monitoring, rigorous analysis, and proactive adjustments to the portfolio. By actively addressing these challenges, stakeholders can enhance their ability to optimise PPA portfolio performance and navigate the complexities of the energy market successfully.

Using the Speedwell Wind Power indices to hedge volume risk, EEX Power Futures for price risk and the Renewable Power Quanto EPEX SPOT/Speedwell Climate indices, it is possible to setup many different strategies to reduce the volatility of earnings.

Based on the risk appetite of the renewable energy company, it is possible to develop hedging strategies that encompass or address volume, price and QF risk with the following indices:

Strategy	Volume Risk	Price Risk	QF Risk
Speedwell Wind Power Volume Swap (OTC)	✓		
Achieved Revenue Swap (OTC)	✓	✓	✓
Achieved Price Put Option (OTC)		✓	
EPEX/Speedwell QF Swap (OTC)			✓
EEX Power Futures (Listed)		✓	
EEX Power Future (Listed) + EPEX/Speedwell QF Swap (OTC)		✓	✓
EEX Power Future (Listed) + EPEX/Speedwell QF Swap (OTC) + Speedwell Wind Power Volume Swap (OTC)	✓	✓	✓

Market participants are increasingly aware of power price cannibalisation (long-term decline in Quality Factor) as well as the impact of shorter-range volatility in the QF. The availability of tradeable indices for hedging purposes, whether to mitigate Volume, Shape or Cannibalisation Risk associated with their own assets or portfolios of PPAs allows participants to manage these risks in the OTC market.

Hedging pure volume risks is easily done using a Speedwell Wind Power OTC Swap. This works well for sellers of Pay-as-Produced PPAs as an example. For more complex situations with volume and price risks, hedging using an Achieved Revenue OTC Swap is probably the simplest strategy to consider. Hedging using an Achieved Price OTC Put/Swap or QF OTC Swap offer good hedges for specific risk such as: price and cannibalisation risks.

The second set of strategies we have discussed is built around existing positions on the EEX power futures as Renewable Power companies may already have. Starting from this position, we have shown how to extend hedging using the Speedwell Wind Power Generation Volume indices and the EPEXSPOT/Speedwell Quality Factor index. The hedges can be partial or complete as may be desired.

In conclusion, this new set of indices offer notable advantages and flexibilities as they can be adapted to cover multiple risks and use cases. We hope that these examples have provided useful insights. If you have any further inquiries or require additional information, please do not hesitate to contact us. We welcome the opportunity to assist you in any way we can.

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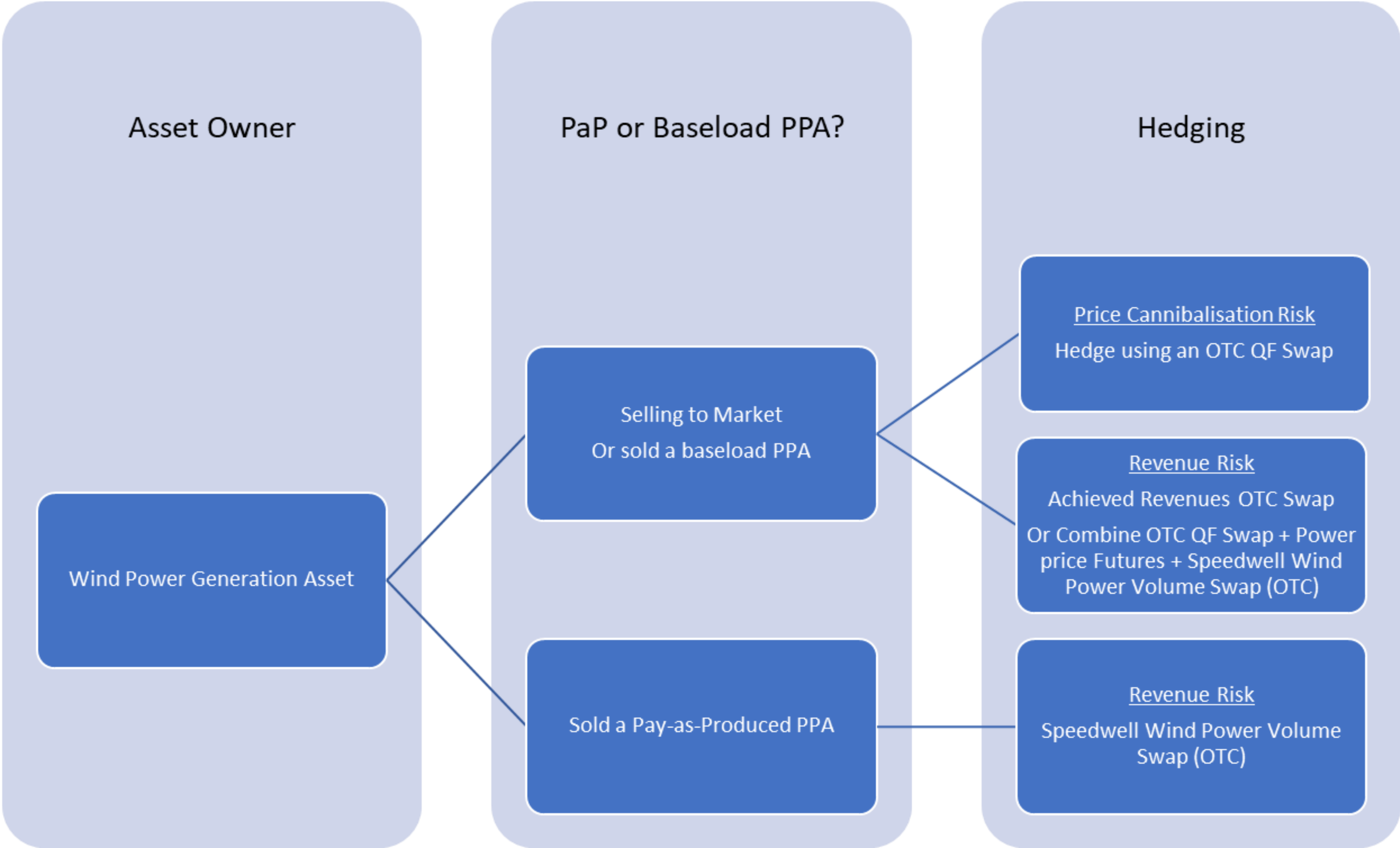
Hedging Strategies Cheat Sheet

This cheat sheet summarizes what strategies may be used when hedging revenues in the market:



Reference Index Availability – Standard Countries/Regions

New indices are constantly being produced according to demand. If an index is not shown below, please contact us.

Renewable Power Quanto EPEX SPOT/Speedwell Climate Indices – Combined Price/Volume Risk

Launched in partnership with EPEX SPOT, Achieved Revenue, Achieved Price and Quality Factor index histories and feeds designed for OTC risk-transfer are available for wind generation for the following countries/regions:

Belgium, Finland, France, Germany, Great Britain, Netherlands, Norway BZ1-4, Sweden BZ1-4, Norway

Likewise, for solar power generation the following countries are available:

Belgium, Germany, Great Britain, Netherlands

Historical data may be purchased either from Speedwell Climate or from the EPEX SPOT online shop. Historical data provides a synthetic history going back from 4 to 9 years depending on country but excludes the most recent period of between 3 and 6 months.

Up-to-date data for final pricing of risk-transfer contracts are available from Speedwell Settlement Services. Real-time feeds for valuation and settlement of risk-transfer contracts are also available from Speedwell Settlement Services. The charges for settlement feeds are dependent on transaction size and term.

https://www.speedwellsettlementservices.com/

Speedwell Climate Wind Power Indices – Volume Risk

Speedwell Wind Power Indices for OTC risk-transfer of volume risk are available for the following countries/regions:

Europe: Belgium, Denmark, Finland, France, Great Britain (ie UK exc NI), Germany Onshore, Germany Offshore, Germany Total, Ireland, Italy North, Italy South, Italy Total, Netherlands, Norway, Portugal Continental, Spain, Sweden, Turkey, UK BM Offshore, UK BM Onshore, UK Embedded, UK Residual Wind Farms, UK Total.

USA: CAISO, MISO, ERCOT Coastal, ERCOT North, ERCOT Panhandle, ERCOT South, ERCOT West, ERCOT Total

Australia: NEM, NSW, QLD, SA, Victoria, WA, WEM.

Speedwell Climate Solar Power Indices – Volume Risk

Speedwell Solar Power Indices for risk-transfer of volume risk are available for the following countries/regions:

Europe: Belgium, Germany, Netherlands, Spain, Great Britain

Australia: Australia Victoria

Client-Specific Indices

We are also able to provide custom reference indices to match specific clients' assets on request.

Please contact Speedwell Climate.

https://www.speedwellclimate.com/

Data Sources for Renewable Power Quanto Indices

All three types of Renewable Power Quanto Indices combine physical power price and modelled power generation. The sources are as follows:

Power Price Data

Power price data are provided by EPEX SPOT: https://www.epexspot.com/

The European Power Exchange EPEX SPOT SE and its affiliates operate physical short-term power markets in 13 countries: in Central Western Europe, the United Kingdom, Switzerland, the Nordics and in Poland. Furthermore, EPEX SPOT newly offers local flexibility markets solution and Guarantees of Origin auctions, to foster the integration of renewable energy sources and to enhance the engagement of consumers and producers in the power market.

As part of EEX Group, a group of companies serving international commodity markets, EPEX SPOT is committed to the creation of a pan-European power market. Over 300 members trade power on EPEX SPOT. 49% of its equity is held by HGRT, a holding of transmission system operators.

For more information, please visit *www.epexspot.com*.

Solar and Wind Power Volume Data

Solar and Wind Power modelled production data are products provided by Speedwell Climate:

https://www.speedwellclimate.com/

Trading the Renewable Power Quanto Indices on the OTC Market

Most energy market participants are familiar with exchange-traded instruments which are usually cleared through a central counterparty. This document has referenced the EEX power futures in this context. Currently, however, there is no exchange-based platform for price discovery or execution for the Renewable Power Quanto Indices discussed in this paper. This means that "price discovery" and execution do not happen on the exchange but are arranged by negotiation bilaterally on the over-the-counter (OTC) market.

Example: Taking a Quality Factor Hedge to the OTC Market

In this example we look at the typical workflow necessary to implement a Quality Factor hedge. We consider an asset holder with a portfolio of wind farms in the UK. The process can be deconstructed into these stages:

<u>1 Determine Reference Index to use</u>

If the wind farm assets correlate sufficiently well with a given country QF Index, then this index should be used as other market participants are likely to have some familiarity and possibly existing open positions possibly leading to more favourable pricing. The alternative is to request a client-specific index based on the specific wind assets in the portfolio (this could include partially owned assets). To make this determination the hedger would request the Speedwell Wind Power Volume Index for the chosen country to perform a correlation study. If a client-specific basket is required, please contact Speedwell Climate.

<u>2 Determine the Risk Period required</u>

Standard periods for all three index types are monthly, quarterly and winter/summer seasons. Multiple seasonal periods can be used to construct multi-year transactions as required.

<u>3 Request the hourly historical data for the required index (Eg Great Britain 2022 Quality Factor)</u>

This data set may be used for initial structuring and pricing.

<u>4 Determine the desired transaction type</u>

Informed by an analysis of the trend and volatility in the QF variable and the financial risks to be protected, a typical asset holder might be interested in selling a QF swap (to protect against a declining QF) or buying a put. In the case of the former, the swap would generally be transacted as a zero-premium swap with a strike at an assessment of "fair value" that suits both seller and buyer. In the case of the latter, the asset holder's "pain threshold" would determine the level of the strike at which the put option starts to pay out. Clearly, the purchase of a put option implicates the payment of a premium. The choice of swap vs put is a strategic decision.

<u>5 Determine the number of "QF Units", or Transaction Size.</u>

This will be all or (usually) part of the expected energy output of the windfarm over the Risk Period.

6 Determine the Payoff Function

With Quality Factor it is likely that the *ideal* hedge involves the multiplication of the settled QF value by the corresponding baseload outturn price for the transaction period as discussed in the examples above:

*Payoff Function = Expected Generation (MWh) * (QF Strike – Realised QF) * Realised Baseload Price*

It might, however, be expedient to implement an imperfect hedge by assuming a fixed power price. This may attract more competitive pricing by virtue of relative simplicity:

*Payoff Function = Expected Generation (MWh) * (QF Strike – Realised QF) * Assumed Fixed Baseload Price*

7 Set Financial Caps

In the above examples, caps have not been considered for simplicity. However, in parametric risk transfer contracts, payouts are usually capped to help limit the size of required credit risk lines. Caps are usually represented as a maximum currency value (e.g. EUR) and will normally apply symmetrically in the case of swaps. The cap should be placed at a level consistent with an estimate of the "worst case" outturn. Historical data may inform this decision.

8 Identify possible counterparties with whom to trade

We expect a number of brokers to start supporting markets in these indices for the standard periods. Please contact Speedwell Climate for any required introductions. We may also be able to directly introduce companies who we are aware have traded or are interested in trading these indices. Again, please contact Speedwell Climate for introductions. For the removal of doubt, Speedwell Climate has no direct or indirect financial interest in making such introductions.

9 Confirm Licence Fee cost for Settlement Feeds

Having identified a suitable counterparty (which clearly encompasses issues of transaction price and availability of credit lines and agreeing ISDA documents), contact Speedwell Settlement Service (SSS) to confirm the licence fee for the necessary real-time data feeds for the required index (eg Quality Factor; Great Britain 2022; Winter 23-24). The licence fee is dependent on the length of the Risk Period and transaction size.

10 Agree the Term Sheet.

The Term Sheet summarises all of the moving parts of the transaction. This includes details of settlement period. Note that the data feeds run with a delay meaning that the final settlement is usually made at period end + 5 days. The settlement details defined on the Term Sheet need to reflect the details of the feed provided by SSS. A specification of this is provided when a contract is entered into with SSS for the licence for the feeds.

11 Execute transaction and requests data feeds from SSS

12 Monitor transaction over Term and then determine final payoff at business D+5

Note that the Settlement Data feeds take two forms:

Initial Settlement Data: Initial settlement data is produced with a one-day lag. Given the delay in ERA5 publishing data Speedwell uses the ECMWF forecast data to generate an estimated ERA5 dataset. This initial ERA5 dataset is then processed through the index model to produce initial index values. While serving as a proxy for the final index values, the initial values are subject to potential changes upon the release of the actual ERA5 dataset.

Final Settlement Data

Final settlement data is produced with the publication of the ERA5 reanalysis dataset, which has a five-day lag. These final values are considered definitive and will not be modified thereafter.

Speedwell Climate LinkedIn Mini Articles

The following LinkedIn mini articles may be useful (most recent articles are at the top):

Speedwell 2022b vs Germany ENTSOE onshore metered data

An analysis of performance of the Speedwell index which is based on modelled generation data using the asset base frozen as of 2022 versus actual production data

https://www.linkedin.com/posts/michaelmoreno_speedwell-wind-power-index-for-germany-activity-7076461696914989056-FY7t

Solar Power Generation Modelling – the US NY ISO Case

https://www.linkedin.com/posts/michaelmoreno_solar-solarenergy-solarpower-activity-7069240269262450688-BxpL

Solar Power Generation in Germany – Average Daily Quality Factor

https://www.linkedin.com/posts/michaelmoreno_solar-powergeneration-capturerate-activity-7051815464364044288-eQ_g

Germany Solar Power Generation Hedging Power Price Cannibalisation

https://www.linkedin.com/posts/michaelmoreno_solar-solarpower-renewables-activity-7051457396962947072-CL3g

Are Hybrid Wind and Solar Farms the Future?

https://www.linkedin.com/posts/michaelmoreno_renewableenergy-powertrading-wind-activity-7049293841505366016-woAW

Buy a PPA and get a Cannibalisation Index for Free!

https://www.linkedin.com/posts/michaelmoreno_ppa-renewableenergy-weatherderivative-activity-7046732307444961281-s0X7

Wind of Change

https://www.linkedin.com/posts/michaelmoreno_climaterisk-weatherderivative-energytransition-activity-7043847042766417920-d5Ke

Renewable Power Indices offer Dynamic Hedging vs Static Hedging

https://www.linkedin.com/posts/michaelmoreno_ppa-renewableenergy-qualityfactor-activity-7042049294207451137-zrwA

How can Renewable Energy Companies Lock in their Achieved Price

https://www.linkedin.com/posts/michaelmoreno_renewableenergy-climaterisk-achievedprice-activity-7041680211301531648-xQJ4

Solar Power Generation Cannibalisation - The case of the Netherlands

https://www.linkedin.com/posts/michaelmoreno_solar-powergeneration-renewableenergy-activity-7040940530385481728-w_42

Creating Indices for Managing Wind Power Generation Risks

https://www.linkedin.com/posts/michaelmoreno_powergeneration-activity-7036623788423151616-_Tee

Renewable Power Generation – Shape Risk

https://www.linkedin.com/posts/michaelmoreno_in-this-mini-article-i-will-present-a-key-activity-7034849479857987584-95Bt

Measuring and Trading Wind Power Generation Cannibalisation

https://www.linkedin.com/posts/michaelmoreno_wind-power-cannibalisation-is-probably-one-activity-7034454503747657728-oh8C

Wind Power Generation Indices that can be Traded

https://www.linkedin.com/posts/michaelmoreno_in-this-mini-article-i-will-discuss-wind-activity-7034117713694191616-8hyK

Wind Power Generation Correlation in Europe

https://www.linkedin.com/posts/michaelmoreno_wind-power-generation-has-a-concentration-activity-7033400514474082304-VaOb

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About Speedwell Climate

Founded in 1999 Speedwell Climate Ltd and its group companies provide the data and software necessary to structure, price, transact and clear index-based environmental risk-transfer contracts including those based on renewable energy, temperature, rainfall and other environmental variables.

Our key products and services include:

- Environmental Data Services: historical data products for pricing risk-transfer contracts
- Modelled Wind and Solar Production Indices: indices for hedging wind and solar energy production
- Speedwell Environmental System: an enterprise software system for structuring, pricing, back-office processing, and portfolio management of environmental risk-transfer contracts
- Settlement Services: providing the data required to settle environmental risk-transfer contracts
- The weatherXchange® Platform - a web delivered structuring platform that helps companies access index-based climate risk protection.

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