LCPDelta

The true cost of risk

Solar PPA hedging

Independent analysis proposed by EDF

FEBRUARY 2025

A Power Insights report

Summary and key points

Recent solar PPA offtaker outcomes have benefitted from fortunate conditions and should not be expected in future

Solar Power Purchase Agreements (Solar PPAs), along with the government backed Contract for Differences, will be a crucial component of expanding intermittent renewable generation capacity to meet the ambitious targets of Clean Power 2030. Prices of these types of PPAs must be robust to maintain the confidence of both sellers (generators) and buyers (offtakers). Many solar projects have their PPAs up for renewal in spring 2025, so how these negotiations work out will lay the foundations for driving growth in the UK's solar industry.

In this report, we investigated the costs and revenues of a typical offtaker as they hedged their solar PPA price over the past 12 seasons to find that the past three years have seen an unexpected series of alignment between seasonal conditions and market prices. This has resulted in an upside to the offtakers. However, our analysis also shows that they could have equally made significant losses. Therefore, generators and offtakers must not assume that this alignment will continue – in fact, it is already looking to stop this winter.

Our analysis shows that solar PPA prices should incorporate the true cost of offtakers taking on the hedging risk – if prices creep too high, offtakers are more likely to lose money. The consequences of this can lead to decreased liquidity in the solar PPA market. To better understand the risks they are exposed to, offtakers should analyse their revenues as seasonal and short-term components.

If we don't get this round of negotiations right, there is a real danger that the solar PPA market will be in jeopardy – which would endanger the Clean Power 2030 plans and hit the interests of customers around GB.

***LCP Delta recommends** that both offtakers and generators set realistic expectations for the upcoming negotiations – they need to go back to first principles on the likely upsides and downsides, as well as the long-run marginal cost of solar generation, rather than rely on recent history as precedent when negotiating the strike price. This could lead to lower solar PPA prices than many may be expecting but it is essential to maintain the long-term health and growth of the sector.*

In a rush… this is what you need to know:

- Recent low solar PPA costs have not been representative of risks that offtakers should be considering when pricing future PPAs. This is due to a fortunate combination of weather and market price conditions, which we have referred to as 'long-run shaping revenues'.
- Seasonal generation volumes and price movements have been unexpectedly aligned, meaning offtakers have had extra volume to sell at high prices and have been buying back hedges during low prices. This is shown in our analysis of historical PPA revenues from 2019 to 2024.
- Price movements in the past few years were driven by the energy crisis, independently of solar generation. We also show that there is no reason to expect this trend to continue in future, as there is no strong correlation between seasonal prices and generation levels – the alignment has occurred due to chance.
- We demonstrate that this trend could negatively impact the hedging value for solar PPA offtakers if generation volumes or price movements had been different – it is important for offtakers to consider this for future seasons.
- Separately, we note that short-run shaping costs, defined by the within-day shape of generation volumes and prices, often referred to as "solar cannibalisation", have become more volatile over recent years. This may persist as more solar generation is added to the system and require higher hedging premia from offtakers – which we feel warrants further exploration in future reports.

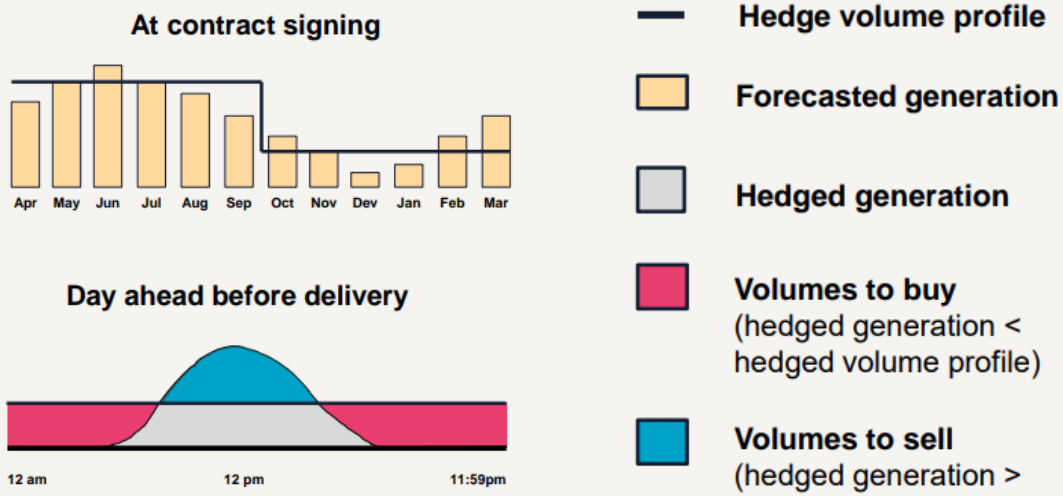
Introduction to Power Purchase Agreements

PPAs are the workhorse of the intermittent renewable sector

Pay-as-produced PPA

Power Purchase Agreements (PPAs) have become a key instrument for hedging power prices, financing bankable renewable projects, and for large consumers (such as Amazon, Google, Meta, etc.) enabling them to ensure their power consumption comes from low carbon sources. PPAs allow utility companies to manage their delivery risk across multiple time frames.

In its base form, a Solar PPA is a bilateral contract where a buyer, also known as an offtaker, contracts to buy power from a seller at an agreed strike price. Pay-as-produced PPAs transfer the balancing risk (difference between forecasted and delivery volumes) to the offtaker as the seller is only paid for the volumes they produce.



Pricing a solar fixed-price, pay-as-produced PPA

A fixed-price, pay-as-produced PPA is where the buyer agrees to purchase volumes generated by the seller at a fixed price into the future. The buyer takes on the risk of over- and under-delivery but hedges their exposure to price volatility. We focus on fixed-price, pay-as-produced PPAs transacted with solar generators.

Solar PPAs are typically signed at the season ahead stage or earlier, but at this time the main source of market liquidity to hedge the expected generation volumes comes from seasonal baseload products. This means the PPA strike price has to be informed by seasonal expectations about overall supply and demand, as well as the seasonal average expectation for solar generation. Contracts are therefore set with offtakers also having determined their initial hedge volume.

Offtakers go on to reposition their hedges as market liquidity increases closer to delivery but in the case of solar generation, this is still principally informed by overall power prices rather than anything specific to solar generation. This changes at the day-ahead stage where it becomes clearer how much actual generation is expected to be delivered.

The actual generation will vary from the initial hedge volume, leading to an excess or shortfall in generation at different periods. The excess or shortfall is then bought or sold in the spot market as required to shape the hedge.

The strike price is calculated based on the capture price and the hedging premium:

- Price estimates and forecasted generation profiles are used to calculate expected revenue and the capture price.
- The hedging premium arises from the costs and revenues associated with shaping the fixed hedge volume to the actual output on the month-ahead and day-ahead scale (or at other timescales).

The source of PPA profitability

An offtaker can make or lose money in multiple ways

Revenue

For an offtaker, the revenue or cost of a PPA will arise from buying or selling power to shape the fixed hedge volume to the actual generation. This can be split into long-run and short-run shaping components based on the different drivers of shaping.

- The long-run component is determined by seasonal changes in generation and price, for example if a sunnier than expected season leads to excess generation.
- The short-run component is from short-term weather patterns, for example due to shaping the hedge to match the actual daily generation.

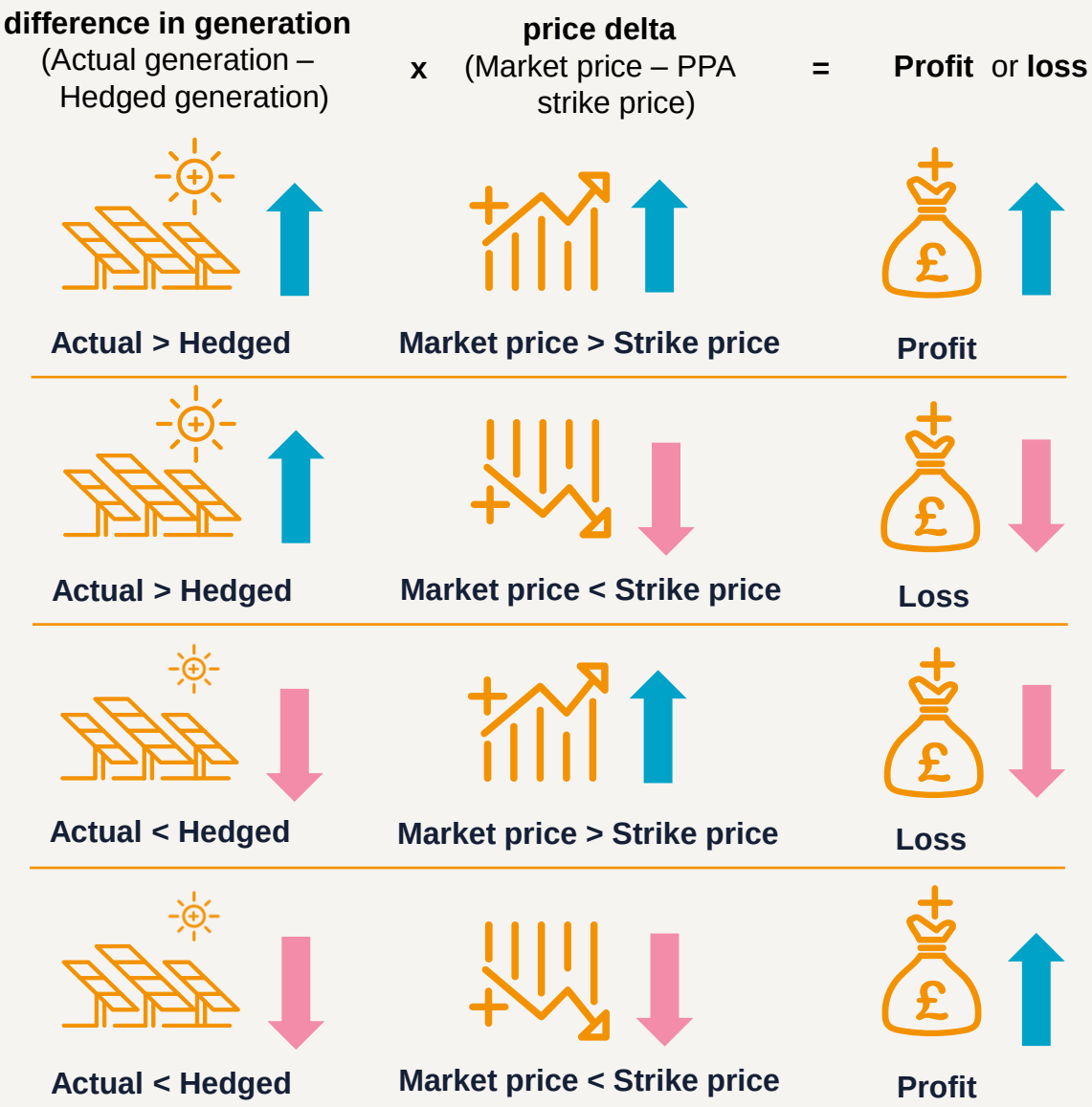
Profitability

A PPA offtaker can generate an overall profit if:

- they can sell any excess generation (actual generation exceeding hedged volume) at a market price higher than the PPA strike price;
- they can purchase a shortfall in generation (actual generation less than hedged volume) at a market price lower than the PPA strike price.

The long-run shaping profit will arise from seasonal over- and under-generation compared to historic averages, and seasonal price spreads: the difference between the PPA strike price and the average seasonal day-ahead price.

Short-run shaping activity can also lead to profit or loss to an offtaker, depending on how the price was set and whether the actual generation on a specific day is higher or lower than the hedged generation.



Introduction to modelling

Our analysis looks at a typical Solar PPA offtaker

Methodology

Our analysis covers the period from Summer 2019 to the first three months of Winter 2024.

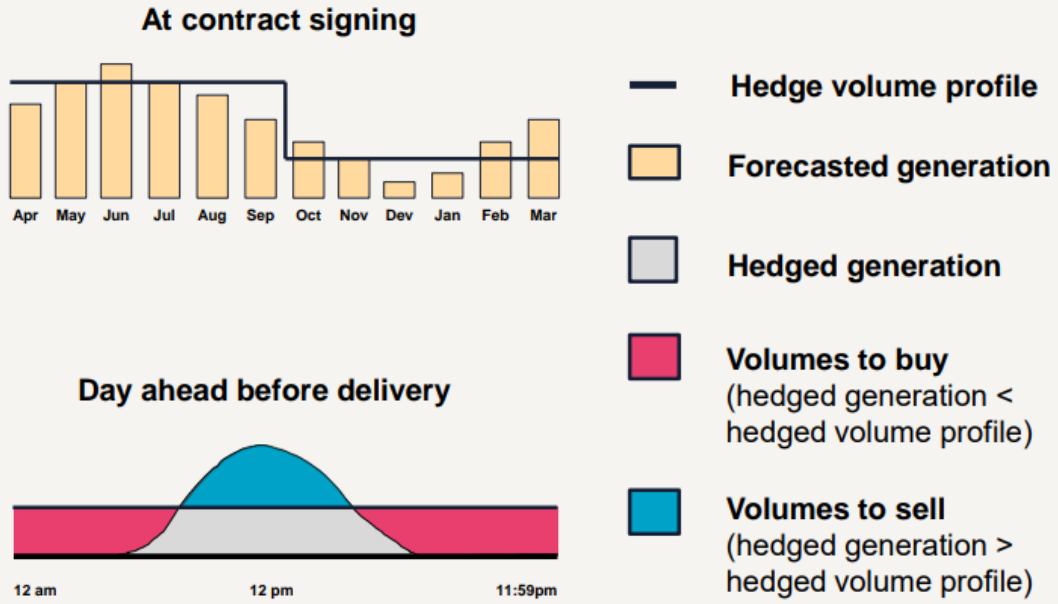
- The **initial hedge volume** has been calculated as the average load factor from Summer 2019 to Winter 2024.
- The **Solar PPA strike price** has been set as the Baseload Market Reference Price (BMRP), as published by the LCCC. This represents the expected power price for the season ahead, when market liquidity starts to increase and broadly reflects the lead time for PPA contract purchases. As PPAs are often signed for a full year, a two-season ahead forward price can be more accurate, but we wanted to ensure transparency and reproducibility by using the LCCC's data.

In our modelling, the hedge is only shaped the day before delivery in the day-ahead market. In reality, Solar PPA offtakers may shape their hedge more frequently based on forward markets such as the monthly forward market. However, these markets are typically influenced by broader factors, such as overall supply and demand, and gas prices, rather than the actual seasonal solar generation. Therefore, more frequent hedges will have minimal impact on the long-run shaping revenues.

We have calculated the shaping costs and revenue for each settlement period as:

- **Long-run shaping revenue** as the product of the difference in generation (Outturn seasonal average volume – Initial hedged volume) and the price delta (N2EX hourly day-ahead price – PPA strike price).
- **Short-run shaping revenue** as the product of the difference in generation (Actual generation – Outturn seasonal average volume) and the N2EX hourly day-ahead price.

This is then added up for all settlement periods and normalised by actual generation across the season to calculate the profit per MWh.



EDF approached LCP Delta with a proposal for a research project to better understand hedging risks and whether the recent unusual series of shaping revenues may be expected to continue. EDF provided insights into hedging practices and made suggestions for data sources, which were then independently verified and analysed by LCP Delta.

Seasonal generation and price

How did forecasted price and generation compare to actual price and generation?

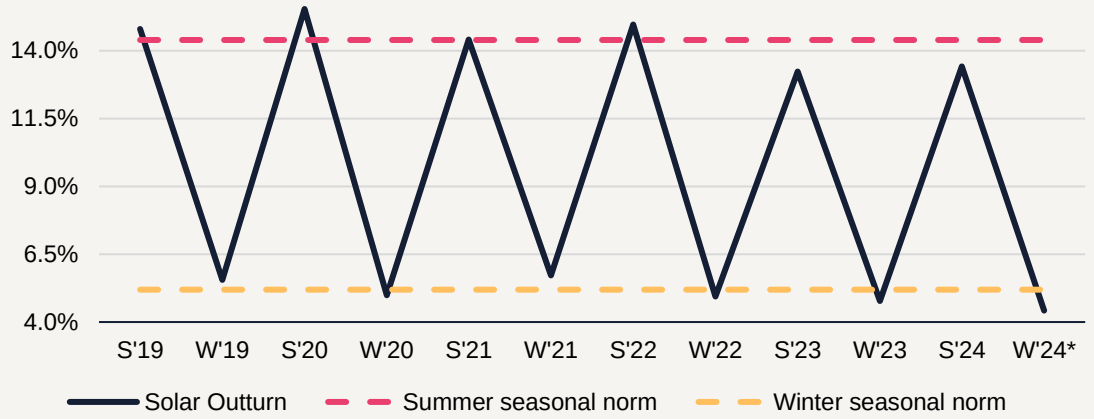
Seasonal generation

- Solar PPA offtakers may initially set their hedge volumes based on average seasonal generation forecasts. There are usually different forecasts for summer and winter.
- In our model, the initial hedge volume is determined using the seasonal average load factor (the average solar load factor from 2019 to 2024). The seasonal norms are represented by the dashed lines in the chart on the right.
- The actual seasonal load factors are shown by the solid black line, with some seasons having excess solar generation (S'20, W'21) and others having a shortfall in solar generation (S'23, W'23).

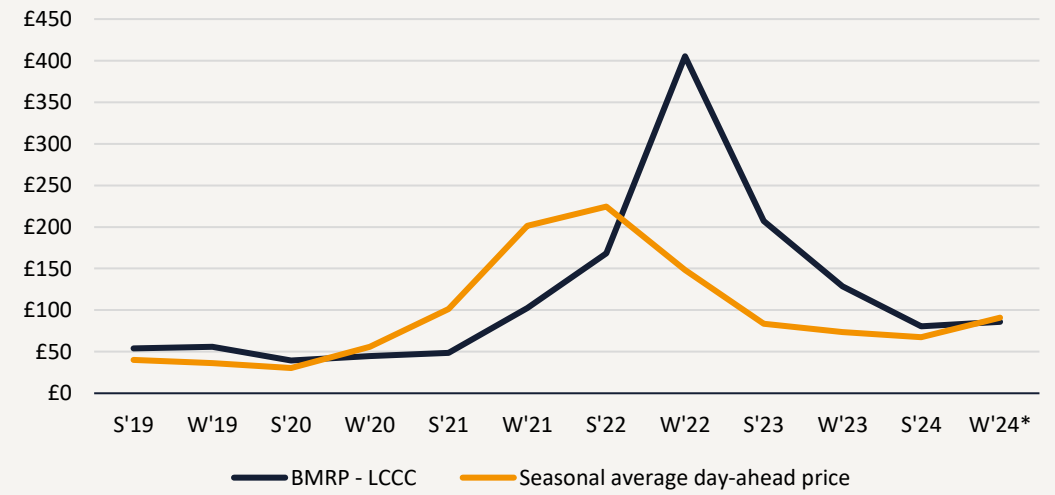
Seasonal price

- The Solar PPA price (£/MWh) has been set equal to the BMRP - LCCC which represents the expected power price for the season ahead in this study. This is represented by the black line.
- The average N2EX day-ahead price across the season is shown by the orange line.
- The difference between the two lines represents the seasonal price delta, creating an opportunity for profit or loss.

Solar load factors



Solar long-run price, £/MWh



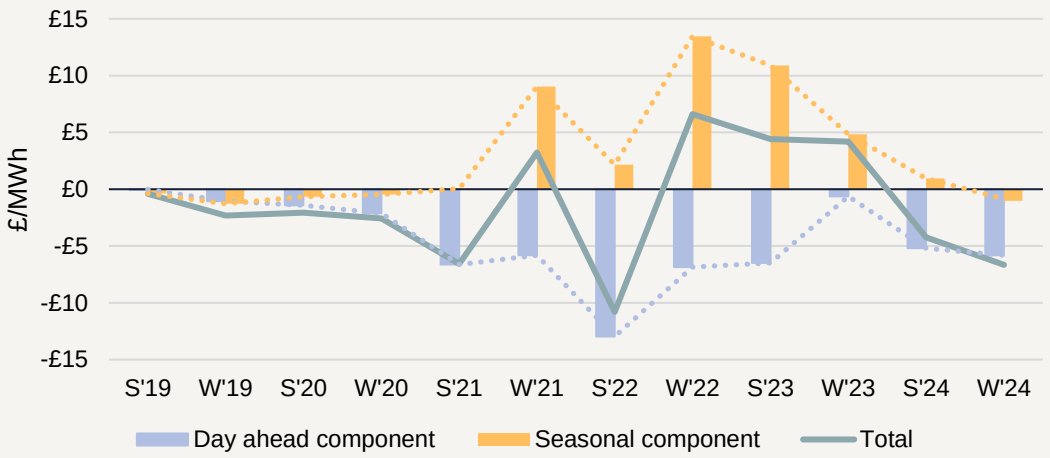
Short-run shaping revenue

Short-run shaping revenue has consistently been negative over the last 6 years

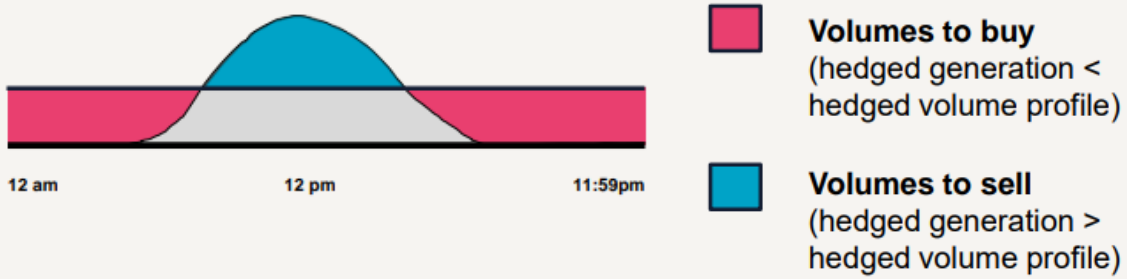
- The chart on the right illustrates the long-run (seasonal) and short-run (day-ahead) shaping profit and loss from Summer 2019 to the first three months of Winter 2024.
- The short-run shaping cost reflects the cost of shaping the hedge to the actual generation in the day-ahead market to ensure that the generator is balanced. This involves buying any shortfall in generation and selling any excess generation at the day-ahead price.
- This is calculated as the:
  - The product of the **difference in generation** (Actual outturn generation – Seasonal average outturn volume) with the **day-ahead price** in a settlement period.
  - This has been added up for all settlement periods and normalised by actual generation across the season to calculate the profit per MWh.
- For all seasons between Winter 2019 to Summer 2024, short-run shaping has been a cost to offtakers, and with a larger magnitude between 2021 and 2024 than seen prior to 2021, primarily driven by the energy crisis.
- Since Winter 2020, there have been significant variation in the magnitude of the short-run shaping costs, suggesting higher uncertainty and potentially increasing hedging premiums in the future.

The short-run costs have become more volatile over recent years and this effect may persist in future years as more solar generation is added to the system. Higher generation at the day-ahead scale can depress prices directly, so Solar PPA offtakers may be exposed to higher uncertainty in shaping their hedge at the day-ahead price, which could lead to higher hedging premiums. LCP Delta plans to explore this effect further in future reports.

Solar long-run and short-run shaping profits per MWh



Solar short-run shaping



Long-run shaping revenue

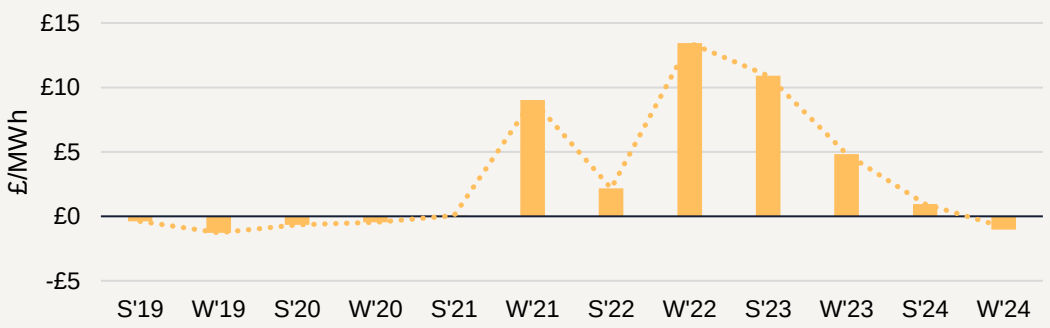
Long-run shaping profits have remained positive for the last three years.

- The long-run shaping profit reflects the profit due to a difference in generation and the price delta across the whole season. It is calculated as the product of the **difference in generation** (seasonal average generation – Hedged volume) and the **price delta** (day-ahead price – PPA strike price).
- From Summer 2021 to Summer 2024, the long run shaping profit has been consistently positive.
  - Whilst the difference in generation varied across the seasons, the difference in generation and the price delta were aligned in the directions that generate a profit.
  - For example, Winter 2019 and Winter 2021 both had similar excess generation. However, due to the price delta, Winter 2021 was profitable and Winter 2019 led to a loss.
- The scatter plot on the right highlights this, with a plot of load factor delta (representing difference in generation) and the price delta.
  - Summer 2021, Winter 2021 and Summer 2022 were **profitable due to excess generation and a positive price delta.**
  - Winter 2022, Summer 2023, Winter 2023 and Summer 2024 were **profitable due to a shortfall in generation and a negative price delta.**

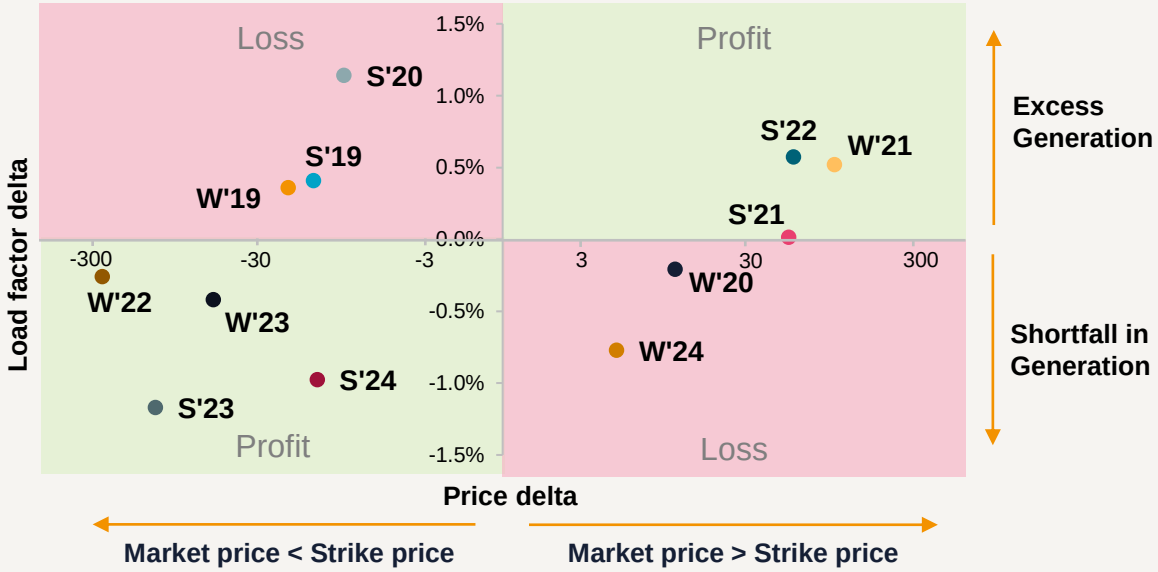
If Solar PPA offtakers can continue to expect this alignment, they can continue to expect consistent profits in future seasons, as well.

So is there a reason to expect the difference in generation and the price delta to correlate?

Solar long-run shaping profits per MWh



Solar seasonal load factor delta and price delta



Historic trends in price and generation deltas

Power price movements in recent years can clearly be attributed to the energy crisis

Trends in price

In 2019 and 2020, the BMRP and the average seasonal day-ahead price were closely aligned, leading to a small price delta – as expected in an efficient market with no shocks.

Between 2021 and 2023, the price delta increased, reaching its maximum magnitude in Winter 2022. The price movements can be explained by the evolution of gas prices during the energy crisis, which has a fundamental impact on power prices in GB:

Summer 2021 – Russia began withholding gas to force Nordstream 2's approval. The Summer 2021 forward prices were still formed under regular market conditions in Winter 2020, but the day-ahead prices rose due to the difficulty in refilling storage, leading to a large price delta.

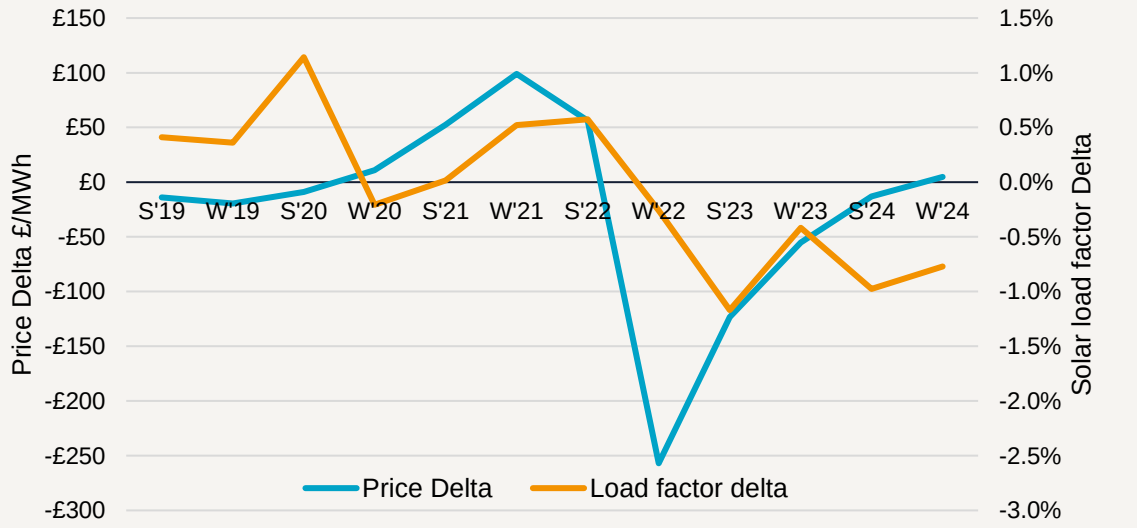
Winter 2021 - Summer 2022 – Forward prices were high due to tight gas markets but still expecting that normal gas flows would resume. However, as the invasion of Ukraine made it clear that this would not occur, day-ahead prices stayed well above forward prices, peaking in Summer 2022 when Europe had to refill gas storage from more expensive sources.

Winter 2022 – A risk of severe energy shortage in Winter 2022, energy price caps, and gas storage mandates were introduced leading Winter 2022 forward prices surging at record levels by summer 2022. With warmer temperatures in the winter itself, the day-ahead prices were much lower than expected, creating a £250/MWh price delta.

Summer 2023 – Gas storage mandates and concerns about energy shortage remained, keeping the gas forward prices high despite the actual low day-ahead prices.

Winter 2023 – As Europe's gas storage remained high, markets started to normalise, with the delta between the forward and the day-ahead power narrowing to the same level as where they were before Summer 2021.

Average seasonal price delta (BMRP – Average seasonal day ahead price) and Average seasonal load factor delta (seasonal norm – seasonal average)



Trends in generation

- The solar load factor delta has fluctuated between slightly above 1% and just below -1%, with the values suddenly jumping from season to season.

Over the past three years, the price delta has been defined by the energy crisis, with no room for a link with generation differences.

But can there be a link in the future, especially as more and more solar generation comes onto the system?

Solar generation and price spread correlation

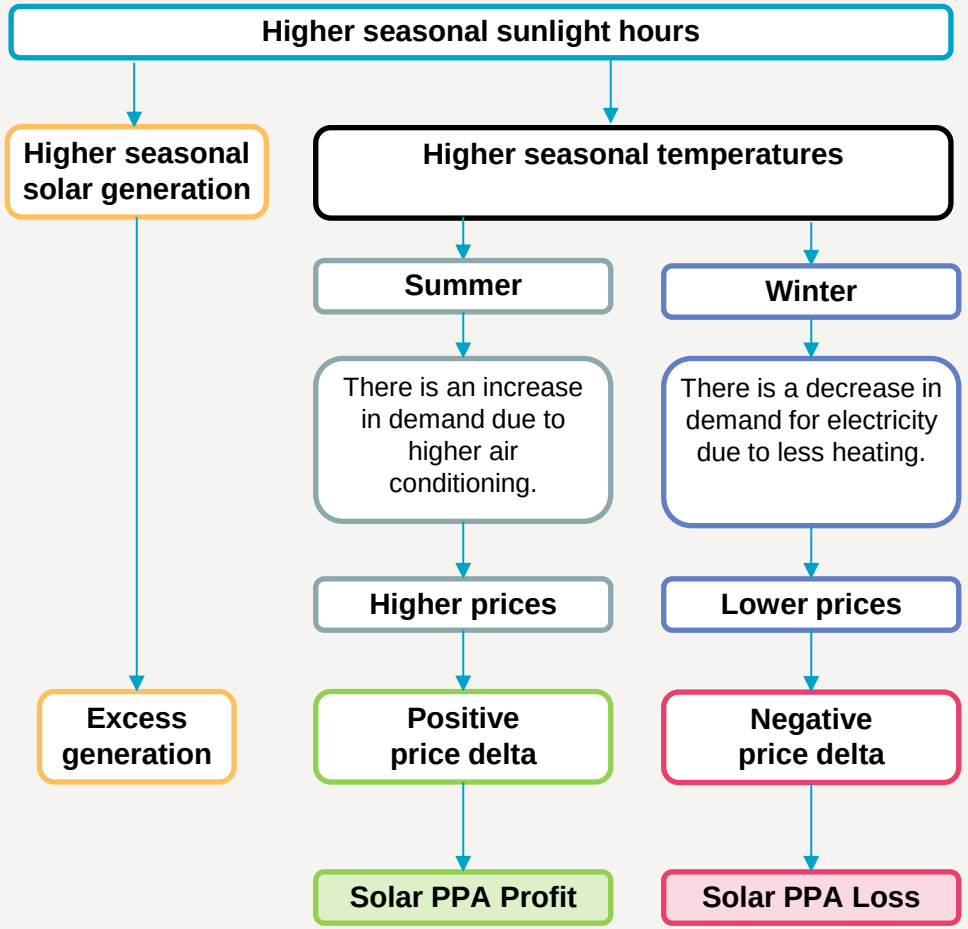
A correlation between the generation difference and the price variation is required for consistent profits from long-run shaping revenue.

The solar generation difference and price deltas should not have a direct greater but they might both be correlated with a third variable.

For example, a high amount of sunlight hours can impact both solar generation and the average seasonal price.

1. Greater solar generation can reduce market prices, creating an anti-correlation. This is likely to have a greater impact on short-run shaping revenue than long-run, as the seasonal average proportion of solar generation remains low.
2. In summer, higher temperatures may lead to higher demand for electricity due to air conditioning. This will drive up prices.
   - Due to the lack of air conditioning units in the UK, it is unlikely this would be a strong correlation.
3. In winter, higher temperatures may lead to less heating demand and drive down prices. This would lead to an anti-correlation which would lead to a loss for solar PPA offtakers.
   - An additional 100 hours of sunshine per season can increase the solar load factor by 1% and the seasonal temperature by 0.8°C.
   - A decrease of 1°C when the temperature is below 10°C leads to an increase in the power price of £1.10/MWh.
   - This means that a 1% increase in load factor correlates with a £0.88/MWh decrease in price, which is significantly lower than the price deltas we have seen, even prior to 2021.

It is unlikely these factors would cause a material correlation between solar generation and price spreads.



Solar generation and price spread correlation

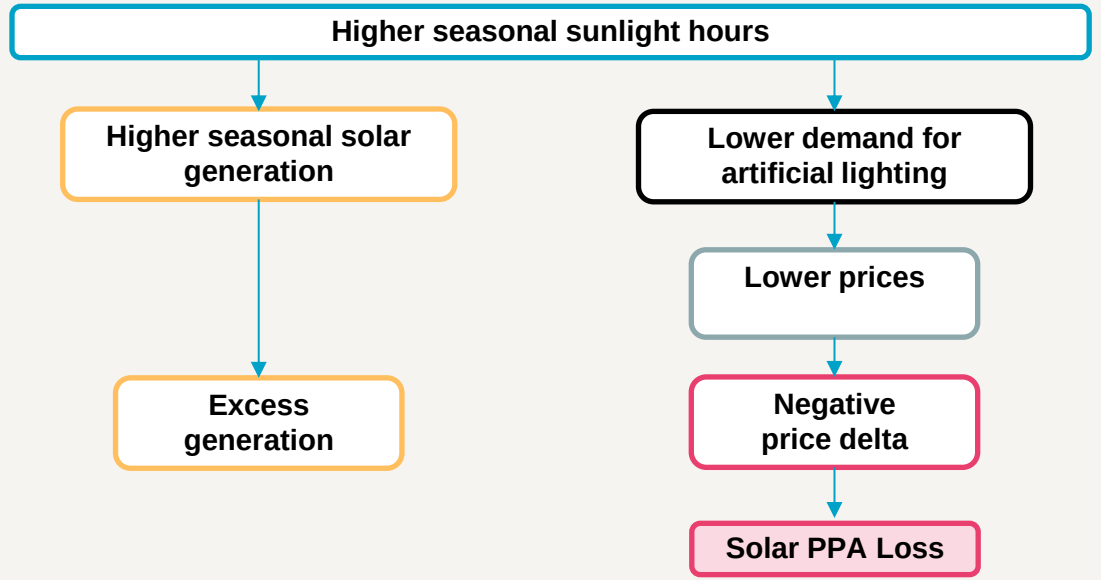
A correlation between the generation difference and the price variation is required for consistent profits from long-run shaping revenue.

Many other correlations are possible:

4. In the summer months, higher temperature from excess sunlight will reduce the efficiency of transformers across the GB grid. It is estimated an increase of 1°C leads to a drop in efficiency of 1%.
   - Lower efficiencies will require higher generation to meet the same consumer demand, pushing up prices.
   - However, the same efficiency issue will impact transformers which connect solar panels to the grid, decreasing generation.
   - Therefore, it is unlikely there will be a strong correlation between solar generation and price.
5. Higher sunlight hours may lead to lower demand due to:
   - lower usage of artificial lighting and lower usage of all power due to more people spending time outdoors.
   - This will drive down prices and lead to a negative correlation with solar generation – and a loss to solar PPA offtakers. However, the high efficiency of artificial lighting means that the impact of this effect will be small.
6. Higher solar generation will also increase behind-the-meter solar generation for consumers who have solar panels directly on their property.
   - This will reduce their demand electricity from the grid.
   - This will drive down prices and lead to a negative correlation with solar generation, and a loss to solar PPA offtakers.

It is unlikely that a material correlation exists between solar generation and price spreads, especially a positive one that would result in a consistent profit for Solar PPA offtakers.

If the two can change independently of each other, what is the expected long-term shaping revenue?



Possibilities of solar PPA profitability

The long-run hedging profits could have been very different

Having demonstrated that there is no substantial correlation between differences in seasonal generation and the price delta, we can investigate how the past few years could have looked with a different combination of load factors and price deltas.

- The chart on the right shows the long-run shaping costs for all possible combinations of differences in seasonal generation and seasonal price deltas from Summer 2019 to Winter 2024.
  - The actual long-run shaping profit for each season is highlighted and shown on the diagonal of the chart.
  - Of the 144 possible options, 72 led to a profit and 72 led a loss.
  - A change in the load factor delta or price delta for a particular season could have changed the long-run profits seen in the season. For example, offtakers observed a £9.02/MWh profit in winter 2021 but the same price deltas would have led to a £5.15/MWh loss with the solar load factors of winter 2022, as highlighted.
- The large negative price delta seen in Winter 2022 could have led to a maximum possible loss of -£46.07/MWh, or a maximum possible profit of £74.21/MWh – by far the largest values for a single season.
- This magnitude of the profits and losses is magnified by the large price deltas caused by the volatility in prices over Winter 2021 to Summer 2023. This could have led to large losses or even higher profits.

The profitability of solar PPAs could have varied drastically if seasonal generation and seasonal price deltas had not been so fortunately aligned.

Long-run shaping profits from all possible combinations of difference in generation and price deltas

Price delta season \ Load factor delta season	S'19	W'19	S'20	W'20	S'21	W'21	S'22	W'22	S'23	W'23	S'24	W'24
S'19	**-£0.38**	-£0.34	-£1.01	£0.20	-£0.02	-£0.48	-£0.53	£0.25	£1.22	£0.41	£1.00	£0.78
W'19	-£1.43	**-£1.27**	-£3.53	£0.81	-£0.06	-£1.78	-£1.95	£1.02	£5.68	£1.71	£4.51	£3.41
S'20	-£0.25	-£0.22	**-£0.66**	£0.13	-£0.01	-£0.32	-£0.35	£0.17	£0.80	£0.27	£0.66	£0.51
W'20	£0.79	£0.70	£1.95	**-£0.45**	£0.03	£0.99	£1.08	-£0.57	-£3.14	-£0.94	-£2.49	-£1.88
S'21	£1.45	£1.29	£3.87	-£0.77	**£0.06**	£1.84	£2.02	-£0.96	-£4.65	-£1.57	-£3.82	-£2.98
W'21	£7.19	£6.41	£17.74	-£4.09	£0.31	**£9.02**	£9.81	-£5.15	-£28.58	-£8.60	-£22.73	-£17.16
S'22	£1.55	£1.38	£4.13	-£0.82	£0.06	£1.96	**£2.16**	-£1.03	-£4.97	-£1.68	-£4.08	-£3.18
W'22	-£18.67	-£16.64	-£46.07	£10.61	-£0.81	-£23.30	-£25.47	**£13.38**	£74.21	£22.34	£59.00	£44.56
S'23	-£3.41	-£3.02	-£9.07	£1.80	-£0.14	-£4.31	-£4.74	£2.25	**£10.90**	£3.68	£8.96	£6.98
W'23	-£4.04	-£3.60	-£9.96	£2.29	-£0.18	-£5.04	-£5.51	£2.89	£16.05	**£4.83**	£12.76	£9.64
S'24	-£0.36	-£0.32	-£0.96	£0.19	-£0.02	-£0.46	-£0.50	£0.24	£1.16	£0.39	**£0.95**	£0.74
W'24	£0.18	£0.16	£0.44	-£0.10	£0.01	£0.22	£0.24	-£0.13	-£0.71	-£0.21	-£0.56	**-£0.85**

Variable shaping profits

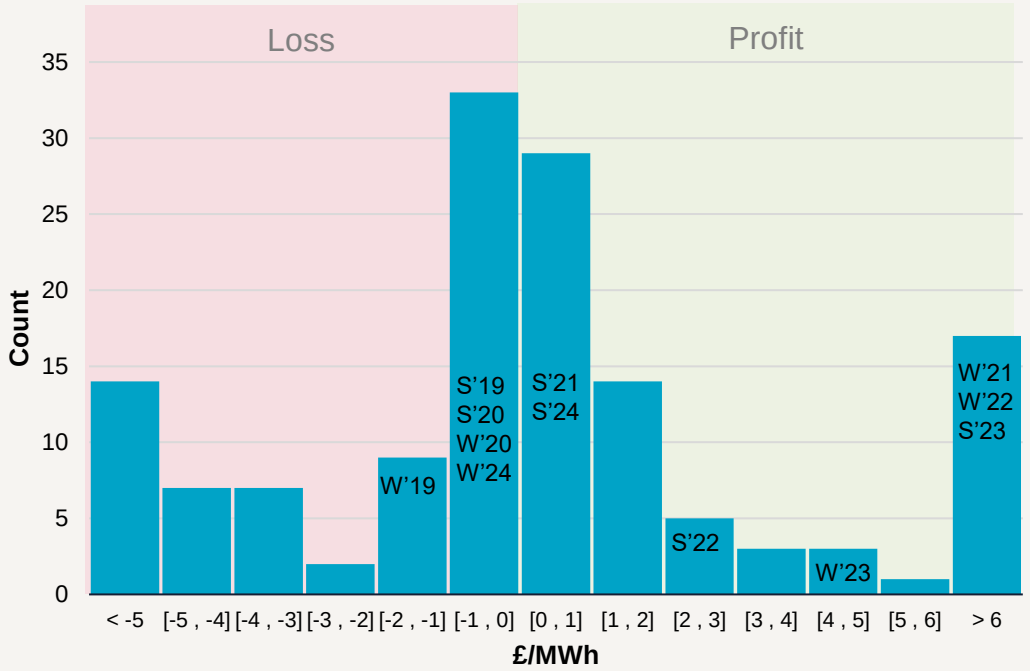
The outturn long-run shaping profits are on the tail end of possibilities

We have plotted the histogram of the possible long-run profits calculated on the previous slide and marked where the outturns fall.

- The histogram follows a roughly normal distribution – other than the extreme tail values that are caused by the extreme price deltas between 2021 and 2023.
- A normal distribution would be expected if the price delta and difference in generation were themselves independent normal distributions.
- Assuming both the price delta and difference in generation are independent normal distributions, in any given season, the probability of making a profit will be 50% based on our analysis.
  - Over the last 12 seasons, there have been more profitable seasons than expected in reality.
  - The probability of getting 7 seasons of profits in a row, as we have seen between Summer 2021 to Summer 2024, is 0.8%.
- Winter 2021, Winter 2022 and Summer 2023 generated large profits, but we did not experience any of the potential large losses in any season.

Assuming a normal distribution, the expected long-run shaping profit is £0/MWh. Therefore, it cannot be relied upon to produce a consistent profit like the one we have seen over the last seven seasons.

Histogram of the possible long-run shaping profits



A histogram of 144 possible long-run profits calculated on the previous slide.

The text within the bar represents where the actual long-run shaping profit sits.

Unlikely run of high prices

The average long-run shaping profit has been much higher than expected

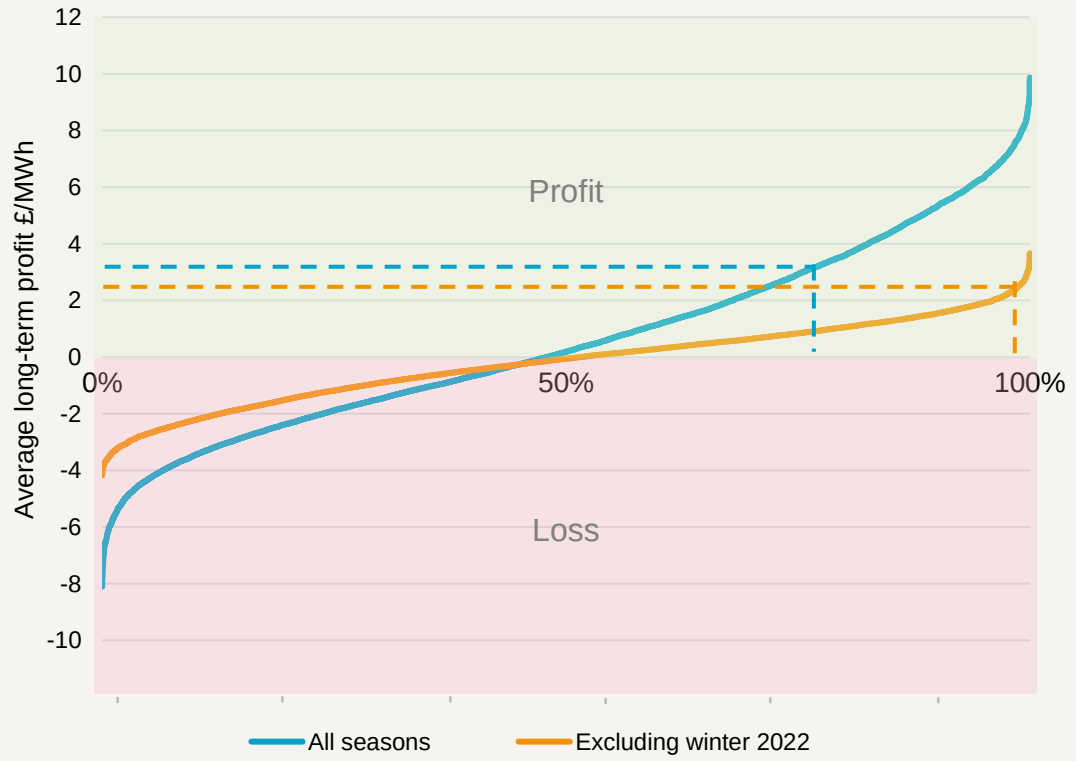
In addition to higher frequency of seasonal profits, the magnitude we have seen has also been higher than expected: the average seasonal profit per MWh from 2019 to 2024 was £3.15/MWh.

- We have run 10,000 simulations to analyse the probability of making an average profit of £3.15/MWh or higher. In each simulation, we have kept the seasonal price deltas constant and varied the difference in generation randomly from the 12 possible options seen from Summer 2019 to Winter 2024. For each simulation, we have calculated the average profit per MWh across the 12 seasons.
- The chart on the right shows the probability of the average profit being a given value or less. For example, the results of the simulation shows that there is a 50% probability of making a profit – in other words, there is a 50% probability that the average long-run shaping losses are £0/MWh.
- This results in a probability of 23.4% that the average seasonal profit will be £3.15/MWh or higher – but there was an equal probability of an average seasonal profit of -£2.04/MWh or less.
- If we remove the extremely high profits seen in Winter 2022, the average long-run shaping profit is £2.21/MWh – and there is only a 2.5% chance that the profits would be as high or higher as this.

Over the past six years, solar PPA profitability has been much higher than expected due to fortunate circumstances, so the true offtaker risk has not materialised.

This means that future solar PPA negotiations must consider the potential downsides of long-run shaping profits, and not set strike prices too high.

Cumulative distribution function of average long-run shaping profit



Appendix –Data & Assumptions

Data and Assumptions

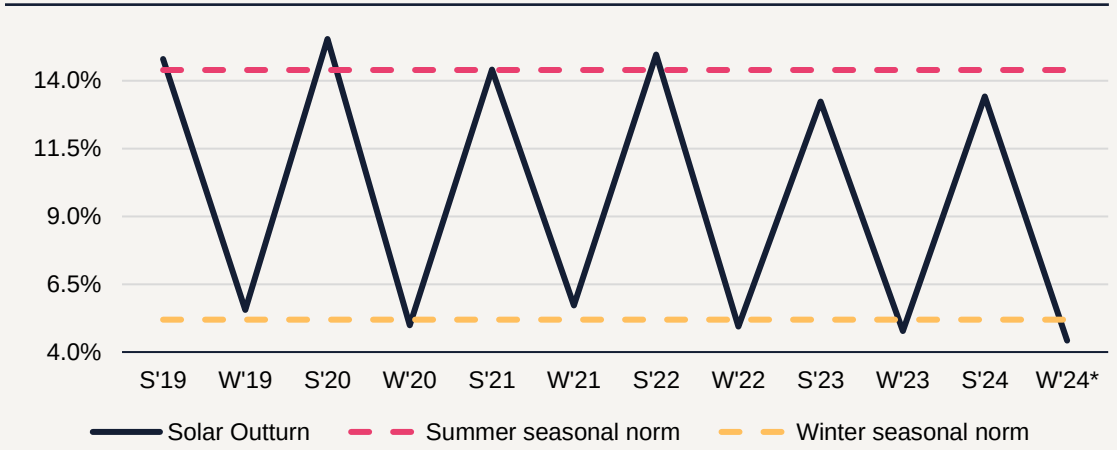
Data

- The BMRP - LCCC is used to set the solar PPA strike price for each season. This represents the expected power price for the season ahead, when market liquidity starts to increase and broadly reflects the lead time for Solar PPA contract purchases. As solar PPAs are often signed for a full year, a two-season ahead forward price can be more accurate, but we wanted to ensure transparency and reproducibility by using the LCCC's data.
- N2EX values are used for historical day-ahead prices for each settlement period.
- Historical solar generation and the available solar capacity for each settlement period is from National Energy System Operator's publication.

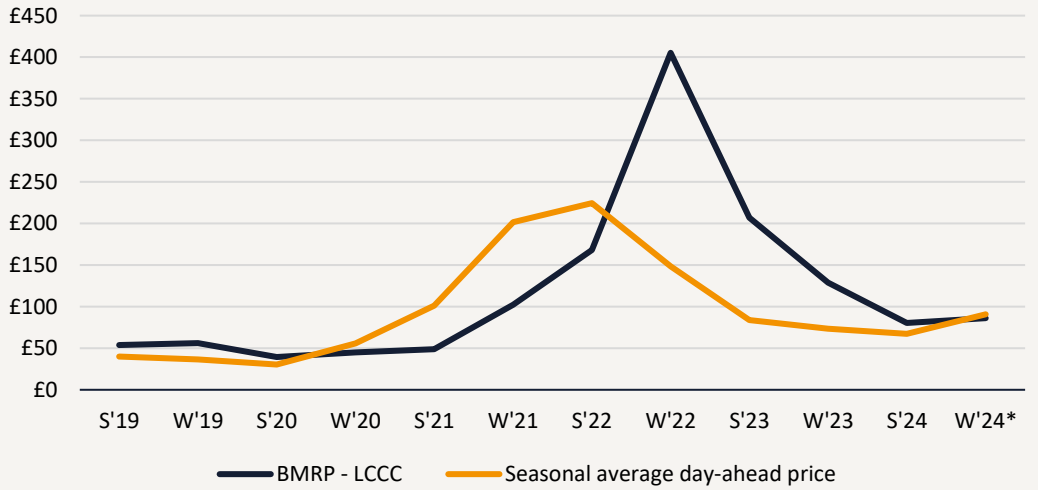
Key assumptions

- It is assumed any seasonal excess or shortfall in generation is evenly spread out across each season.
- The initial hedge is set as average load factor of all seasons in the analysis, excluding Winter 2024.
- The values for the first three months Winter 2024 have been projected forward based on the data for previous winter seasons.

Solar load factors



Solar long-run price, £/MWh



Contact us

Faisal Wahid
Senior Consultant
+44 (0)20 7550 4655
faisal.wahid@lcp.com

Bertalan Gyenes
Consultant
+44 (0)20 7432 0613
bertalan.gyenes@lcp.com

Iris Shrestha
Associate Consultant
+44 (0)19 6287 2728
iris.shrestha@lcp.com

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