Battery Viability Assessment

Report prepared for GMCR

V8 – 24 Jan 2025

Contents

Summary (1 of 2)

- We were commissioned by GMCR to (a) assess the viability of retrofitting battery storage to five existing GMCR sites, (b) provide a methodology for incorporating battery storage into GMCR's site viability assessment, and (c) assess the environmental impact of battery storage for these sites.
- We have modelled the returns from installing batteries alongside the existing PV arrays on the five sites. The batteries have potential to reduce the sites' energy costs by increasing the amount of the energy generated by the arrays that they self-consume and by shifting some of their demand to off-peak times. There is also potential to earn additional returns by using the batteries to participate in energy flexibility markets. (Noting that doing this will require GMCR to partner with a suitable aggregator.)
- Our modelling suggest that the optimum battery size for each site is as set out in the table below. The potential returns from these batteries (see next slide) are insufficient to cover their costs, so it is unlikely that installing them would be viable for GMCR at this point. However, battery costs are constantly declining so it would be worthwhile regularly reviewing the models we have provided.

	Battery
Site A	30kWh
Site B	30kWh
Site C	40kWh
Site D	30kWh
Site E	100kWh

- Note that this modelling is dependent on assumptions about the the sites' energy consumption patterns, future energy prices and tariffs, battery prices, etc, so cannot be guaranteed. The payback times we have calculated are generally above the average for the UK (e.g. Google AI reports that "*In the UK, the average payback time for a home battery storage system is around 10–12 years.*"). This is because the sites already have relatively high self-consumption during the day (by comparison to a typical home), and because the differential between their peak and off-peak tariffs is relatively low. Thus, it is difficult to see a viable payback from installing batteries on the sites unless the cost of the batteries can be reduced and/or additional revenue streams can be accessed.

Summary (2 of 2)

- We have updated GMCR's site viability template to account for the potential returns from installing a battery. Inserting the outputs from our models into this template yields the following results:

	Annual Consumption	Self-Consumption with PV Only[1]	Battery	Increased Self-Consumption[2]	Time-shifted Consumption[2]	Saving to Site[3]	Return to GMCR[4]
Site A	68,000kWh	25,000kWh (37%)	30kWh	4,100kWh (16%)	4,400kWh (18%)	£922	-£21,613 (-127%)
Site B	60,000kWh	18,500kWh (31%)	30kWh	2,700kWh (11%)	5,900kWh (32%)	£2,649	-£18,386 (-108%)
Site C	85,000kWh	27,500kWh (32%)	40kWh	4,000kWh (15%)	8,800kWh (32%)	£6,039	-£14,463 (-69%)
Site D	120,000kWh	30,400kWh (25%)	30kWh	2,700kWh (9%)	7,200kWh (24%)	£2,926	-£17,371 (-102%)
Site E	500,000kWh	183,600kWh (37%)	100kWh	16,300kWh (9%)	18,800kWh (10%)	£8,704	-£42,894 (-82%)

- Clearly these are not attractive returns for GMCR. GMCR might be able to achieve positive returns if it could:
  a) Reduce the capital cost to buy and install the battery
  b) Take a greater proportion of the savings

- For example, reducing battery costs by 25% and taking all of the timeshifting benefit (rather than 75%) would mean that a battery could yield a small positive return at Site C. Battery costs would need to be reduced by significantly more before a battery would yield positive returns at Site A, Site B, Site D and Site E. However, the cost of li-ion battery packs fell by 20% in 2024, so it is possible that batteries will become viable on some of these sites within the next couple of years.[5]

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[1] % is percentage of consumption that is served by PV, **not** percentage of PV generation that is self-consumed.

[2] % is percentage of self-consumption (from previous column) by which self-consumption is increased / that is time-shifted from peak to off-peak times by the battery

[3] This is the total saving across the 20-year horizon modelled by the viability template, not the annual saving

[4] Return includes financing and administrative costs for GMCR, and battery maintenance and insurance, across the 20-year horizon. It does not include any cost for replacing / upgrading components during the 20-year period covered by the template. However, it should be noted that li-ion batteries degrade over time, so may need replacement after 10-15 years.

[5] BloombergNEF, e.g. https://about.bnef.com/blog/lithium-ion-battery-pack-prices-see-largest-drop-since-2017-falling-to-115-per-kilowatt-hour-bloombergnef/

Modelling Approach – Overview

Our approach has been to use our generic model to calculate the scale of self-consumption and timeshifting benefits from installing a battery. This model does not account for financing costs or the commercial relationship between GMCR and the site owner. We have then inserted the outputs from this model into GMCR's site viability template, to account for GMCR's financing and commercial model.

Our generic model calculates each site's energy consumption and generation pattern across a full year, then calculates the benefits that adding solar PV and a battery could create by increasing self-consumption of solar energy, timeshifting energy consumption into off-peak periods and selling flexibility services to the grid. This process entails:

1) **Inserting generic data** for tariffs, and cost of PV & batteries. Tariffs are based on the tariffs currently paid by the sites. PV and battery costs were obtained from ChatGPT and represent typical UK costs for these systems in 2024. It should be noted that these costs are site-specific (as installation is influenced by site conditions) and dependent on the quality of the equipment, OEM and installer discounts, etc. So all calculations are generic, and should be refined by obtaining detailed quotes from suitable vendors.
2) **Importing site energy consumption and generation data**. Ideally we would have several years of data for a site so that we can average the patterns over time to build a generic consumption and generation profile. In practice, we have had to fill in data for several sites by averaging over shorter periods or, in the worst case, by assuming their profile is similar to that for other sites.
3) **Calculating generic annual profiles** for each site. We calculate the site's average hourly consumption for day of the week and month of the year by averaging across several years of data, and then generate a generic profile for the analysis year. Likewise, we calculate hourly PV generation for each month of the year, break it down by quartiles to account for weather variation, then build a generic annual generation profile for the site. Both profiles, consumption and generation, are then normalised against the site's typical total annual consumption/generation.
4) **Creating a starting configuration** for the PV and battery systems.
5) **Calculating the impact of this configuration** and adjacent variants (incrementally smaller and larger systems) on the site's energy costs. The options we calculate and algorithm we use are outlined on the next 2 slides.
6) **Adjust and iterate**. We adjust the PV and battery configuration based on the outputs, and iterate as necessary.

Modelling Approach – Options generated by the generic model

The model estimates the site's energy costs for five options, as below. Again, this is a generic calculation – it does not account for the commercial relationship between GMCR and the site, and the way this apportions costs and benefits between the two parties.

1) **Base energy costs**: The site's energy costs before installing PV or battery. If tariff data is available, we calculate these for both fixed and variable (time-of-use) tariffs.
2) **PV only**: Energy costs with a solar array but no battery. Any excess generation from the PV will be exported to grid.
3) **Battery for self-consumption**: A battery is installed alongside the PV array but is used only to maximise self-consumption of the energy generated by the array – it does not attempt to import from the grid in order to optimise use of off-peak tariff rates (effectively timeshifting some of the site's energy consumption into the off-peak period.) Note that increasing self-consumption will inherently tend to reduce export from the PV array.
4) **Battery for self-consumption and timeshifting**: The battery is now used to import energy at off-peak times, and hence timeshift some of the site's consumption into those off-peak periods. This would ideally be done without increasing the level of export from the PV (as that has zero marginal cost for the site, so should always be used in preference to imported energy); in practice, that requires perfect foresight as to what will be generated and consumed the next day, so any real-world algorithm may create some increase to the export c.f. (3).
5) **Actively traded battery**: When the battery is not being used for self-consumption or timeshifting, this option makes it available for delivering flexibility to markets such as DSO flex, DFS, or Balancing Mechanism. The algorithm embeds some simple assumptions about how the battery's capacity can be traded and what returns these trades might deliver. There may be scope to trade more actively than this, but that would entail added risk and would require a partner who can provide a suitable dynamic optimisation algorithm. (Note that this trading will increase both energy import and export, as it typically creates value by arbitraging between the two. The algorithm does not account for this – it simply tracks the spread that might be obtained by such trading.)

Modelling Approach – Battery modelling algorithm

The algorithm for calculating the effect of the battery is as follows. For each hour of the year it:

1) Calculates the amount of generation and consumption in the previous 24 hours. This is used to help estimate the excess of generation in the next 24 hours, and hence to reserve battery capacity to capture this excess for self-consumption. This estimate is then combined with a forward view of the actual export for the next 24 hours in model (2) (PV only) to simulate the forward estimate of a typical real-time forecasting algorithm (which would use weather data, historical data, etc, to refine its estimates).
2) Calculates how much of current consumption can be met direct from the PV array, and hence how much residual demand or generation there is for the site (one or other of these must be zero).
3) If there is residual demand, it meets this from the battery, within the constraints of its current state-of-charge and inverter capacity. Likewise, if there is residual generation, it sends this to the battery, within its capacity constraints. It then updates the residual demand & generation, and battery state-of-charge. At this point we have the results for option (3) (battery used for self-consumption only).
4) Calculates how much capacity is available in the battery to import energy, after accounting for the forward requirements to capture PV from step (1) above. If it is currently an off-peak hour and if battery capacity is available, it imports energy from the grid, within the constraints of the available battery capacity and inverter. This energy will then be available for consumption in the next peak period. The algorithm then calculates the updated battery state-of-charge. At this point we have the results for option (4) (battery used for self-consumption and timeshifting).
5) It then rolls forward to the next hour, and starts again at step (1).
6) Once it has calculated consumption, generation, import, export and state-of-charge across the full year, the algorithm identifies how many times the state-of-charge is low (less than 25% full) or high (more than 25% full) for 5 consecutive hours. It assumes that the battery can be used for trading during these periods, as there is time to discharge and recharge (or vice versa) to capture arbitrage opportunities without affecting the core battery usage. The algorithm then makes the simple assumption that it is worth trading in 1% of these hours, for an average of £0.20/kWh in each trade. This essentially assumes that the battery trades relatively infrequently, for high value price spikes/lows. That is realistic given (a) the administrative and other costs of trading (which will need to be done via a VLP or similar partner) and (b) the potential impact of additional cycles on battery life. This then gives the results for option (5) (actively traded battery).

Modelling Approach – Caveats

The model is necessarily forward-looking – it is forecasting energy costs relevant to the life (typically 10 years or more) of the PV and battery systems that we are considering installing. Thus all costs and benefits should be taken as forecasts, not guarantees. The quality of these forecasts is dependent on factors such as:

- **Quality of the input consumption and generation data**: Is there enough data, of sufficient quality, to adequately reflect the site's energy usage patterns? Are these patterns likely to change over the life of the equipment being considered?
- **Tariffs**: The benefits of a battery will be strongly influenced by the difference between peak and off-peak tariff, and by what export tariff can be achieved. These tariffs will in turn by driven by market conditions, the site's success in negotiating with suppliers / brokers, etc. The output of the model can only be valid to the extent that the input tariffs are reasonable.
- **Equipment pricing**: We have used a very simple, generic model for the cost of PV and batteries. As noted earlier, the actual cost will be strongly influenced by installation costs (which are site specific), the quality of the equipment selected, ongoing maintenance costs, etc. We recommend obtaining detailed quotes from installers/OEMs[1] before committing to investment.
- **Forecasting algorithm**: We need to forecast energy generation and consumption in order to optimise use of the battery between capturing excess PV generation and importing off-peak energy from grid. We've used a simple algorithm that balances a very simple "same as yesterday" calculation with more sophisticated forecasting. The returns the site actually achieves will be dependent on the quality of the algorithm employed by the system in live usage. Again, sites should obtain an estimate from equipment providers (or a suitable trading partner) as to what benefits their algorithm can achieve in day-to-day usage.
- **Dynamic trading**: Active trading is dependent on markets which are very volatile, both day-to-day and over longer time horizons. We've used a very simple approximation to estimate what benefits this might achieve. A site may well be able to get better returns using more aggressive and dynamic trading strategies. But it will need to take more risk to do this. It will also need to engage a specialist aggregators / optimiser to handle market administration and rules (e.g. on the minimum size that can be traded), and to implement an effective trading strategy.

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[1] Original Equipment Manufacturers – the manufacturers of the battery systems,

Site A

The following slides show key results for Site A.

Full results are given in the accompanying spreadsheet, which contains the full model, input data, etc.

Note that:

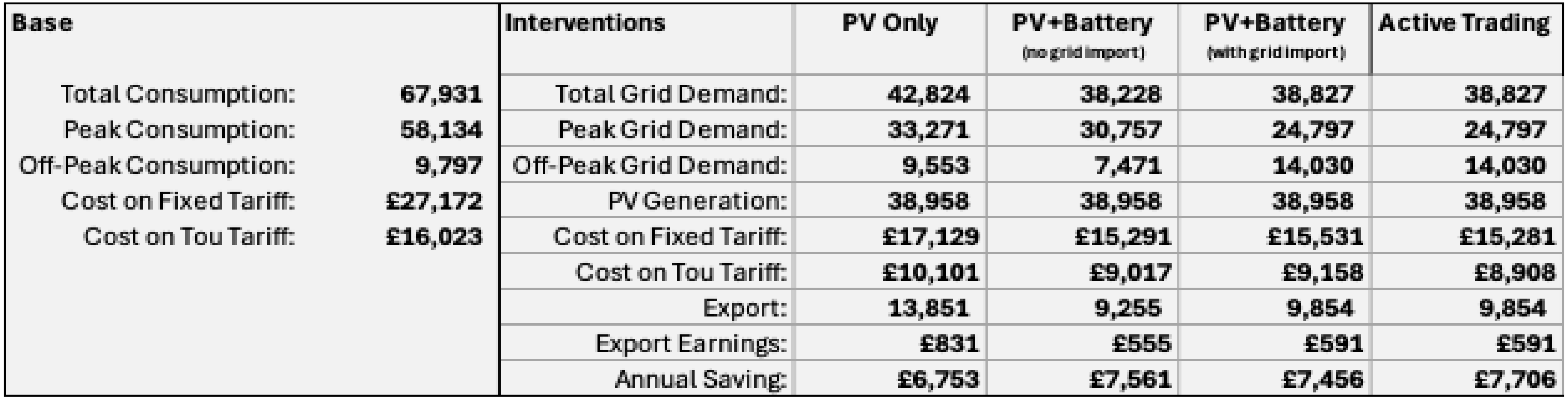
a) We have used energy consumption and generation data for 1 Sep 2021 to 31 Aug 2024, downloaded from the SolarEdge portal for the site's PV system. Hourly data was available for the full 3-year period.

b) We have used the site's current tariff (23.59p/kWh at peak and off-peak times). We have assumed that the off-peak period is from midnight to 7am. The model does not attempt to forecast how these tariffs might vary in the future. (One benefit of a battery is that it helps insulate the site from the risk of future price increases. This benefit is however very difficult to value.)

c) We have used an export tariff that aligns to the rate GMCR uses in its site viability template.

Site A – Generic Scenario Summary

(does not account for financing costs and cost/benefit split between site and GMCR)



Base		Interventions	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading
Total Consumption:	67,931	Total Grid Demand:	42,824	38,228	38,827	38,827
Peak Consumption:	58,134	Peak Grid Demand:	33,271	30,757	24,797	24,797
Off-Peak Consumption:	9,797	Off-Peak Grid Demand:	9,553	7,471	14,030	14,030
Cost on Fixed Tariff:	£27,172	PV Generation:	38,958	38,958	38,958	38,958
Cost on Tou Tariff:	£16,023	Cost on Fixed Tariff:	£17,129	£15,291	£15,531	£15,281
		Cost on Tou Tariff:	£10,101	£9,017	£9,158	£8,908
		Export:	13,851	9,255	9,854	9,854
		Export Earnings:	£831	£555	£591	£591
		Annual Saving:	£6,753	£7,561	£7,456	£7,706

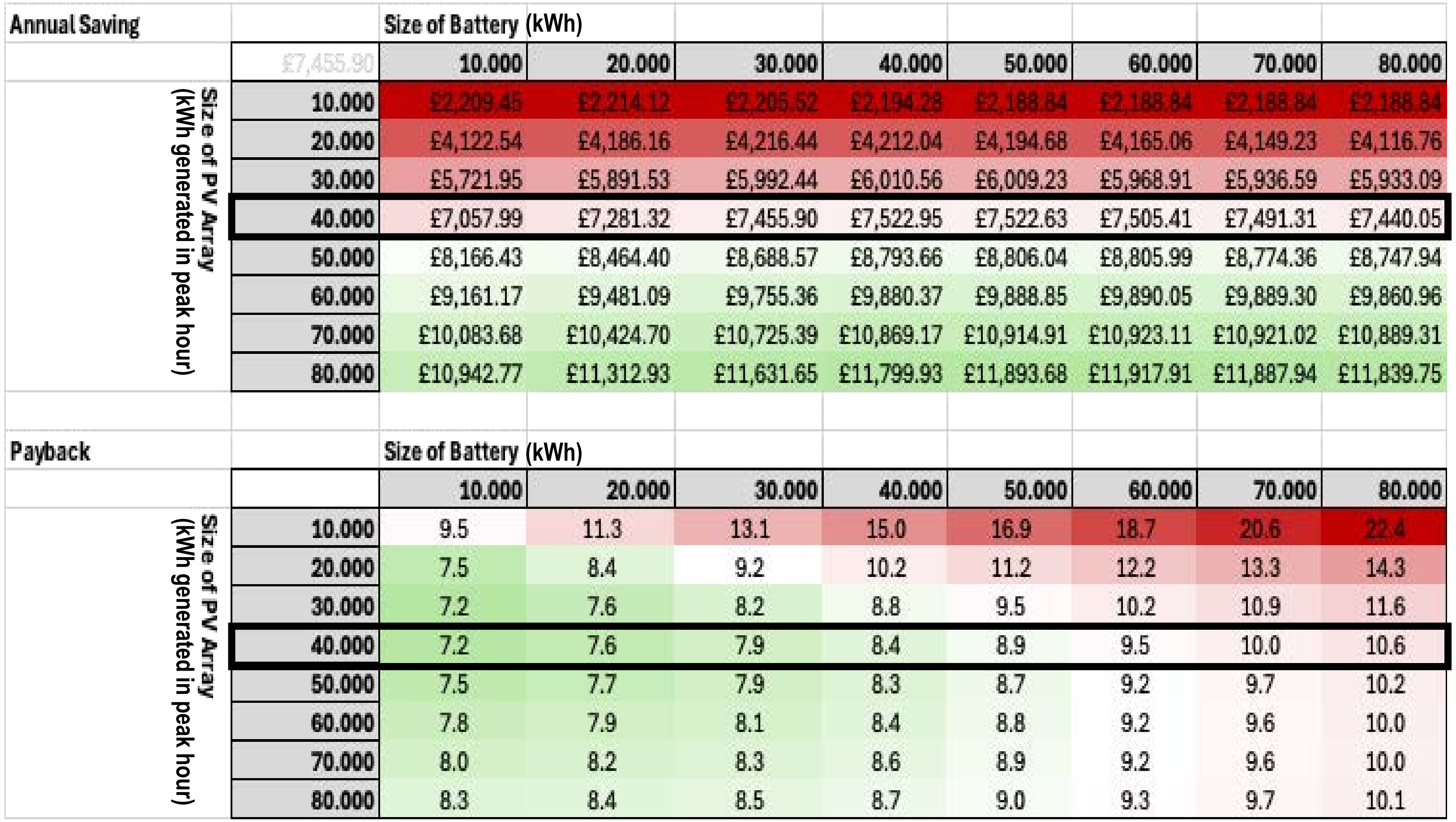
- We estimate the site’s current PV array is reducing its energy costs by approx. £7k (42%) p.a., from £16k to £9k (after accounting for export earnings). A larger array might reduce these costs further, e.g. doubling the array size might take the saving to ~£10.5k (66%) p.a. and would be a reasonable investment (if there is sufficient roof space). That said, the current installation is close to optimal in terms of ROI.
- Adding a 30kWh battery would increase the saving to approx. £7.7k (48%) p.a. This does not represent an especially attractive ROI, giving payback after approx. 18 years. The bulk of this benefit comes from increasing self-consumption of energy generated by the PV array. The benefit of timeshifting consumption to off-peak is minimal against the current tariffs, although there is some potential benefit in trading the battery actively on energy and flexibility markets. (A more active trading strategy might increase this benefit and might be worth exploring, given the lack of timeshifting benefit. However, this would entail taking more market risk, and is unlikely to shift the returns to the point where an investment in the battery is viable.)

Site A – System Sizing for Generic Scenario

(does not account for financing costs and cost/benefit split between site and GMCR)

These tables show the annual saving and payback (in years) that the site might achieve from a PV plus battery system for a range of array and battery sizes. (Note that they include the benefits of self-consumption and timeshifting but not active trading of the battery – these are explored on the next slide.)

It can be seen that the optimal return is achieved from a PV array that can generate 30-40kW[1] at peak and with no battery. Adding a battery increases the optimal size of the array, e.g. pushing it to 50kW for a 40kWh battery and 60kW for a 80kWh battery. However, the optimum is broad and shallow, so the batteries will work well with a range of PV array sizes. The actual array that can be installed will depend on the amount of roof space available, roof pitch and orientation, etc – the generic model does not take this into account.



Annual Saving

Size of PV Array (kWh generated in peak hour)	Size of Battery (kWh)							
£7,455.90	10.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000
10.000	£2,209.45	£2,214.12	£2,205.52	£2,194.28	£2,188.84	£2,188.84	£2,188.84	£2,188.84
20.000	£4,122.54	£4,186.16	£4,216.44	£4,212.04	£4,194.68	£4,165.06	£4,149.23	£4,116.76
30.000	£5,721.95	£5,891.53	£5,992.44	£6,010.56	£6,009.23	£5,968.91	£5,936.59	£5,933.09
40.000	£7,057.99	£7,281.32	£7,455.90	£7,522.95	£7,522.63	£7,505.41	£7,491.31	£7,440.05
50.000	£8,166.43	£8,464.40	£8,688.57	£8,793.66	£8,806.04	£8,805.99	£8,774.36	£8,747.94
60.000	£9,161.17	£9,481.09	£9,755.36	£9,880.37	£9,888.85	£9,890.05	£9,889.30	£9,860.96
70.000	£10,083.68	£10,424.70	£10,725.39	£10,869.17	£10,914.91	£10,923.11	£10,921.02	£10,889.31
80.000	£10,942.77	£11,312.93	£11,631.65	£11,799.93	£11,893.68	£11,917.91	£11,887.94	£11,839.75

Payback

Size of PV Array (kWh generated in peak hour)	Size of Battery (kWh)							
	10.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000
10.000	9.5	11.3	13.1	15.0	16.9	18.7	20.6	22.4
20.000	7.5	8.4	9.2	10.2	11.2	12.2	13.3	14.3
30.000	7.2	7.6	8.2	8.8	9.5	10.2	10.9	11.6
40.000	7.2	7.6	7.9	8.4	8.9	9.5	10.0	10.6
50.000	7.5	7.7	7.9	8.3	8.7	9.2	9.7	10.2
60.000	7.8	7.9	8.1	8.4	8.8	9.2	9.6	10.0
70.000	8.0	8.2	8.3	8.6	8.9	9.2	9.6	10.0
80.000	8.3	8.4	8.5	8.7	9.0	9.3	9.7	10.1

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[1] The generic model does not account for site-specific factors such as roof orientation: it calculates the peak generation the array needs to achieve. It is then a separate exercise to design an array that can deliver this output given the site's roof space, orientation and pitch, etc. This array will need a higher rated capacity to achieve the recommended peak generation. Site A currently has an array rated at 50kWp, which produces about 40kWh in the peak hour, well aligned to the optimum identified by the generic model.

Site A – Battery Sizing for Generic Scenario

(does not account for financing costs and cost/benefit split between site and GMCR)

These tables show the proportion of the annual saving that can be attributed to the battery, and the payback (in years) that this would yield for investing in the battery.

It can be seen that the optimum return is achieved for a 20-30kWh battery at the current PV array size. Increasing the size of the array improves the return on the battery, but the optimum size remains ~30kWh. However, again the optimum is fairly broad, so there would be little lost if a common battery size were installed across several sites. (This would potentially improve your ability to negotiate discounted pricing on the batteries and reduce maintenance overheads.)

Battery Saving with Trading — Size of Battery (kWh)

Size of PV Array (kWh generated in peak hour)	£952.91	10.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000
	10.000	£149.95	£249.91	£292.67	£286.39	£291.67	£292.15	£284.91	£288.87
	20.000	£251.29	£411.64	£495.84	£493.16	£485.08	£456.82	£432.51	£403.92
	30.000	£335.60	£602.73	£753.70	£768.70	£774.76	£738.37	£699.61	£700.95
	40.000	£410.20	£728.57	£952.91	£1,015.93	£1,020.36	£1,003.38	£986.08	£941.06
	50.000	£449.89	£844.08	£1,114.03	£1,210.48	£1,227.66	£1,229.73	£1,199.70	£1,181.12
	60.000	£475.96	£894.47	£1,213.24	£1,327.72	£1,345.28	£1,350.69	£1,348.09	£1,327.72
	70.000	£506.77	£946.59	£1,293.50	£1,426.83	£1,478.17	£1,488.61	£1,484.09	£1,458.17
	80.000	£538.76	£1,003.58	£1,367.97	£1,525.58	£1,622.20	£1,646.35	£1,619.22	£1,579.27

Battery Payback — Size of Battery (kWh)

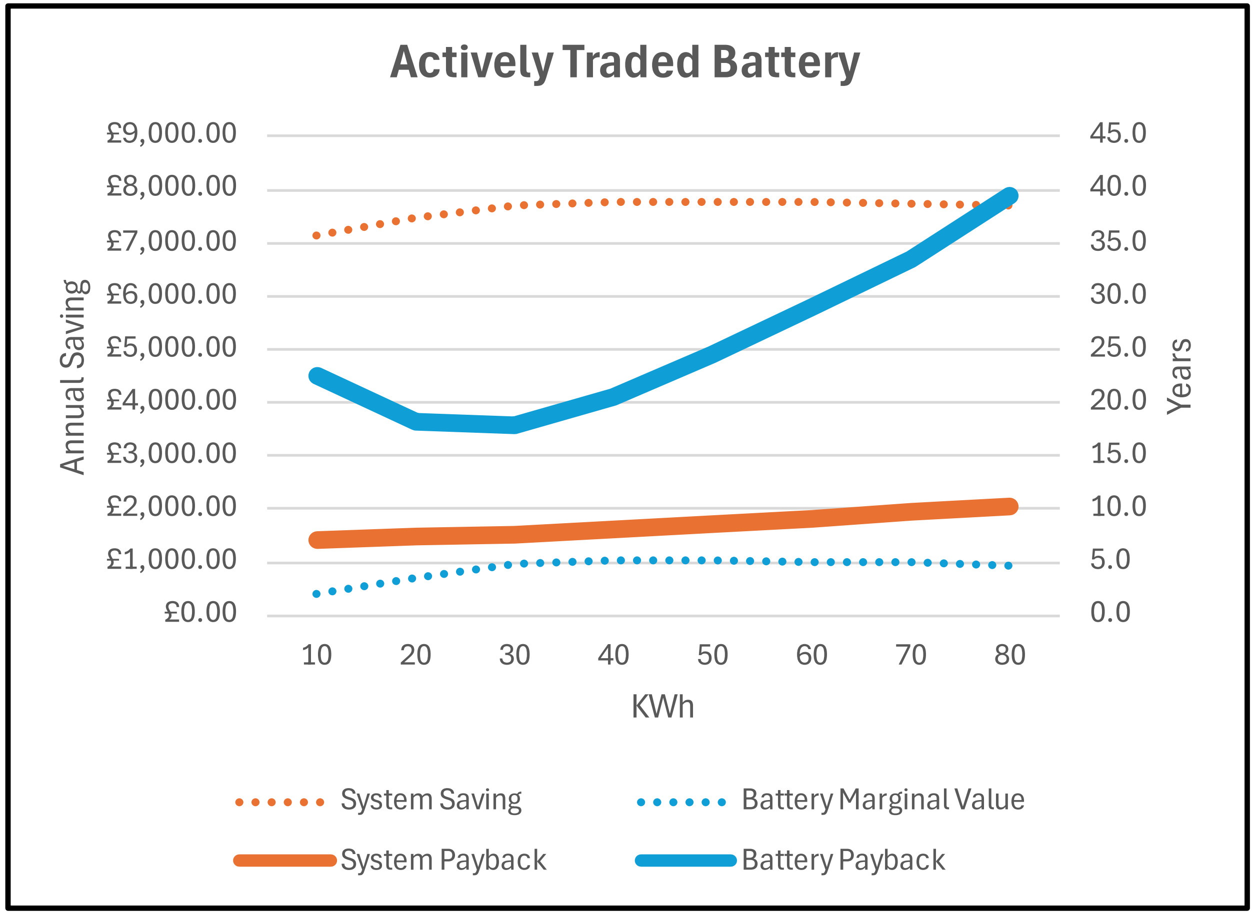
Size of PV Array (kWh generated in peak hour)		10.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000
	10.000	60.0	52.0	58.1	73.3	85.7	99.3	115.8	128.1
	20.000	35.8	31.6	34.3	42.6	51.5	63.5	76.3	91.6
	30.000	26.8	21.6	22.6	27.3	32.3	39.3	47.2	52.8
	40.000	21.9	17.8	17.8	20.7	24.5	28.9	33.5	39.3
	50.000	20.0	15.4	15.3	17.3	20.4	23.6	27.5	31.3
	60.000	18.9	14.5	14.0	15.8	18.6	21.5	24.5	27.9
	70.000	17.8	13.7	13.1	14.7	16.9	19.5	22.2	25.4
	80.000	16.7	13.0	12.4	13.8	15.4	17.6	20.4	23.4

Site A – Battery Sizing for Generic Scenario

(does not account for financing costs and cost/benefit split between site and GMCR)

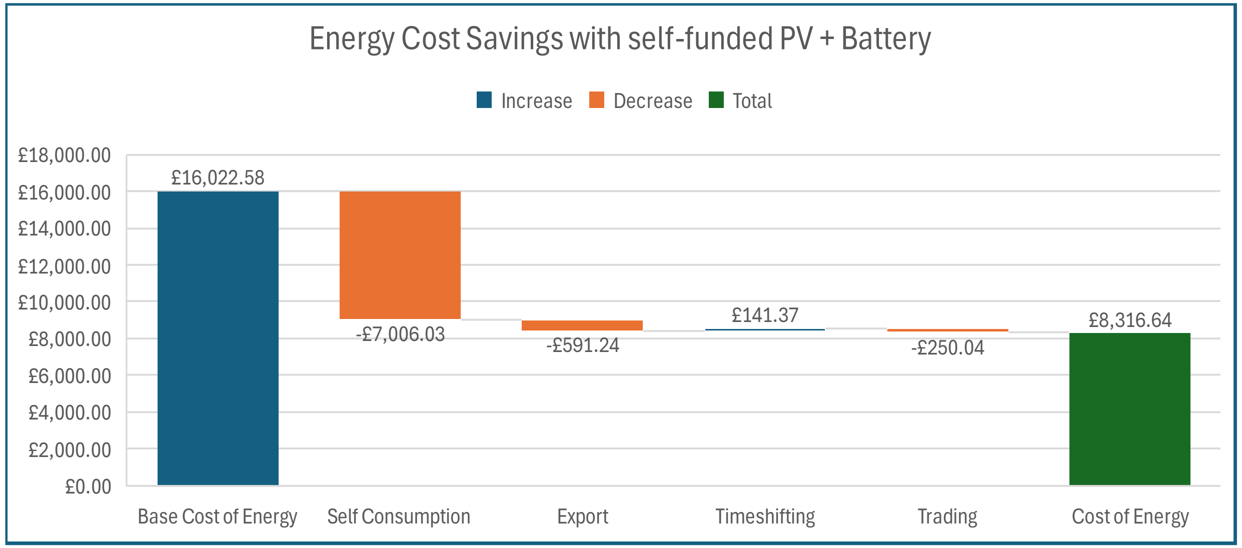
This chart again shows the value of adding a battery to the site's current PV array, separating the marginal value of the battery out from the overall site value.

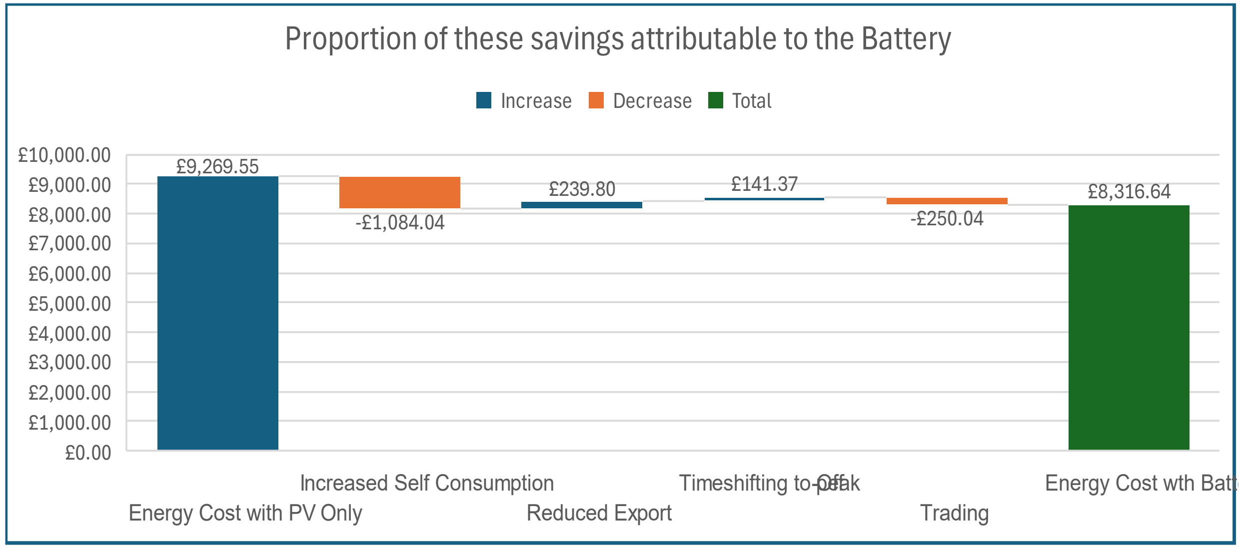
It can be seen that the optimal size for a battery on this site is about 30kWh, yielding an additional saving to the site's energy costs of about £1k p.a. c.f. the current costs with the PV array. This represents a payback of about 18 years, which is not especially attractive.



Site A – Energy Cost Savings for battery purchased with own funds

(does not account for financing costs and cost/benefit split between site and GMCR)


Energy Cost Savings with self-funded PV + Battery


Proportion of these savings attributable to the Battery

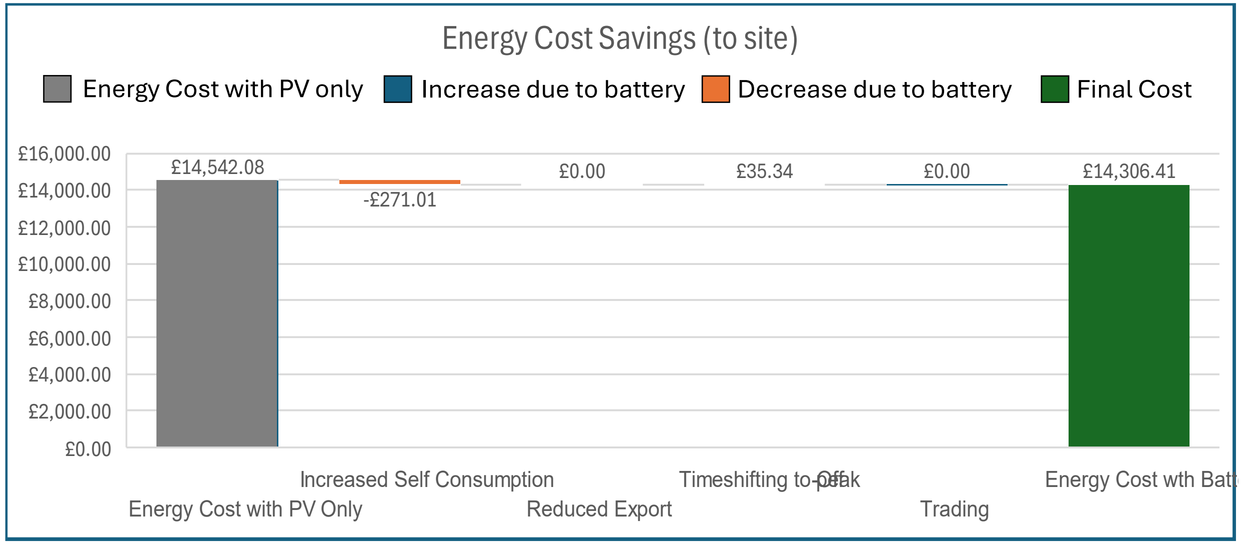
The bulk of the benefit from the PV+battery system comes from self-consumption of the energy generated by the PV array. The principal benefit of the battery is to increase this self-consumption by about £1.1k p.a.

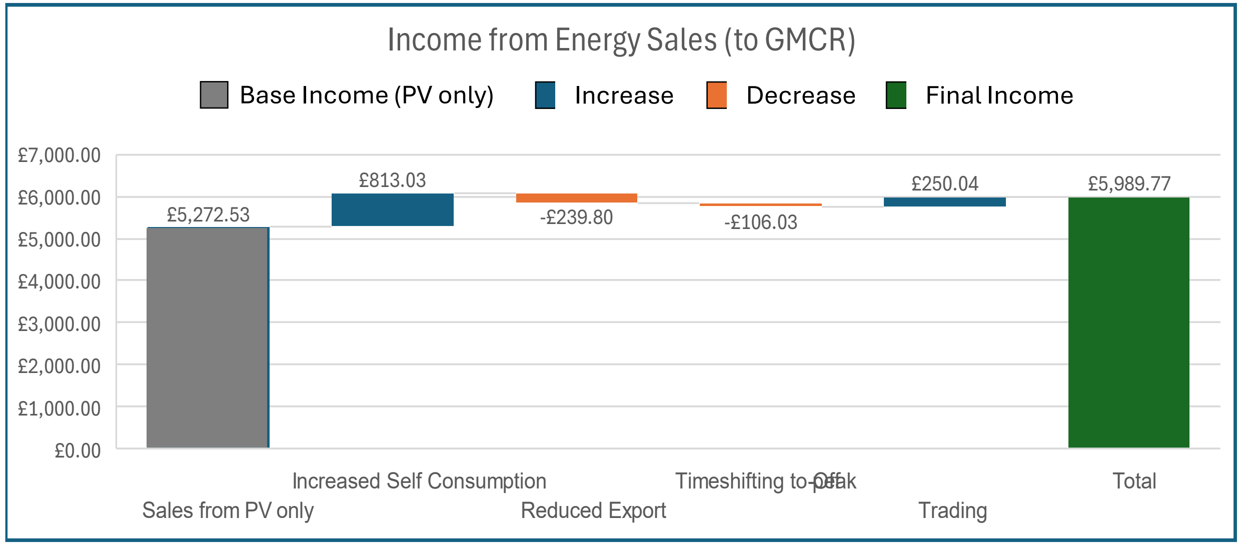
That benefit is achieved at the cost of reducing the array's earnings from exporting to the grid by about £200p.a. There is also a slight cost from the battery's attempt to timeshift consumption – errors in the forecasting algorithm are penalised heavily by the tariffs, which the relatively small differential between peak and off-peak rates cannot fully counteract.

A small saving is generated from additional active trading of the battery. Given the lack of benefit received from timeshifting, it might be worthwhile exploring an even more active trading strategy for this site. However, this would entail taking some market risk, and it's unlikely that this strategy would yield sufficient return to shift the battery's ROI to the point where it is viable.

Site A – Allocation of Benefits for GMCR-funded Battery

(does not account for financing costs)



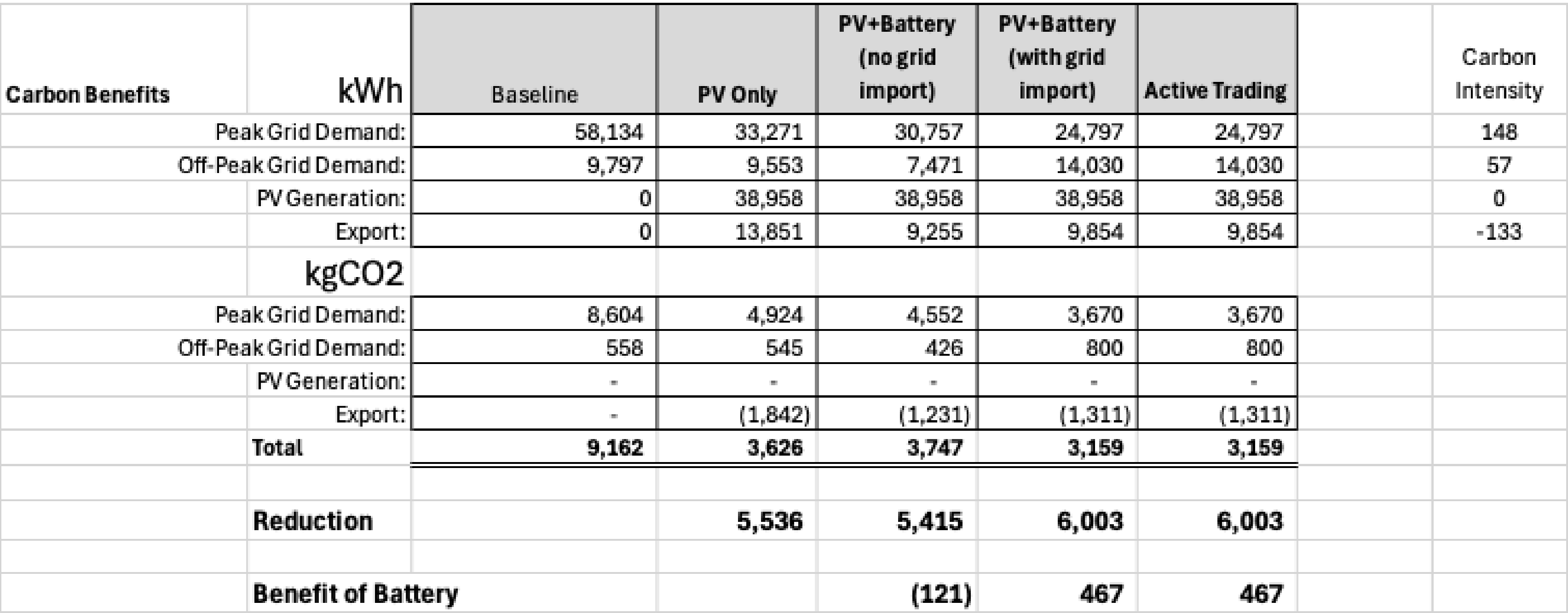


The previous slides identified the "DIY" benefits of the battery, i.e. assuming that the battery is owned by the party incurring the energy costs. In the case where GMCR owns the battery, these benefits will be split between it and the site.

These graphs show what this split might look like if GMCR captures 75% of the self-consumption and time-shifting benefit and 100% of the export and trading revenues. The table below shows the payback GMCR might achieve from these returns: installing a 30kWh battery alongside the current array would pay back after about 24 years. Payback improves for larger array sizes but never becomes especially attractive.

Battery Payback		Size of Battery (kWh)							
		10.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000
Size of PV Array (kWh generated in peak hour)	10.000	66.4	55.6	60.8	75.8	88.0	101.9	119.0	131.6
	20.000	44.3	38.0	40.9	50.6	60.6	73.6	87.9	103.5
	30.000	34.8	27.7	29.0	35.3	41.5	50.1	59.9	66.9
	40.000	29.2	23.6	23.7	27.7	32.8	38.6	44.7	52.1
	50.000	26.9	20.7	20.6	23.7	27.8	32.2	37.5	42.5
	60.000	25.6	19.6	19.1	21.8	25.6	29.5	33.7	38.2
	70.000	24.2	18.6	18.0	20.4	23.5	27.0	30.9	35.1
	80.000	22.9	17.7	17.1	19.2	21.6	24.7	28.5	32.7

Site A – Carbon Savings

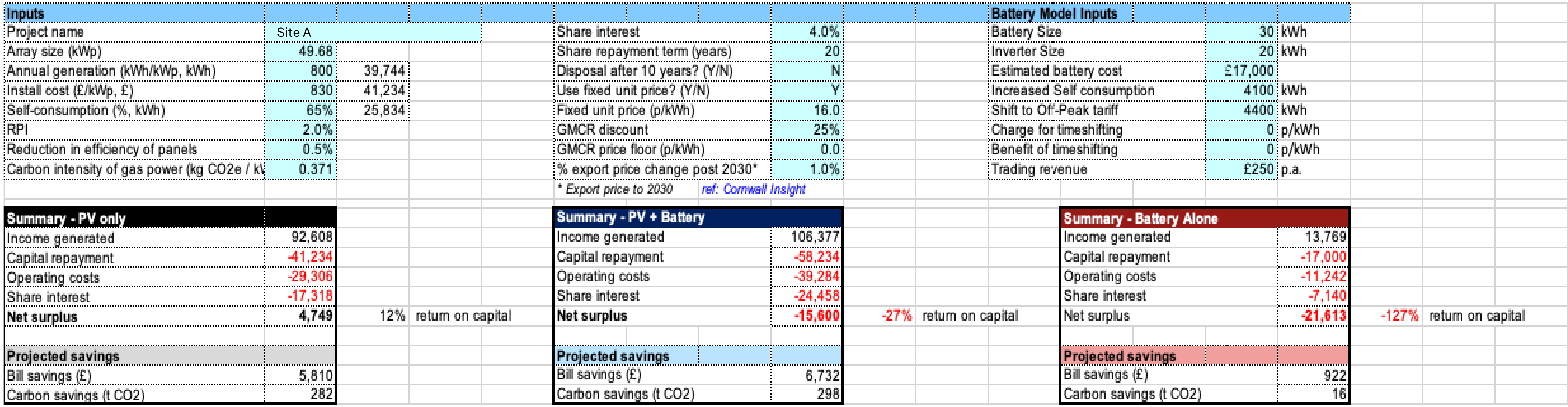


Carbon Benefits	kWh	Baseline	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading		Carbon Intensity
	Peak Grid Demand:	58,134	33,271	30,757	24,797	24,797		148
	Off-Peak Grid Demand:	9,797	9,553	7,471	14,030	14,030		57
	PV Generation:	0	38,958	38,958	38,958	38,958		0
	Export:	0	13,851	9,255	9,854	9,854		-133
	kgCO2							
	Peak Grid Demand:	8,604	4,924	4,552	3,670	3,670		
	Off-Peak Grid Demand:	558	545	426	800	800		
	PV Generation:	-	-	-	-	-		
	Export:	-	(1,842)	(1,231)	(1,311)	(1,311)		
	Total	**9,162**	**3,626**	**3,747**	**3,159**	**3,159**		
	Reduction		**5,536**	**5,415**	**6,003**	**6,003**		
	Benefit of Battery			**(121)**	**467**	**467**		

- We estimate that the battery yields an additional carbon saving of approx. 0.5 tCO2e p.a., primarily by time-shifting the site's consumption to times when grid carbon intensity is lower.
- Note that these calculations are highly dependent on assumptions about grid carbon intensity and how the benefits of the PV array are accounted for. GMCR's site viability model uses alternative assumptions.
- The calculations also do not account for the embedded carbon within the battery. These are dependent on the manufacturing process, shipping, etc. ChatGPT estimates them at 2.4tCO2e for a 30kWh battery.

Site A – Site Viability

(Based on GMCR's site viability template for new sites, as updated to include battery storage options.)



Inputs		
Project name	Site A	
Array size (kWp)	49.68	
Annual generation (kWh/kWp, kWh)	800	39,744
Install cost (£/kWp, £)	830	41,234
Self-consumption (%, kWh)	65%	25,834
RPI	2.0%	
Reduction in efficiency of panels	0.5%	
Carbon intensity of gas power (kg CO2e / k	0.371	

Share interest	4.0%
Share repayment term (years)	20
Disposal after 10 years? (Y/N)	N
Use fixed unit price? (Y/N)	Y
Fixed unit price (p/kWh)	16.0
GMCR discount	25%
GMCR price floor (p/kWh)	0.0
% export price change post 2030*	1.0%

** Export price to 2030* *ref: Cornwall Insight*

Battery Model Inputs		
Battery Size	30	kWh
Inverter Size	20	kWh
Estimated battery cost	£17,000	
Increased Self consumption	4100	kWh
Shift to Off-Peak tariff	4400	kWh
Charge for timeshifting	0	p/kWh
Benefit of timeshifting	0	p/kWh
Trading revenue	£250	p.a.

Summary - PV only			
Income generated	92,608		
Capital repayment	-41,234		
Operating costs	-29,306		
Share interest	-17,318		
Net surplus	**4,749**	12%	return on capital
Projected savings			
Bill savings (£)	5,810		
Carbon savings (t CO2)	282		

Summary - PV + Battery			
Income generated	106,377		
Capital repayment	-58,234		
Operating costs	-39,284		
Share interest	-24,458		
Net surplus	**-15,600**	-27%	return on capital
Projected savings			
Bill savings (£)	6,732		
Carbon savings (t CO2)	298		

Summary - Battery Alone			
Income generated	13,769		
Capital repayment	-17,000		
Operating costs	-11,242		
Share interest	-7,140		
Net surplus	**-21,613**	-127%	return on capital
Projected savings			
Bill savings (£)	922		
Carbon savings (t CO2)	16		

- We have updated GMCR's site viability template to include 3 options – PV only, PV + Battery, and Battery Alone (i.e. as an upgrade to existing PV). Inserting the generic model's outputs (for battery size and costs, and the self-consumption and energy timeshifting benefits it could deliver) for Site A yields the above results. These now incorporate GMCR's financing and administrative costs, assumptions about energy prices and carbon intensity, etc.
- Investing in a battery is clearly not viable, even though there are some additional carbon & bill savings for the site. Battery prices would need to reduce significantly, and/or returns would need to increase significantly, before investing in a battery for this site is viable.

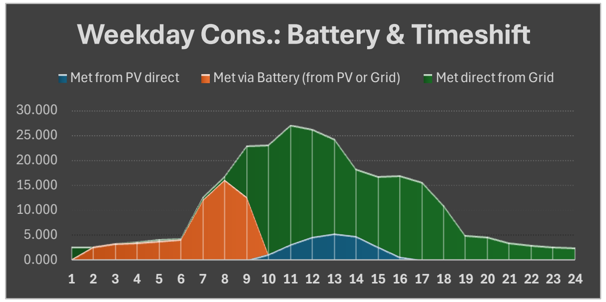
Site A – Energy usage patterns

The next 2 slides show the average daily energy usage pattern for each month of the year, for weekdays and weekends respectively. These give a more detailed feel for how the PV energy and battery might be used. Features of the usage patterns include:

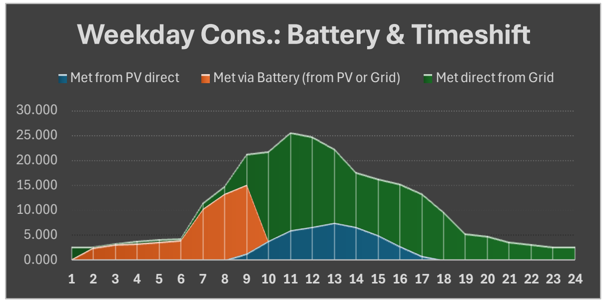
- During winter, the PV array does not generate enough energy to meet weekday consumption. The battery is used primarily to import energy at off-peak times overnight and to use this to meet consumption in the morning.
- By March/April, the PV is beginning to meet consumption on some (sunny) weekdays. The battery captures any excess and uses it to meet evening demand. It then captures another tranche of energy overnight and uses it to meet demand the next morning.
- By May-July, the PV is meeting demand during the day most weekdays, and the excess is sufficient to meet evening demand on those days. Again, the battery captures another tranche of energy overnight and uses this to meet some of the morning demand. However, it does not fully meet the morning demand as it is reserving space to capture excess PV generation in the middle of the day. (The benefit of capturing free solar energy outweighs that of using off-peak energy from the grid, so it forgoes some of the latter.)
- Consumption is significantly lower in August. Demand is met almost entirely by self-consuming the PV generation, either directly during the day or via storage of excess energy in the battery overnight.
- Sep/Oct then goes back to a pattern similar to that of March/April, and hence to the winter pattern in November to February.
- Consumption at weekends is much lower. Demand is met almost entirely from the solar PV or from energy timeshifted from off-peak periods, with the proportion of self-consumption naturally being larger in the summer months. There is also some export from the PV array throughout the year, even on sunny weekend days in the middle of winter.
- (Note that the difference between weekday and weekend consumption sometimes leads to the battery storing too much energy overnight, thus reducing the amount of PV generation it can capture the next day and increasing exports at weekends. This is because, as noted in point 4 of slide 6, the control algorithm does not have perfect foresight and so sometimes leaves insufficient reserve capacity in the battery. The model uses an algorithm that only slightly refines a basic “same as yesterday” forecast. This reflects real life performance of many battery controllers, but a controller with more sophisticated forecasting, e.g. using cloud-based AI, could probably do better.)

Site A – Weekday energy usage

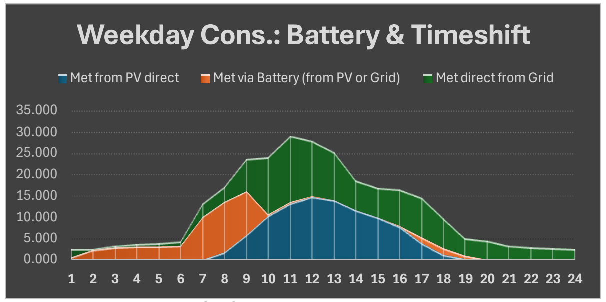
January



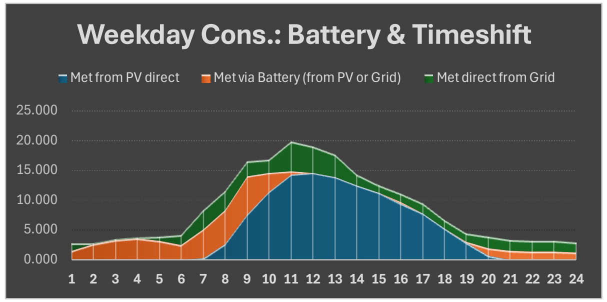
February



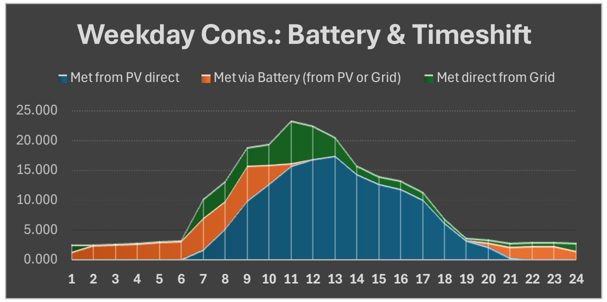
March



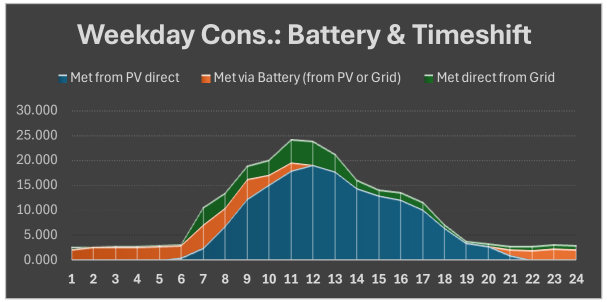
April



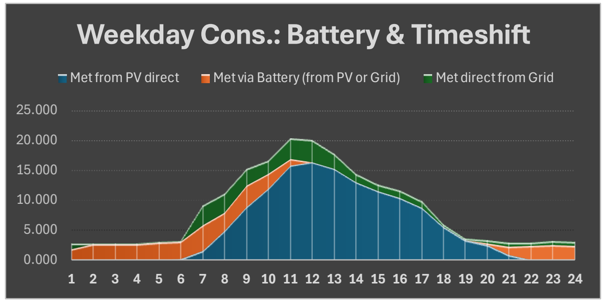
May



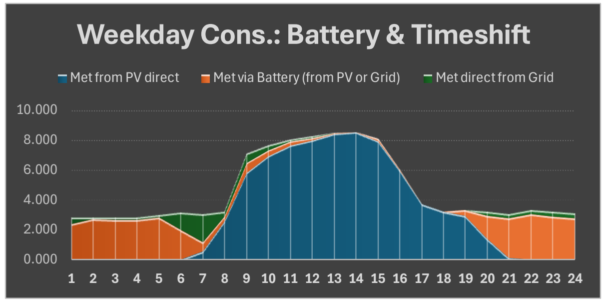
June



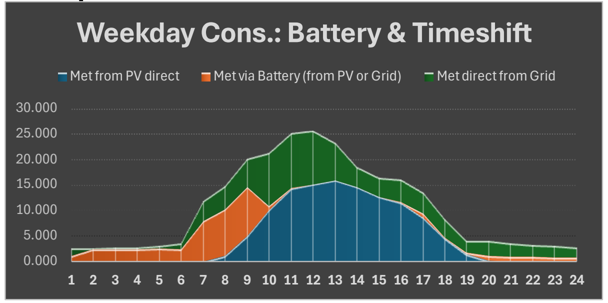
July



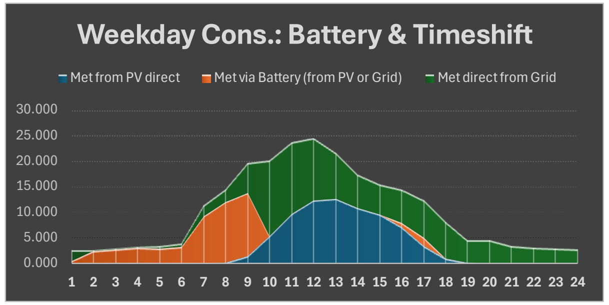
August



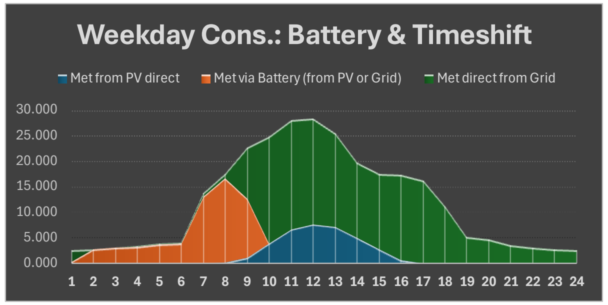
September



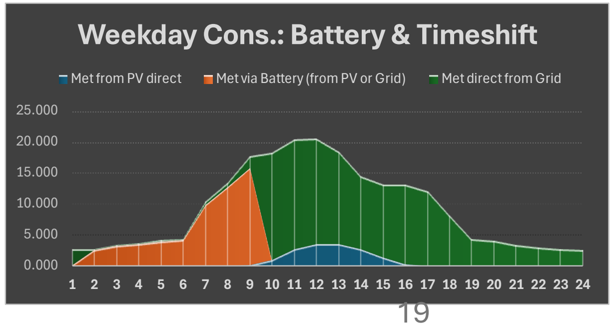
October



November

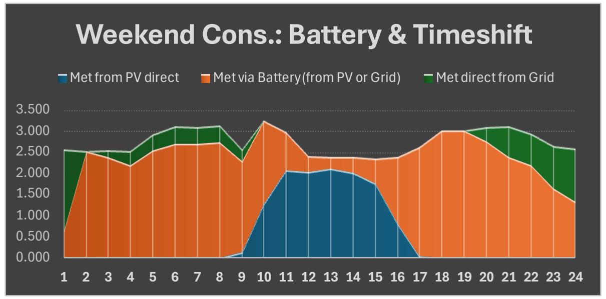


December

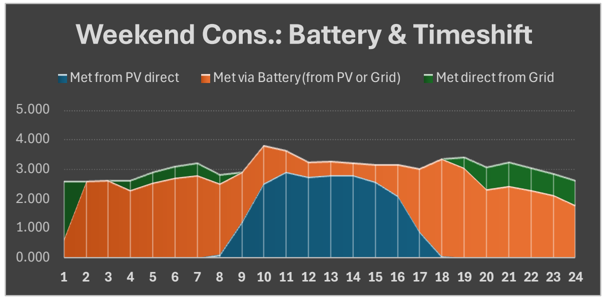


Site A – Weekend energy usage

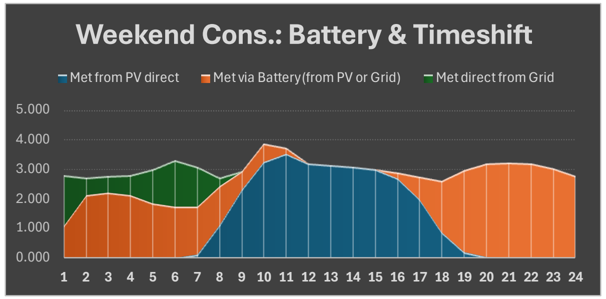
January



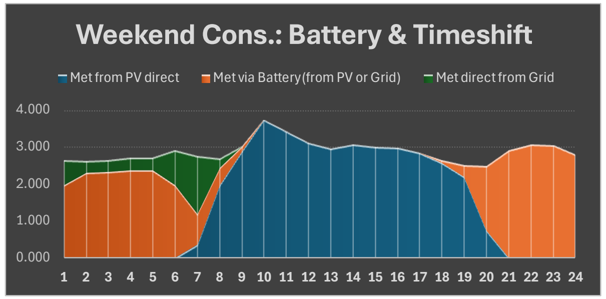
February



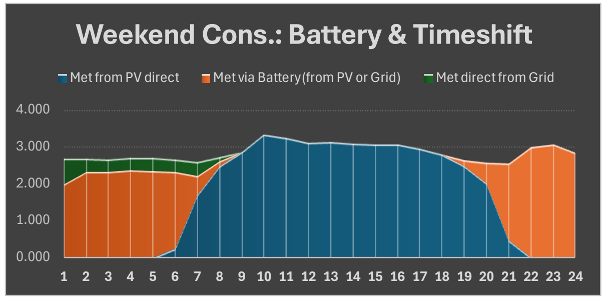
March



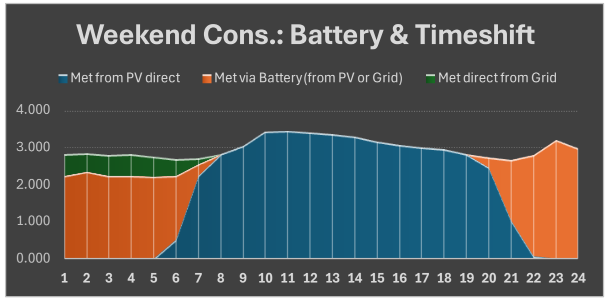
April



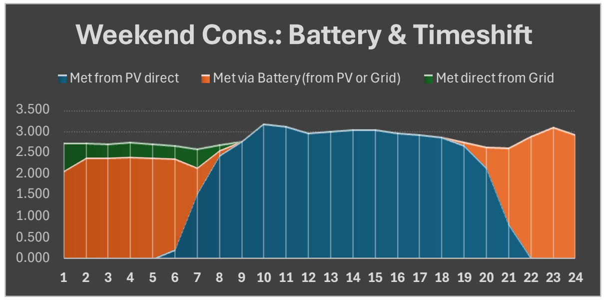
May



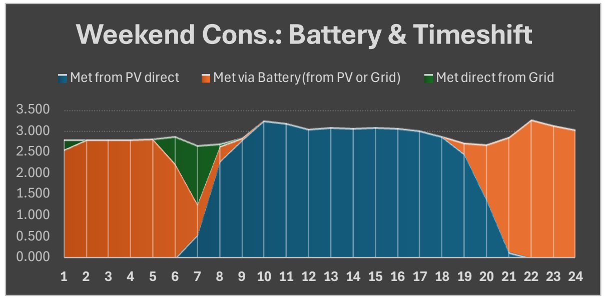
June



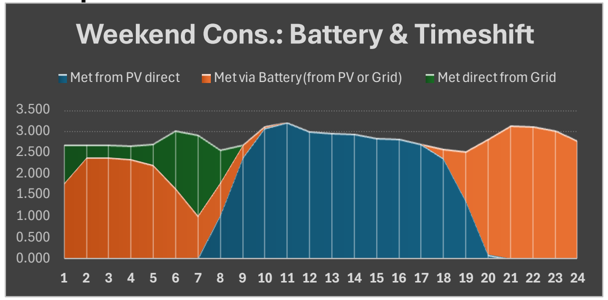
July



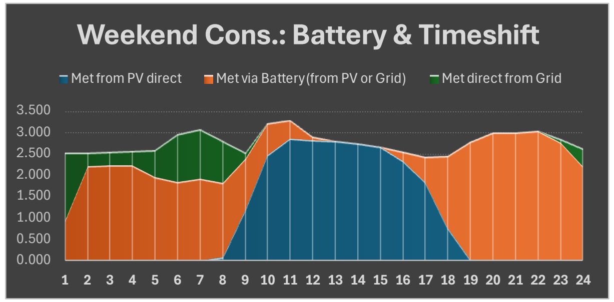
August



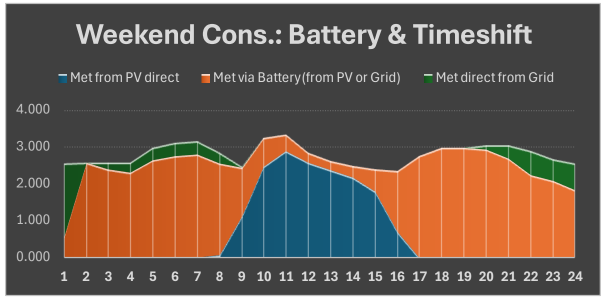
September



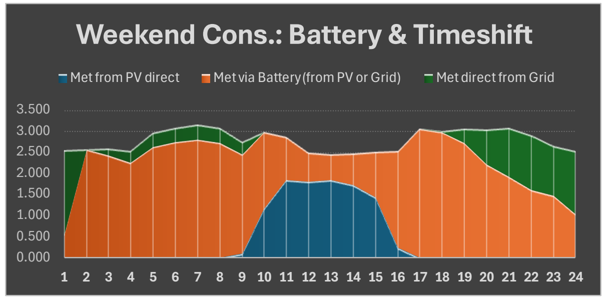
October



November



December



Site B

The following slides show key results for Site B.

Full results are given in the accompanying spreadsheet, which contains the full model , input data, etc.

Note that:

a) We have used energy consumption and generation data for 1 Sep 2021 to 31 Aug 2024, downloaded from the SolarEdge portal for the site's PV system. Hourly data was available for the full 3-year period.

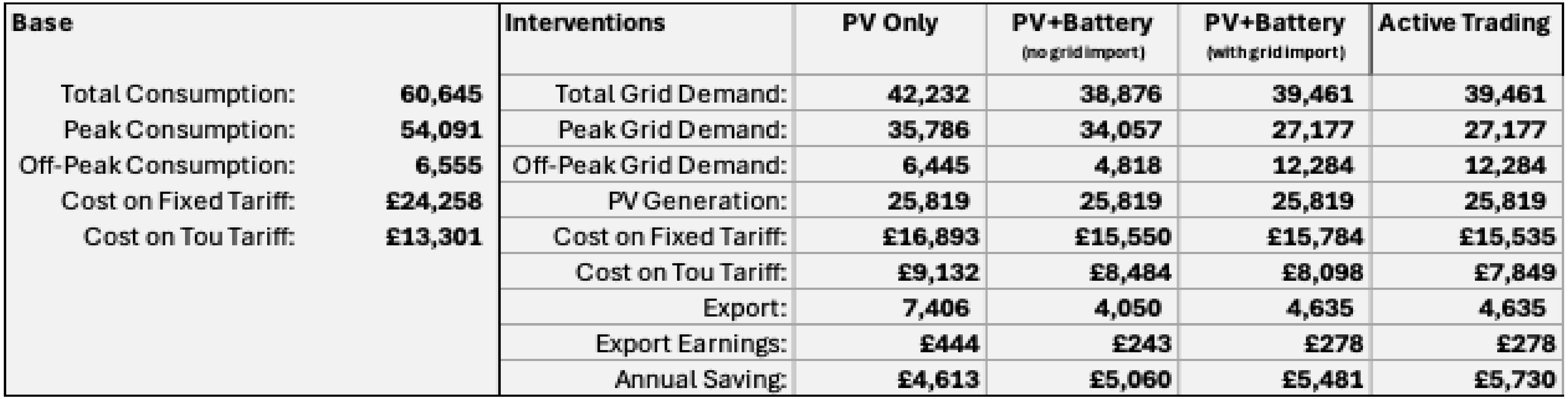
b) We have used the peak and off-peak tariffs that the site is currently paying. We have assumed that the off-peak period is from midnight to 7am. The model does not attempt to forecast how these tariffs might vary in the future. (One benefit of a battery is that it helps insulate the site from the risk of future price increases. This benefit is however very difficult to value.)

c) We have not modelled a fixed tariff option for the site (i.e. we've set the fixed tariff artificially high so that it is never selected by the algorithm), as the site is already on a variable Time-of-Use tariff.

d) We have used an export tariff that aligns to the rate GMCR uses in its site viability template.

Site B – Generic Scenario Summary

(does not account for financing costs and cost/benefit split between site and GMCR)



Base		Interventions	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading
Total Consumption:	60,645	Total Grid Demand:	42,232	38,876	39,461	39,461
Peak Consumption:	54,091	Peak Grid Demand:	35,786	34,057	27,177	27,177
Off-Peak Consumption:	6,555	Off-Peak Grid Demand:	6,445	4,818	12,284	12,284
Cost on Fixed Tariff:	£24,258	PV Generation:	25,819	25,819	25,819	25,819
Cost on Tou Tariff:	£13,301	Cost on Fixed Tariff:	£16,893	£15,550	£15,784	£15,535
		Cost on Tou Tariff:	£9,132	£8,484	£8,098	£7,849
		Export:	7,406	4,050	4,635	4,635
		Export Earnings:	£444	£243	£278	£278
		Annual Saving:	£4,613	£5,060	£5,481	£5,730

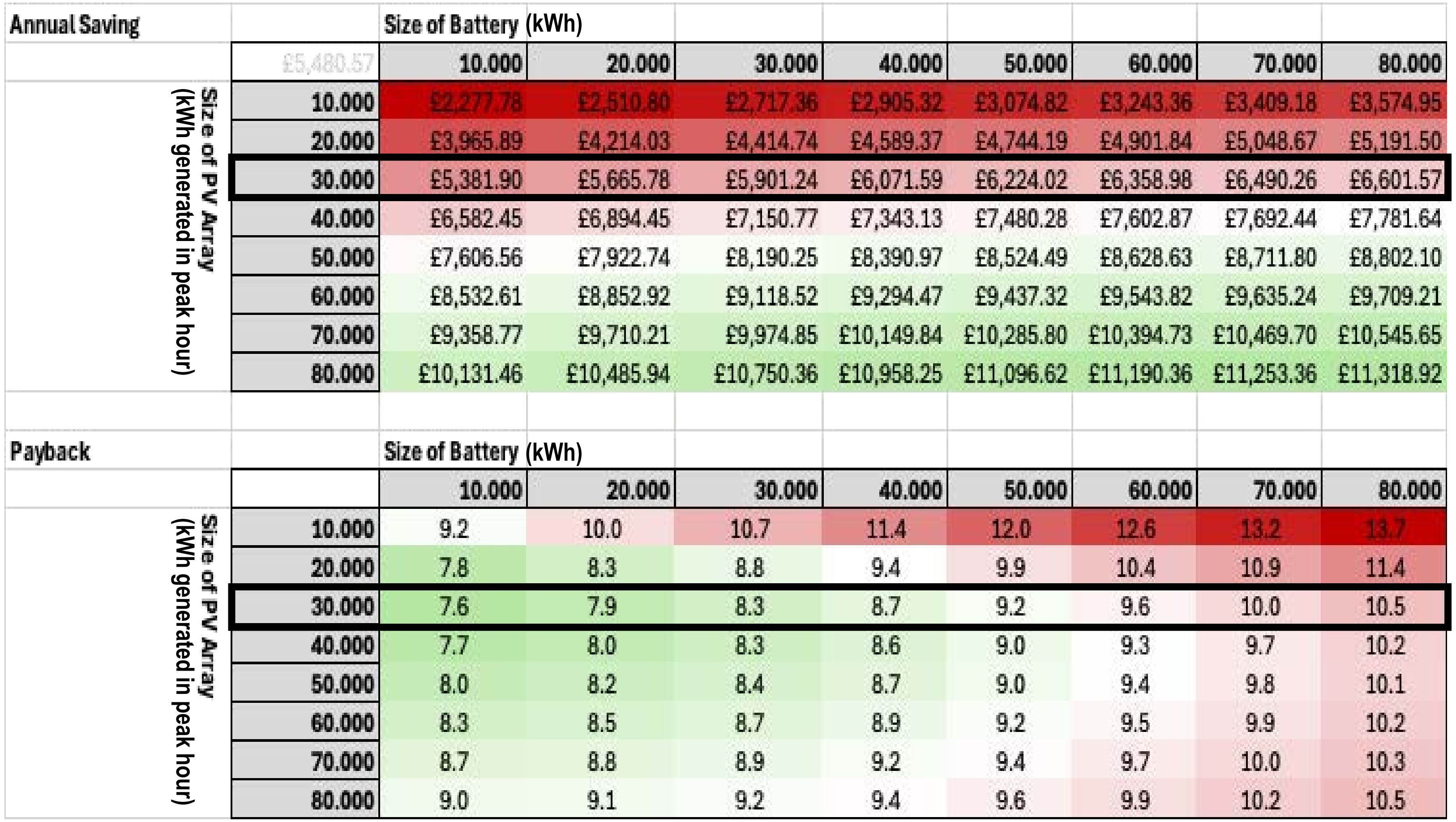
- We estimate the site's current PV array is reducing its energy costs by approx. £4.6k (35%) p.a., from £13.3k to £8.7k (after accounting for export earnings). A larger array might reduce these costs further, e.g. doubling the array size might take the saving to ~£8k (61%) p.a. and would be a reasonable investment (if there is sufficient roof space). However, the current installation is again close to optimal in terms of ROI.
- Adding a 30kWh battery would increase the saving to approx. £5.7k (43%) p.a. This does not represent an especially attractive ROI, giving payback after approx. 15 years. The bulk of this benefit comes from increasing self-consumption of energy generated by the PV array. There is also a reasonable benefit from timeshifting consumption to off-peak tariffs, and from trading the battery actively on energy and flex markets.

Site B – System Sizing for Generic Scenario

(does not account for financing costs and cost/benefit split between site and GMCR)

These tables show the annual saving and payback (in years) that the site might achieve from a PV plus battery system for a range of array and battery sizes. (Note that they include the benefits of self-consumption and timeshifting but not active trading of the battery – these are explored on the next slide.)

It can be seen that the optimal return is achieved from a PV array that can generate 30kW[1] at peak and with no battery. Adding a battery increases the optimal size of the array slightly, e.g. pushing it to 40kW for an 60kWh battery. However, the optimum is broad and shallow, so batteries will work well with a range of PV array sizes (and vice versa). The actual array that can be installed will depend on the amount of roof space available, roof pitch and orientation, etc – the generic model does not take this into account.



Annual Saving		Size of Battery (kWh)							
	£5,480.57	10.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000
Size of PV Array (kWh generated in peak hour)	10.000	£2,277.78	£2,510.80	£2,717.36	£2,905.32	£3,074.82	£3,243.36	£3,409.18	£3,574.95
	20.000	£3,965.89	£4,214.03	£4,414.74	£4,589.37	£4,744.19	£4,901.84	£5,048.67	£5,191.50
	30.000	£5,381.90	£5,665.78	£5,901.24	£6,071.59	£6,224.02	£6,358.98	£6,490.26	£6,601.57
	40.000	£6,582.45	£6,894.45	£7,150.77	£7,343.13	£7,480.28	£7,602.87	£7,692.44	£7,781.64
	50.000	£7,606.56	£7,922.74	£8,190.25	£8,390.97	£8,524.49	£8,628.63	£8,711.80	£8,802.10
	60.000	£8,532.61	£8,852.92	£9,118.52	£9,294.47	£9,437.32	£9,543.82	£9,635.24	£9,709.21
	70.000	£9,358.77	£9,710.21	£9,974.85	£10,149.84	£10,285.80	£10,394.73	£10,469.70	£10,545.65
	80.000	£10,131.46	£10,485.94	£10,750.36	£10,958.25	£11,096.62	£11,190.36	£11,253.36	£11,318.92

Payback		Size of Battery (kWh)							
		10.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000
Size of PV Array (kWh generated in peak hour)	10.000	9.2	10.0	10.7	11.4	12.0	12.6	13.2	13.7
	20.000	7.8	8.3	8.8	9.4	9.9	10.4	10.9	11.4
	30.000	7.6	7.9	8.3	8.7	9.2	9.6	10.0	10.5
	40.000	7.7	8.0	8.3	8.6	9.0	9.3	9.7	10.2
	50.000	8.0	8.2	8.4	8.7	9.0	9.4	9.8	10.1
	60.000	8.3	8.5	8.7	8.9	9.2	9.5	9.9	10.2
	70.000	8.7	8.8	8.9	9.2	9.4	9.7	10.0	10.3
	80.000	9.0	9.1	9.2	9.4	9.6	9.9	10.2	10.5

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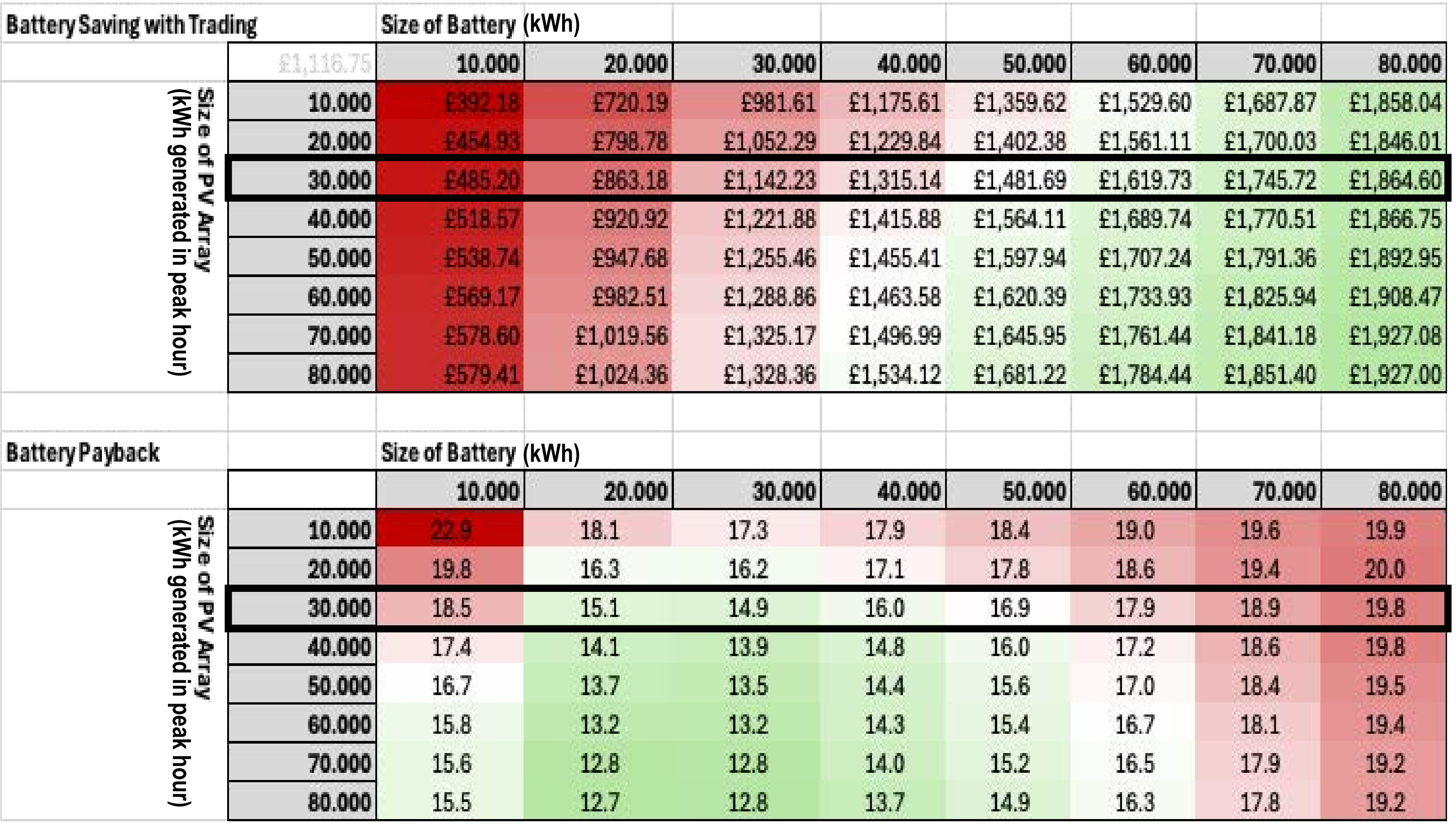
[1] The generic model does not account for site-specific factors such as roof orientation: it calculates the peak generation the array needs to achieve. It is then a separate exercise to design an array that can deliver this output given the site's roof space, orientation and pitch, etc. This array will need a higher rated capacity to achieve the recommended peak generation. Site B currently has an array which produces about 30kWh in the peak hour, well aligned to the optimum identified by the generic model.

Site B – Battery Sizing for Generic Scenario

(does not account for financing costs and cost/benefit split between site and GMCR)

These tables show the proportion of the annual saving that can be attributed to the battery, and the payback (in years) that this would yield for investing in the battery.

It can be seen that the optimum return is achieved for a 30kWh battery at the current PV array size. Increasing the size of the array improves the return on the battery, but the optimum size remains at about 30kWh. However, again the optimum is fairly broad, so there would be little lost if a common battery size were installed across several sites. (This would potentially improve your ability to negotiate discounted pricing on the batteries, and to reduce maintenance overheads.)



Battery Saving with Trading		Size of Battery (kWh)							
	£1,116.75	10.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000
Size of PV Array (kWh generated in peak hour)	10.000	£392.18	£720.19	£981.61	£1,175.61	£1,359.62	£1,529.60	£1,687.87	£1,858.04
	20.000	£454.93	£798.78	£1,052.29	£1,229.84	£1,402.38	£1,561.11	£1,700.03	£1,846.01
	30.000	£485.20	£863.18	£1,142.23	£1,315.14	£1,481.69	£1,619.73	£1,745.72	£1,864.60
	40.000	£518.57	£920.92	£1,221.88	£1,415.88	£1,564.11	£1,689.74	£1,770.51	£1,866.75
	50.000	£538.74	£947.68	£1,255.46	£1,455.41	£1,597.94	£1,707.24	£1,791.36	£1,892.95
	60.000	£569.17	£982.51	£1,288.86	£1,463.58	£1,620.39	£1,733.93	£1,825.94	£1,908.47
	70.000	£578.60	£1,019.56	£1,325.17	£1,496.99	£1,645.95	£1,761.44	£1,841.18	£1,927.08
	80.000	£579.41	£1,024.36	£1,328.36	£1,534.12	£1,681.22	£1,784.44	£1,851.40	£1,927.00

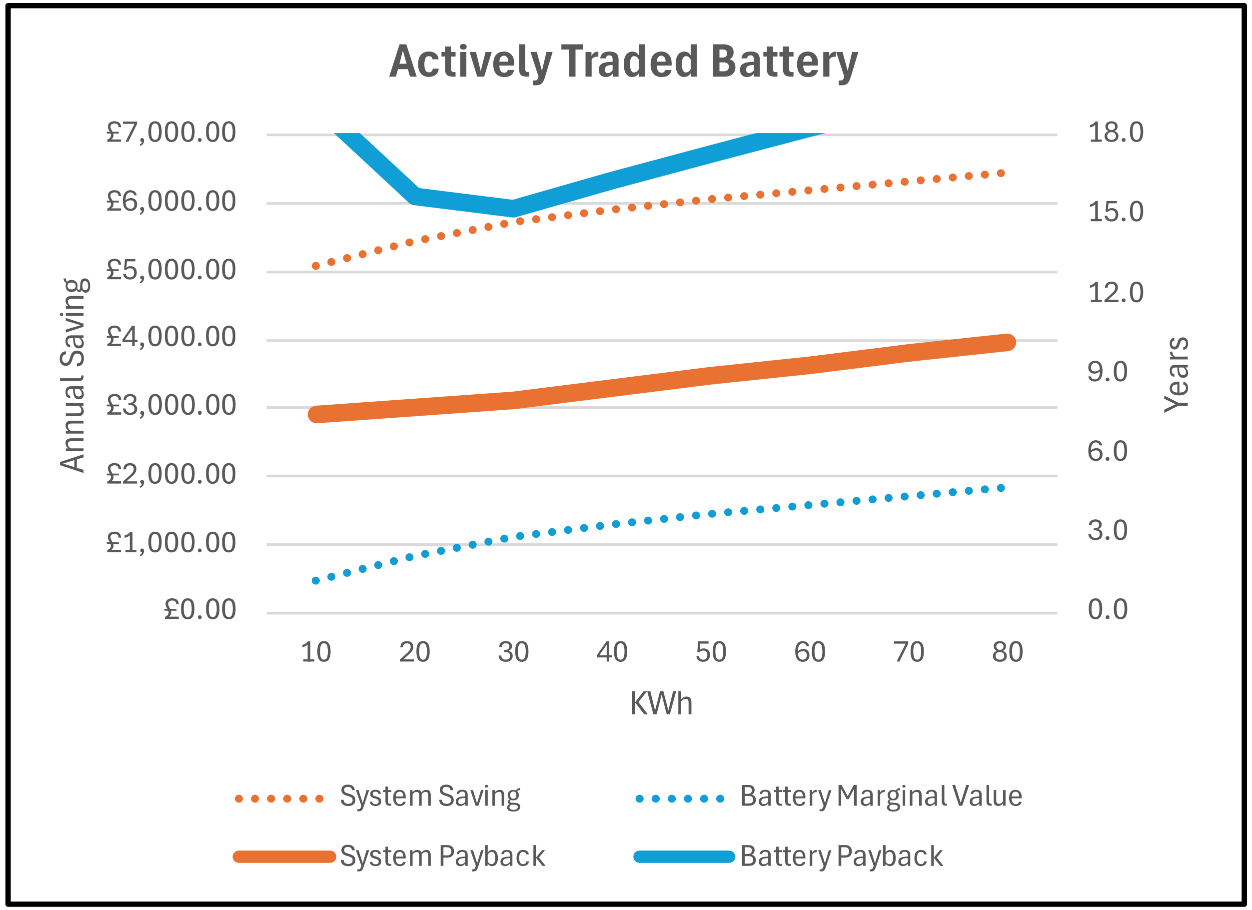
Battery Payback		Size of Battery (kWh)							
		10.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000
Size of PV Array (kWh generated in peak hour)	10.000	22.9	18.1	17.3	17.9	18.4	19.0	19.6	19.9
	20.000	19.8	16.3	16.2	17.1	17.8	18.6	19.4	20.0
	30.000	18.5	15.1	14.9	16.0	16.9	17.9	18.9	19.8
	40.000	17.4	14.1	13.9	14.8	16.0	17.2	18.6	19.8
	50.000	16.7	13.7	13.5	14.4	15.6	17.0	18.4	19.5
	60.000	15.8	13.2	13.2	14.3	15.4	16.7	18.1	19.4
	70.000	15.6	12.8	12.8	14.0	15.2	16.5	17.9	19.2
	80.000	15.5	12.7	12.8	13.7	14.9	16.3	17.8	19.2

Site B – Battery Sizing for Generic Scenario

(does not account for financing costs and cost/benefit split between site and GMCR)

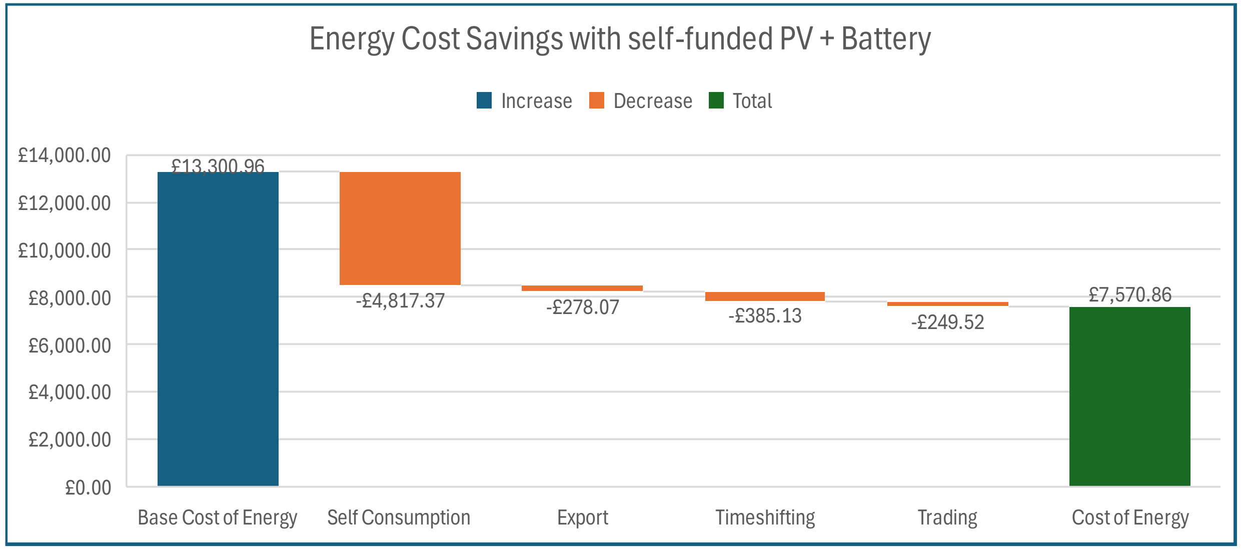
This chart again shows the value of adding a battery to the site’s current PV array, separating the marginal value of the battery out from the overall site value.

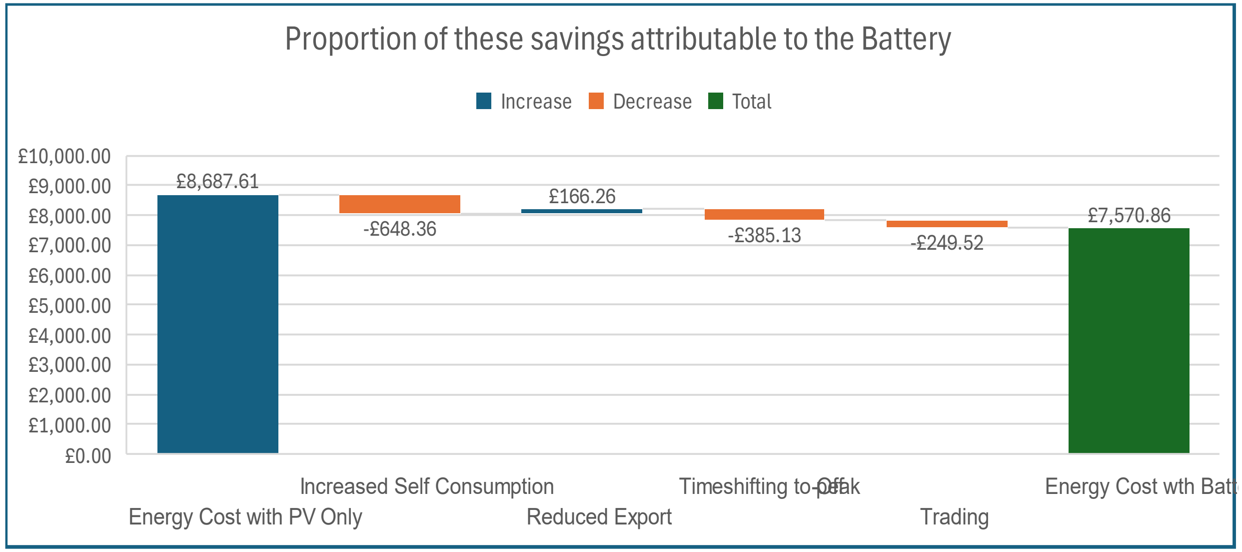
It can be seen that the optimal size for a battery on this site is about 30kWh, yielding an additional saving to the site’s energy costs of about £1.1k p.a. c.f. the current costs with the PV array. This represents a payback of about 15 years, which is not especially attractive.



Site B – Energy Cost Savings for battery purchased with own funds

(does not account for financing costs and cost/benefit split between site and GMCR)


Energy Cost Savings with self-funded PV + Battery

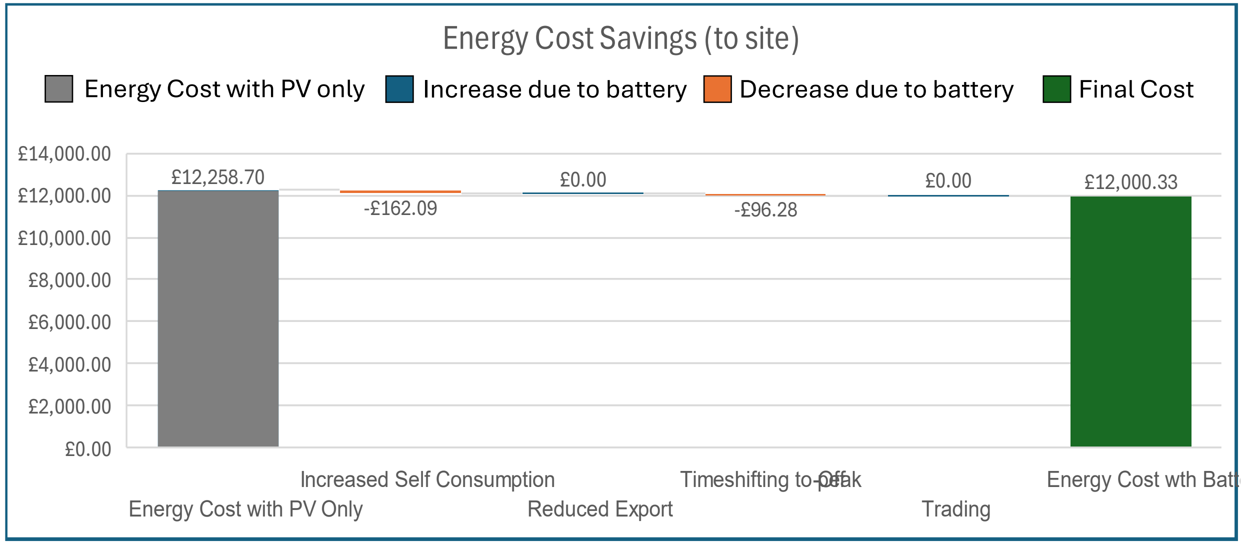

Proportion of these savings attributable to the Battery

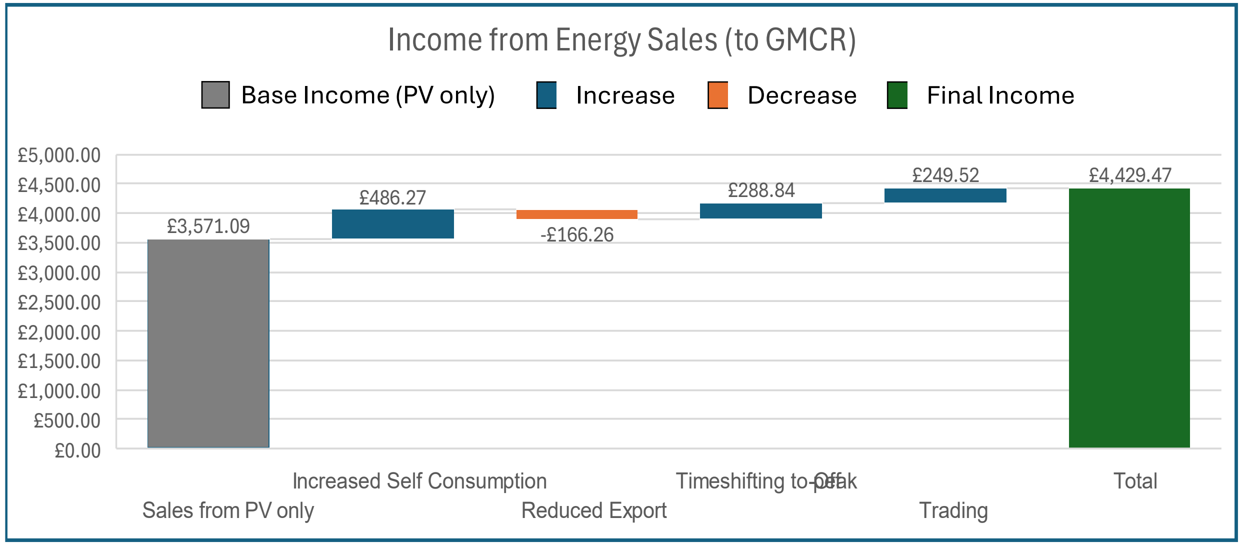
The bulk of the benefit from the PV+battery system comes from self-consumption of the energy generated by the PV array. The principal benefit of the battery is to increase this self-consumption by about £600 p.a.

That benefit is achieved at the cost of reducing the array's earnings from exporting to the grid by about £200p.a. Savings from timeshifting consumption to off-peak periods more than compensate for this cost. Then an additional saving is generated from additional active trading of the battery.

Site B – Allocation of Benefits for GMCR-funded Battery

(does not account for financing costs)



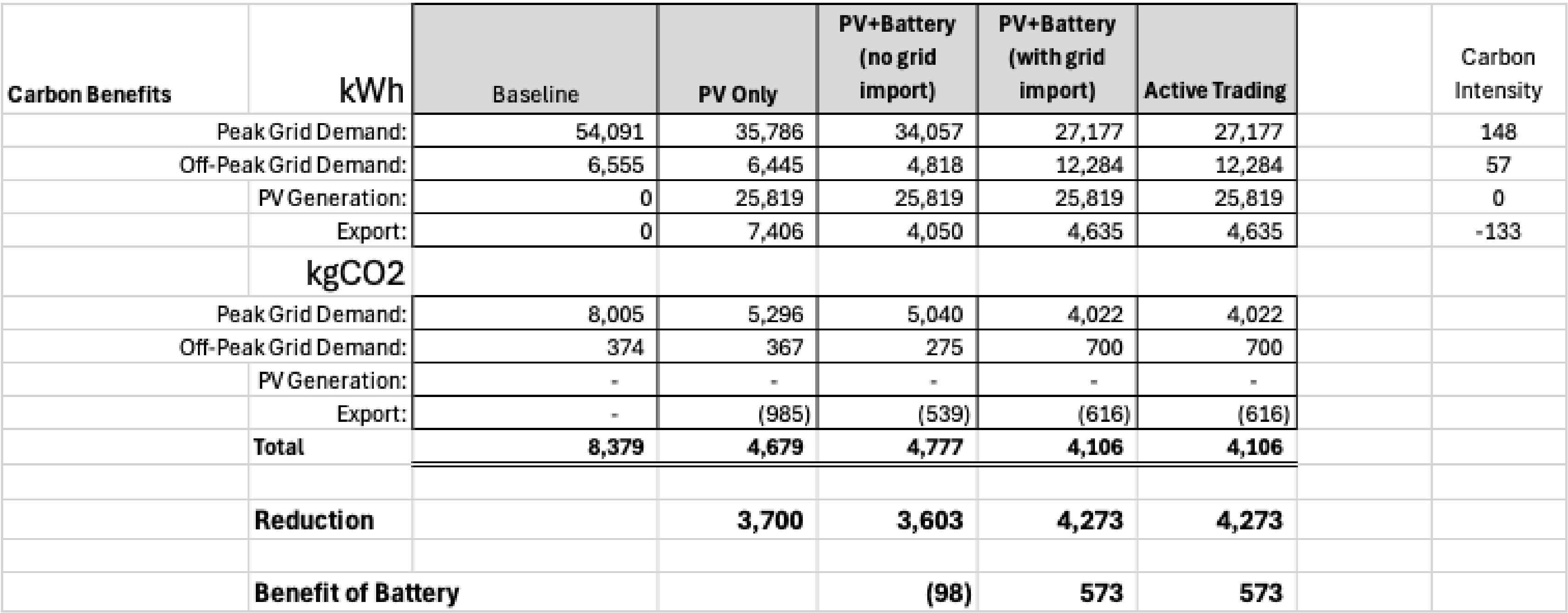


The previous slides identified the "DIY" benefits of the battery, i.e. assuming that the battery is owned by the party incurring the energy costs. In the case where GMCR owns the battery, these benefits will be split between it and the site.

These graphs show what this split might look like if GMCR captures 75% of the self-consumption and time-shifting benefit and 100% of the export and trading revenues. The table below shows the payback GMCR might achieve from these returns: installing a 30kWh battery alongside the current array would pay back after about 20 years. Payback improves for larger array sizes, but never becomes especially attractive.

Battery Payback		Size of Battery (kWh)							
		10.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000
Size of PV Array (kWh generated in peak hour)	10.000	28.6	22.3	21.4	22.3	23.0	23.9	24.8	25.4
	20.000	25.6	20.8	20.6	21.9	22.8	23.8	25.0	25.8
	30.000	24.4	19.7	19.5	21.0	22.2	23.5	24.8	26.0
	40.000	23.2	18.9	18.6	19.9	21.4	23.0	25.0	26.5
	50.000	22.5	18.5	18.4	19.7	21.3	23.0	24.9	26.3
	60.000	21.5	18.0	18.0	19.7	21.1	22.8	24.6	26.3
	70.000	21.2	17.5	17.7	19.4	21.0	22.7	24.6	26.2
	80.000	21.3	17.4	17.7	19.0	20.6	22.5	24.6	26.4

Site B – Carbon Savings

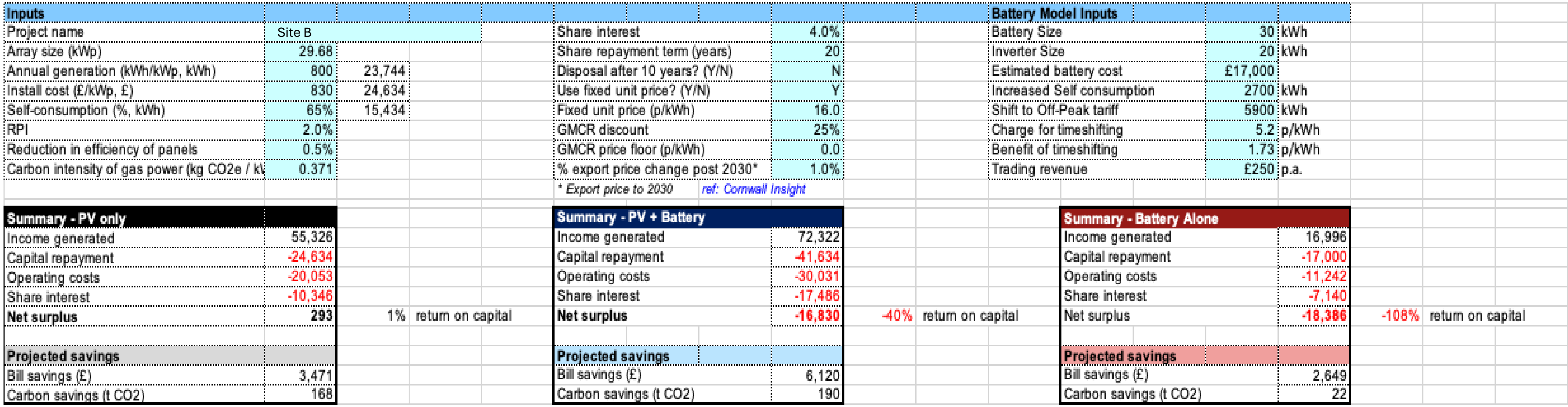


Carbon Benefits	kWh	Baseline	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading		Carbon Intensity
	Peak Grid Demand:	54,091	35,786	34,057	27,177	27,177		148
	Off-Peak Grid Demand:	6,555	6,445	4,818	12,284	12,284		57
	PV Generation:	0	25,819	25,819	25,819	25,819		0
	Export:	0	7,406	4,050	4,635	4,635		-133
	kgCO2							
	Peak Grid Demand:	8,005	5,296	5,040	4,022	4,022		
	Off-Peak Grid Demand:	374	367	275	700	700		
	PV Generation:	-	-	-	-	-		
	Export:	-	(985)	(539)	(616)	(616)		
	Total	**8,379**	**4,679**	**4,777**	**4,106**	**4,106**		
	Reduction		**3,700**	**3,603**	**4,273**	**4,273**		
	Benefit of Battery			**(98)**	**573**	**573**		

- We estimate that the battery yields an additional carbon saving of approx. 0.6 tCO2e p.a., primarily by time-shifting the site's consumption to times when grid carbon intensity is lower.
- Note that these calculations are highly dependent on assumptions about grid carbon intensity and how the benefits of the PV array are accounted for. GMCR's site viability model uses alternative assumptions.
- The calculations also do not account for the embedded carbon within the battery. These are dependent on the manufacturing process, shipping, etc. ChatGPT estimates them at 2.4tCO2e for a 30kWh battery.

Site B – Site Viability

(Based on GMCR's site viability template for new sites, as updated to include battery storage options.)



Inputs		
Project name	Site B	
Array size (kWp)	29.68	
Annual generation (kWh/kWp, kWh)	800	23,744
Install cost (£/kWp, £)	830	24,634
Self-consumption (%, kWh)	65%	15,434
RPI	2.0%	
Reduction in efficiency of panels	0.5%	
Carbon intensity of gas power (kg CO2e / k	0.371	

Share interest	4.0%
Share repayment term (years)	20
Disposal after 10 years? (Y/N)	N
Use fixed unit price? (Y/N)	Y
Fixed unit price (p/kWh)	16.0
GMCR discount	25%
GMCR price floor (p/kWh)	0.0
% export price change post 2030*	1.0%

** Export price to 2030* *ref: Cornwall Insight*

Battery Model Inputs		
Battery Size	30	kWh
Inverter Size	20	kWh
Estimated battery cost	£17,000	
Increased Self consumption	2700	kWh
Shift to Off-Peak tariff	5900	kWh
Charge for timeshifting	5.2	p/kWh
Benefit of timeshifting	1.73	p/kWh
Trading revenue	£250	p.a.

Summary - PV only			
Income generated	55,326		
Capital repayment	-24,634		
Operating costs	-20,053		
Share interest	-10,346		
Net surplus	293	1%	return on capital
Projected savings			
Bill savings (£)	3,471		
Carbon savings (t CO2)	168		

Summary - PV + Battery			
Income generated	72,322		
Capital repayment	-41,634		
Operating costs	-30,031		
Share interest	-17,486		
Net surplus	-16,830	-40%	return on capital
Projected savings			
Bill savings (£)	6,120		
Carbon savings (t CO2)	190		

Summary - Battery Alone			
Income generated	16,996		
Capital repayment	-17,000		
Operating costs	-11,242		
Share interest	-7,140		
Net surplus	-18,386	-108%	return on capital
Projected savings			
Bill savings (£)	2,649		
Carbon savings (t CO2)	22		

- We have updated GMCR's site viability template to include 3 options – PV only, PV + Battery, and Battery Alone (i.e. as an upgrade to existing PV). Inserting the generic model's outputs (for battery size and costs, and the self-consumption and energy timeshifting benefits it could deliver) for Site B yields the above results. These now incorporate GMCR's financing and administrative costs, assumptions about energy prices and carbon intensity, etc.
- Investing in a battery is clearly not viable, even though there are some additional carbon & bill savings for the site. Battery prices would need to reduce significantly, and/or returns would need to increase significantly, before investing in a battery for this site is viable.

Site B – Energy usage patterns

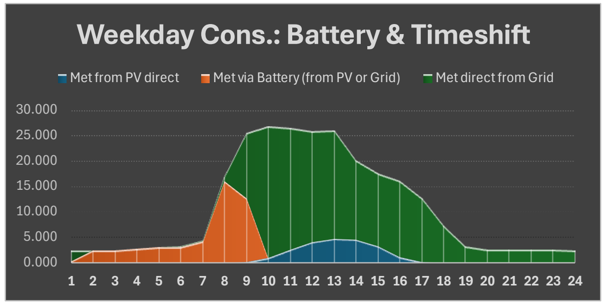
The next 2 slides show the average daily energy usage pattern for each month of the year, for weekdays and weekends respectively. These give a more detailed feel for how the PV energy and battery might be used.

The usage patterns are similar to those for Site A:

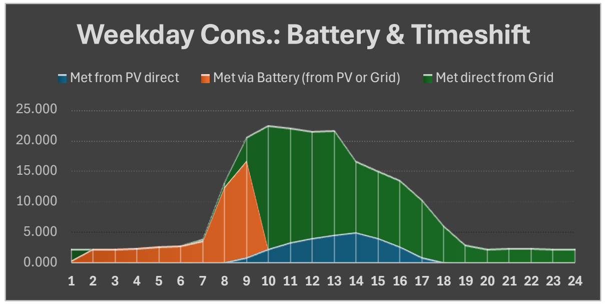
- The PV array does not generate enough energy to meet weekday energy consumption in winter, so the battery is used primarily to import energy from the grid at off-peak times and then use it to meet consumption in the morning.
- In shoulder seasons (Spring and Autumn), PV is able to meet consumption on some sunny weekdays. The battery captures any excess and uses it for the evening demand. It then captures another tranche of energy overnight, to meet demand the next morning.
- In summer, the PV is meeting demand during the day most weekdays, with sufficient excess to meet some evening demand. Again, the battery captures another tranche of energy overnight and uses this the next morning. However, it generally does not fully meet the morning demand as it is reserving space to capture excess PV generation in the middle of the day.
- Consumption is significantly lower in August. Demand is met almost entirely by self-consuming the PV generation, either directly during the day or via storage of excess energy in the battery overnight.
- Consumption at weekends is much lower. Demand is met almost entirely from the solar PV or from energy timeshifted from off-peak periods, with the proportion of self-consumption naturally being larger in the summer months. There is also some export from the PV array throughout the year, even on sunny weekend days in the middle of winter.
- (Again, note that the difference between weekday and weekend consumption sometimes leads to the battery storing too much energy overnight, thus reducing the amount of PV generation it can capture the next day and increasing exports at weekends. This is because the control algorithm does not have perfect foresight and so sometimes leaves insufficient reserve capacity in the battery. The model uses an algorithm that only slightly refines a basic “same as yesterday” forecast. This reflects real life performance of many battery controllers, but a controller with more sophisticated forecasting, e.g. using cloud-based AI, could probably do better.)

Site B – Weekday energy usage

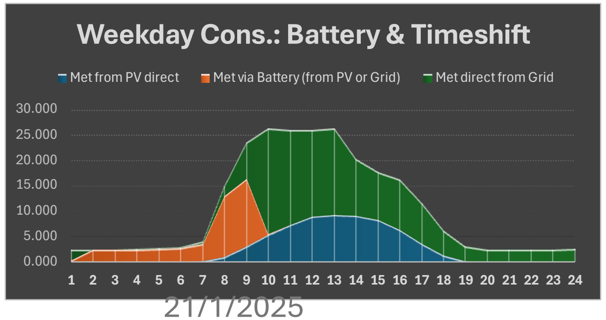
January



February



March



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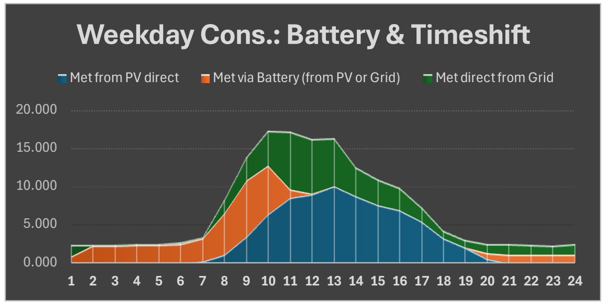
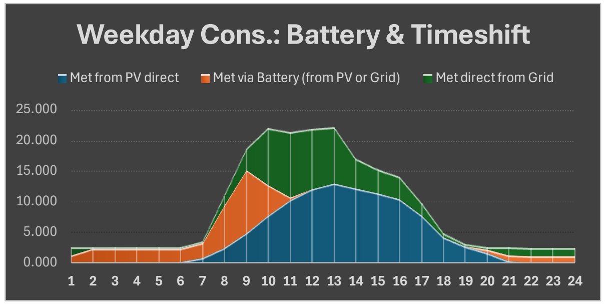
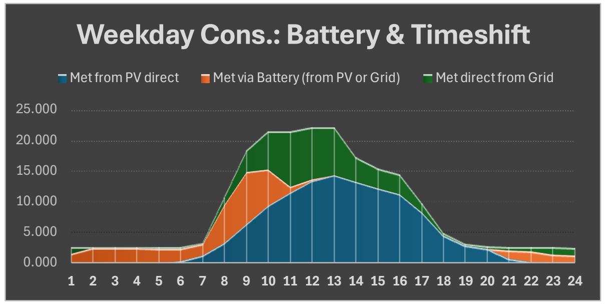


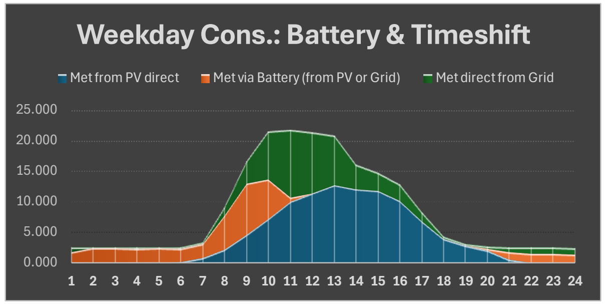
May



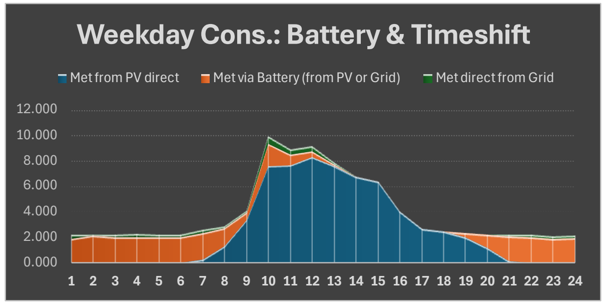
June



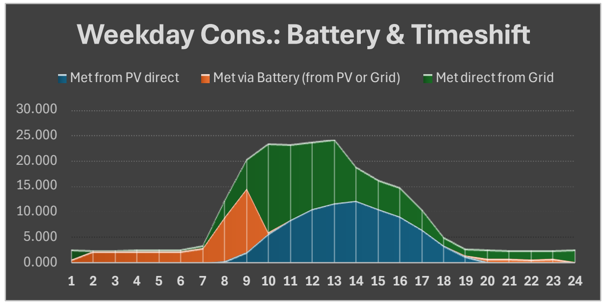
July



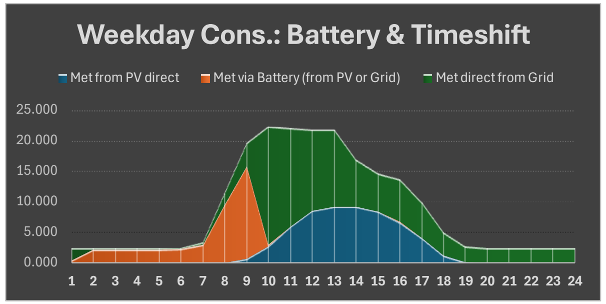
August



September



October



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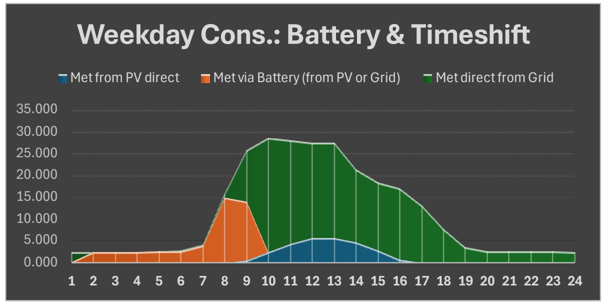
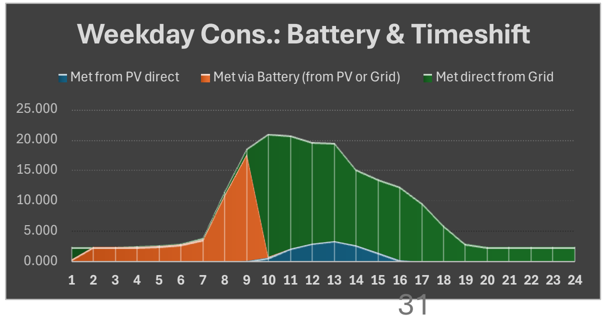
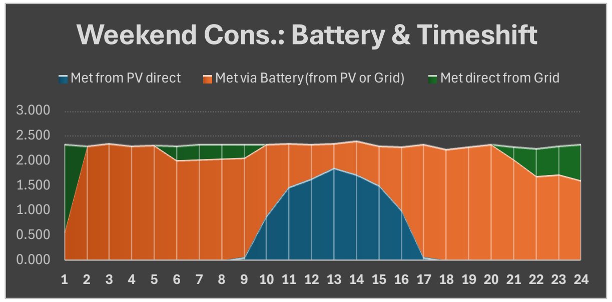


December

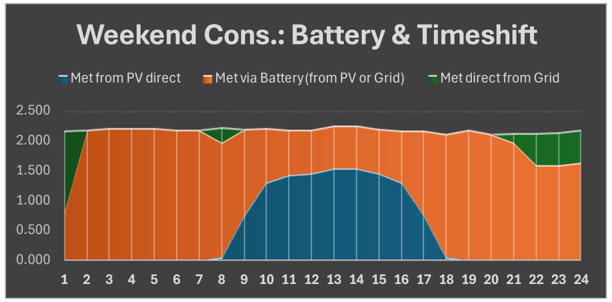


Site B – Weekend energy usage

January



February



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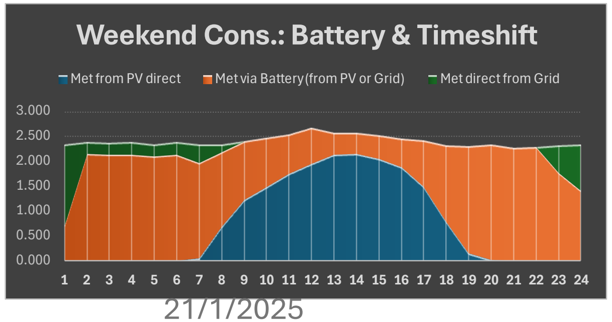

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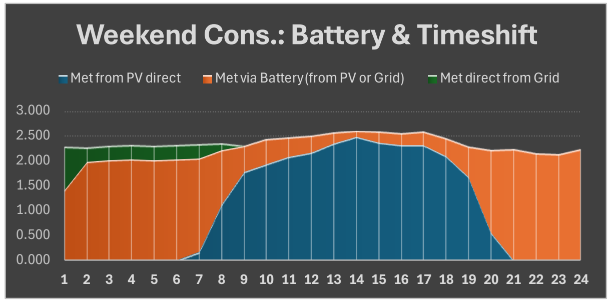
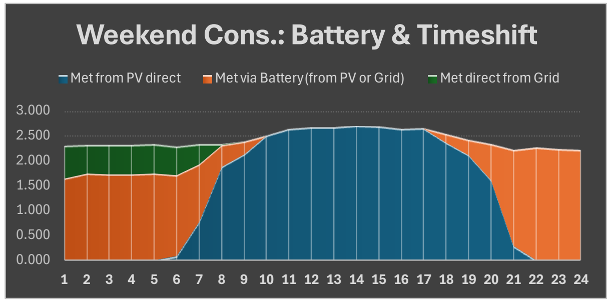
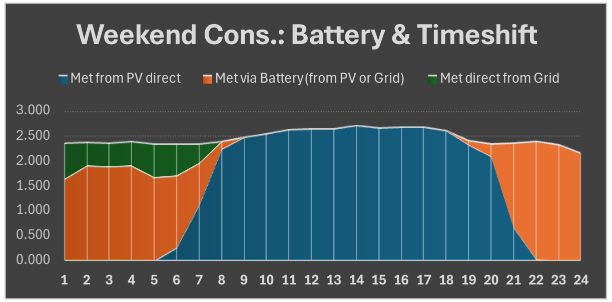


May



June



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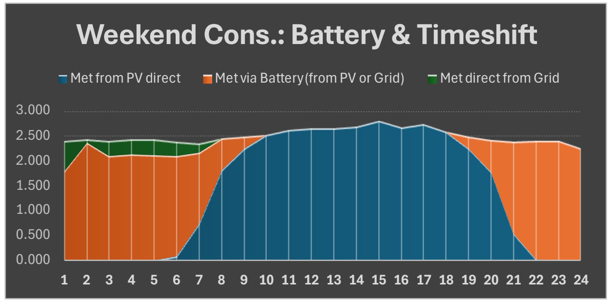

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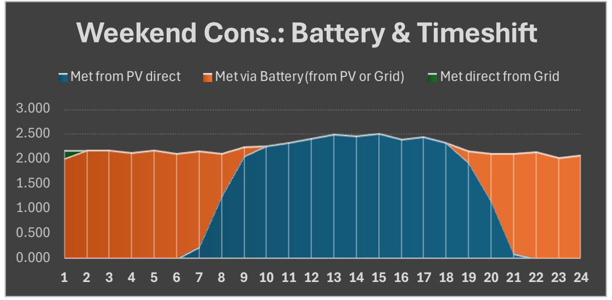

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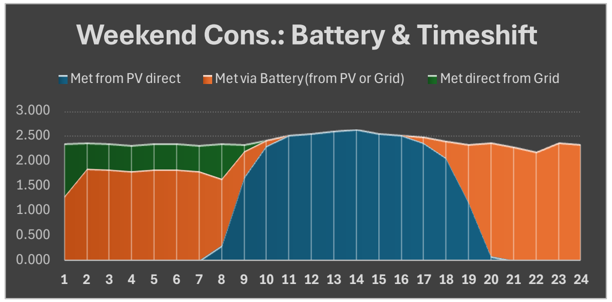

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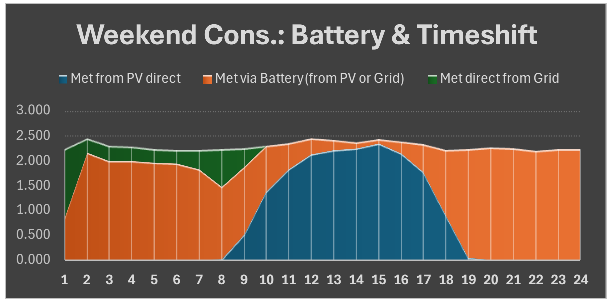
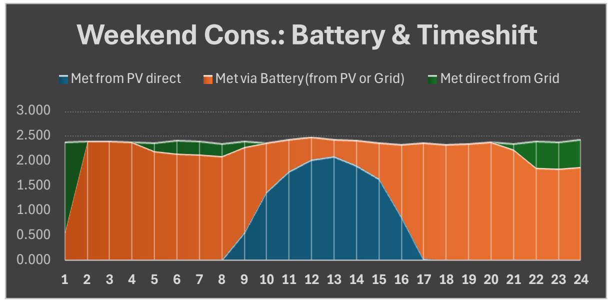
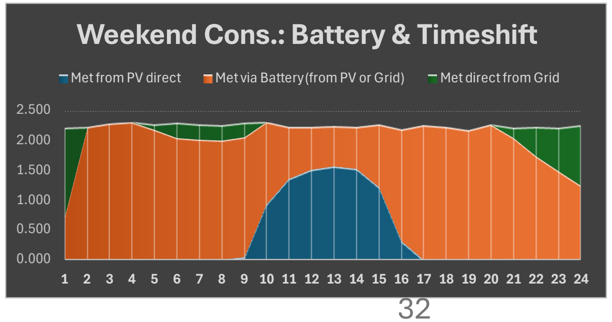


November



December



Site C

The following slides show key results for Site C.

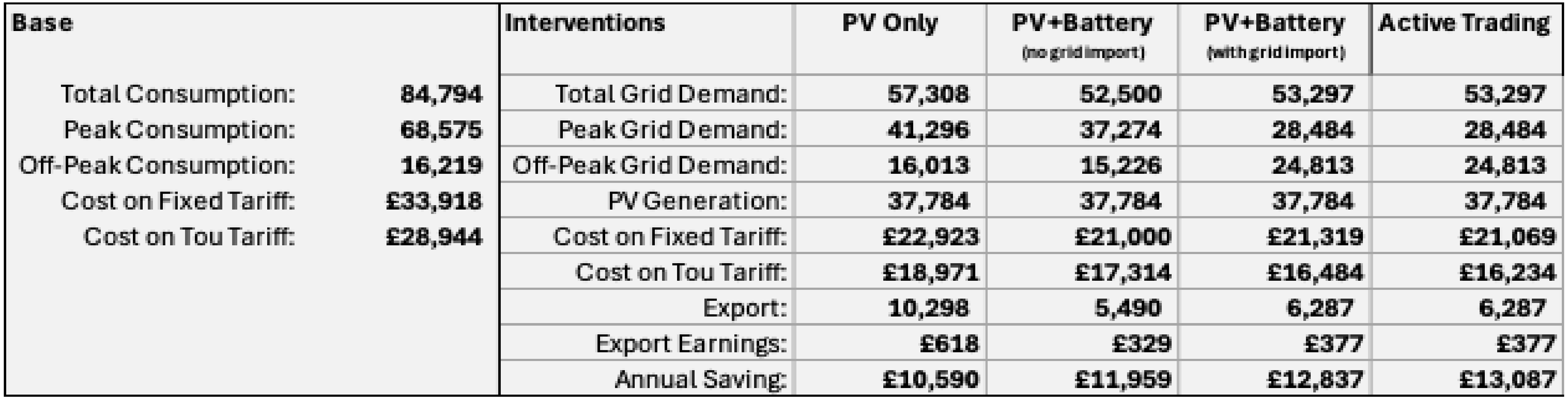
Full results are given in the accompanying spreadsheet, which contains the full model , input data, etc.

Note that:

a) We have used energy consumption and generation data for 1 April 2022 to 31 March 2024, downloaded from the SolarEdge portal for the site's PV system. Contiguous hourly data was only available for a 2-year period.
b) We have used actual peak and off-peak tariffs for the site. We have assumed that the off-peak period is from midnight to 7am.
c) We have not modelled a fixed tariff option for the site (i.e. we've set the fixed tariff artificially high so that it is never selected by the algorithm), as we did not have fixed tariff data.
d) We have used an export tariff that aligns to the rate GMCR uses in its site viability template.

Site C – Generic Scenario Summary

(does not account for financing costs and cost/benefit split between site and GMCR)



Base		Interventions	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading
Total Consumption:	84,794	Total Grid Demand:	57,308	52,500	53,297	53,297
Peak Consumption:	68,575	Peak Grid Demand:	41,296	37,274	28,484	28,484
Off-Peak Consumption:	16,219	Off-Peak Grid Demand:	16,013	15,226	24,813	24,813
Cost on Fixed Tariff:	£33,918	PV Generation:	37,784	37,784	37,784	37,784
Cost on Tou Tariff:	£28,944	Cost on Fixed Tariff:	£22,923	£21,000	£21,319	£21,069
		Cost on Tou Tariff:	£18,971	£17,314	£16,484	£16,234
		Export:	10,298	5,490	6,287	6,287
		Export Earnings:	£618	£329	£377	£377
		Annual Saving:	£10,590	£11,959	£12,837	£13,087

- We estimate the site's current PV array is reducing its energy costs by approx. £11k (37%) p.a., from £29k to £18k (after accounting for export earnings). A larger array might reduce these costs further, e.g. doubling the array size might take the saving to ~£18k (52%) p.a. and would be a reasonable investment. However, the current installation is again close to optimal (or perhaps slightly oversized) in terms of ROI.
- Adding a 40kWh battery would increase the saving to approx. £13k (45%) p.a. This would represent a moderate ROI, giving payback on the investment after approx. 8 years. The bulk of this benefit comes from increasing self-consumption of energy generated by the PV array, although an appreciable amount also comes from timeshifting consumption to off-peak. If the site is not able to access a Time-of-Use tariff or is unwilling to participate in at least simple trading schemes, then a battery is unlikely to pay back under current market conditions.

Site C – System Sizing for Generic Scenario

(does not account for financing costs and cost/benefit split between site and GMCR)

These tables show the annual saving and payback time (in years) that the site might achieve from a PV plus battery system for a range of array and battery sizes. (Note that they include the benefits of self-consumption and timeshifting but not active trading of the battery – these are explored on the next slide.)

It can be seen that the optimal return is achieved from a PV array that can generate 20-30kW[1] at peak and with no battery. Adding a battery increases the optimal size of the array slightly, e.g. pushing it to 40kW for an 60kWh battery. However, the optimum is broad and shallow, so batteries will work well with a range of PV array sizes (and vice versa). And the actual array that can be installed will also depend on the amount of roof space available, roof pitch and orientation, etc – the generic model does not take this into account.

Annual Saving

Size of Battery (kWh)

Size of PV Array (kWh generated in peak hour)	£12,837.19	0.000	10.000	20.000	30.000	40.000	50.000	60.000	80.000
	10.000	£3,429.47	£3,813.49	£4,197.50	£4,581.52	£4,965.54	£5,349.55	£5,733.57	£6,497.81
	20.000	£6,623.39	£7,093.09	£7,502.31	£7,897.06	£8,244.95	£8,606.10	£8,950.57	£9,607.58
	30.000	£8,905.24	£9,496.03	£10,020.78	£10,478.77	£10,871.76	£11,189.26	£11,456.05	£11,987.18
	40.000	£10,590.29	£11,260.66	£11,871.28	£12,416.61	£12,837.19	£13,236.01	£13,536.30	£13,976.57
	50.000	£11,971.36	£12,680.46	£13,327.95	£13,924.13	£14,409.69	£14,799.77	£15,179.17	£15,658.33
	60.000	£13,150.64	£13,909.46	£14,610.53	£15,225.87	£15,759.48	£16,178.35	£16,575.00	£17,142.22
	70.000	£14,215.81	£15,021.14	£15,752.45	£16,402.84	£16,920.77	£17,405.27	£17,821.46	£18,340.33
	80.000	£15,180.27	£16,013.29	£16,800.12	£17,450.52	£18,030.30	£18,513.46	£18,922.23	£19,488.94

Payback

Size of Battery (kWh)

Size of PV Array (kWh generated in peak hour)		0.000	10.000	20.000	30.000	40.000	50.000	60.000	80.000
	10.000	5.0	5.5	6.0	6.3	6.6	6.9	7.2	7.6
	20.000	4.1	4.4	4.7	4.9	5.2	5.5	5.7	6.1
	30.000	4.2	4.3	4.5	4.7	4.9	5.1	5.3	5.8
	40.000	4.4	4.5	4.6	4.8	4.9	5.1	5.2	5.7
	50.000	4.8	4.8	4.9	5.0	5.1	5.2	5.3	5.7
	60.000	5.1	5.1	5.1	5.2	5.3	5.4	5.5	5.8
	70.000	5.4	5.4	5.4	5.4	5.5	5.6	5.7	5.9
	80.000	5.7	5.7	5.7	5.7	5.7	5.8	5.9	6.1

---

[1] The generic model does not account for site-specific factors such as roof orientation: it calculates the peak generation the array needs to achieve. It is then a separate exercise to design an array that can deliver this output given the site's roof space, orientation and pitch, etc. This array will need a higher rated capacity to achieve the recommended peak generation. Site C's current array produces outputs that are well aligned to the optimum identified by the generic model.

Site C – Battery Sizing for Generic Scenario

(does not account for financing costs and cost/benefit split between site and GMCR)

These tables show the proportion of the annual saving that can be attributed to the battery, and the payback (in years) that this would yield for investing in the battery.

It can be seen that the optimum return is achieved for a 30-40kWh battery at the current PV array size. Increasing the size of the array improves the return on the battery, but the optimum size remains 30-40kWh. However, again the optimum is fairly broad, so there would be little lost if a common battery size were installed across several sites. (This would potentially improve your ability to negotiate discounted pricing on the batteries, and reduce maintenance overheads.)

Battery Saving with Trading		Size of Battery (kWh)							
	£2,496.58	5.000	10.000	20.000	30.000	40.000	50.000	60.000	80.000
Size of PV Array (kWh generated in peak hour)	10.000	£241.37	£486.44	£965.43	£1,417.49	£1,794.99	£2,188.04	£2,553.26	£3,300.82
	20.000	£296.40	£570.80	£1,070.47	£1,526.64	£1,867.05	£2,234.91	£2,563.63	£3,207.11
	30.000	£351.22	£693.22	£1,308.50	£1,829.85	£2,213.48	£2,534.54	£2,787.65	£3,313.79
	40.000	£391.26	£772.13	£1,476.74	£2,086.88	£2,496.58	£2,900.28	£3,178.97	£3,613.44
	50.000	£408.62	£811.77	£1,557.05	£2,215.97	£2,692.41	£3,083.13	£3,449.25	£3,914.21
	60.000	£436.40	£861.76	£1,659.54	£2,338.95	£2,864.04	£3,283.67	£3,668.92	£4,215.58
	70.000	£459.38	£906.74	£1,736.80	£2,448.79	£2,961.56	£3,446.66	£3,846.36	£4,346.23
	80.000	£469.95	£934.98	£1,819.29	£2,536.49	£3,105.87	£3,587.19	£3,982.52	£4,530.96

Battery Payback		Size of Battery (kWh)							
		5.000	10.000	20.000	30.000	40.000	50.000	60.000	80.000
Size of PV Array (kWh generated in peak hour)	10.000	29.0	18.5	13.5	12.0	11.7	11.4	11.4	11.2
	20.000	23.6	15.8	12.1	11.1	11.2	11.2	11.3	11.5
	30.000	19.9	13.0	9.9	9.3	9.5	9.9	10.4	11.2
	40.000	17.9	11.7	8.8	8.1	8.4	8.6	9.1	10.2
	50.000	17.1	11.1	8.3	7.7	7.8	8.1	8.4	9.5
	60.000	16.0	10.4	7.8	7.3	7.3	7.6	7.9	8.8
	70.000	15.2	9.9	7.5	6.9	7.1	7.3	7.5	8.5
	80.000	14.9	9.6	7.1	6.7	6.8	7.0	7.3	8.2

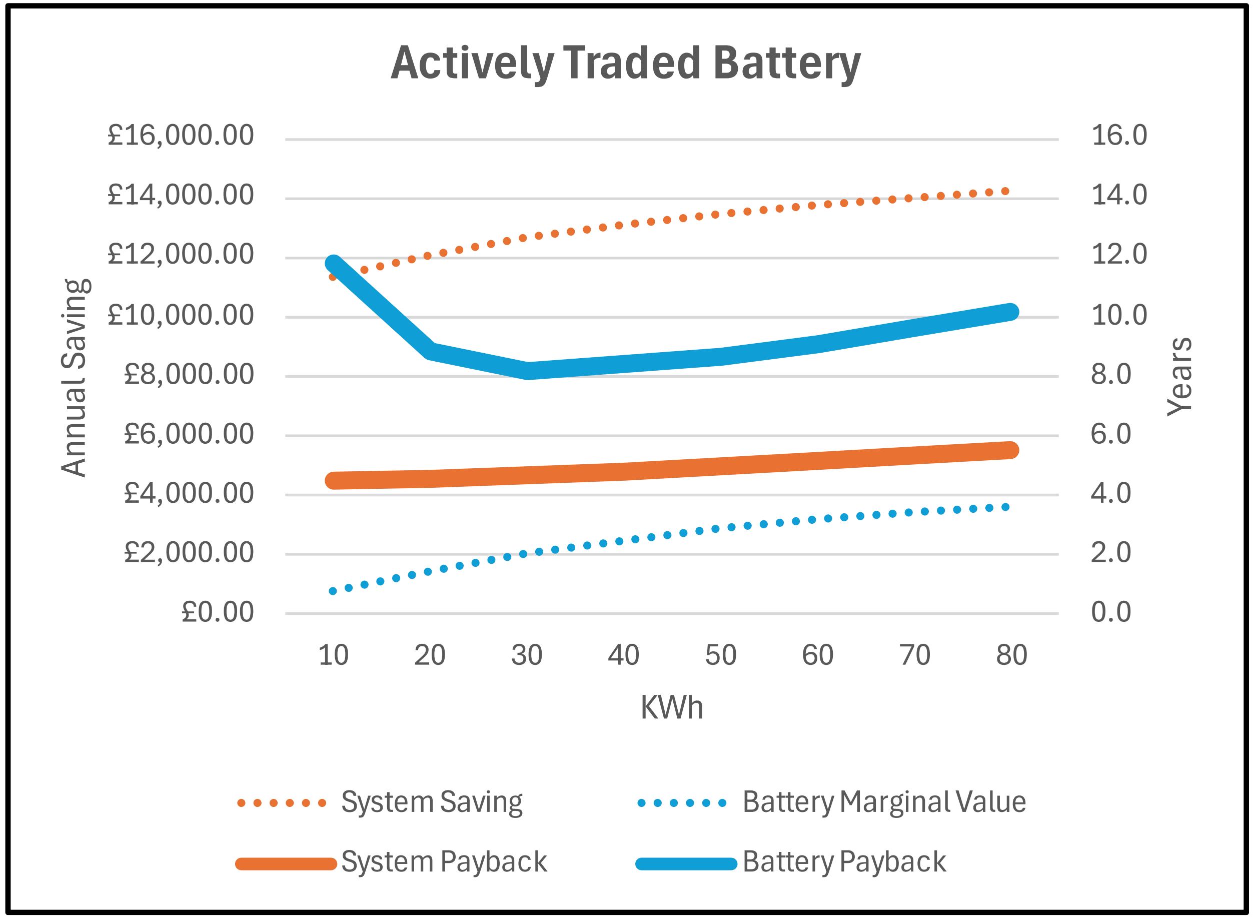
Site C – Battery Sizing for Generic Scenario

(does not account for financing costs and cost/benefit split between site and GMCR)

This again chart shows the value of adding a battery to the site's current PV array, separating the marginal value of the battery out from the overall site value.

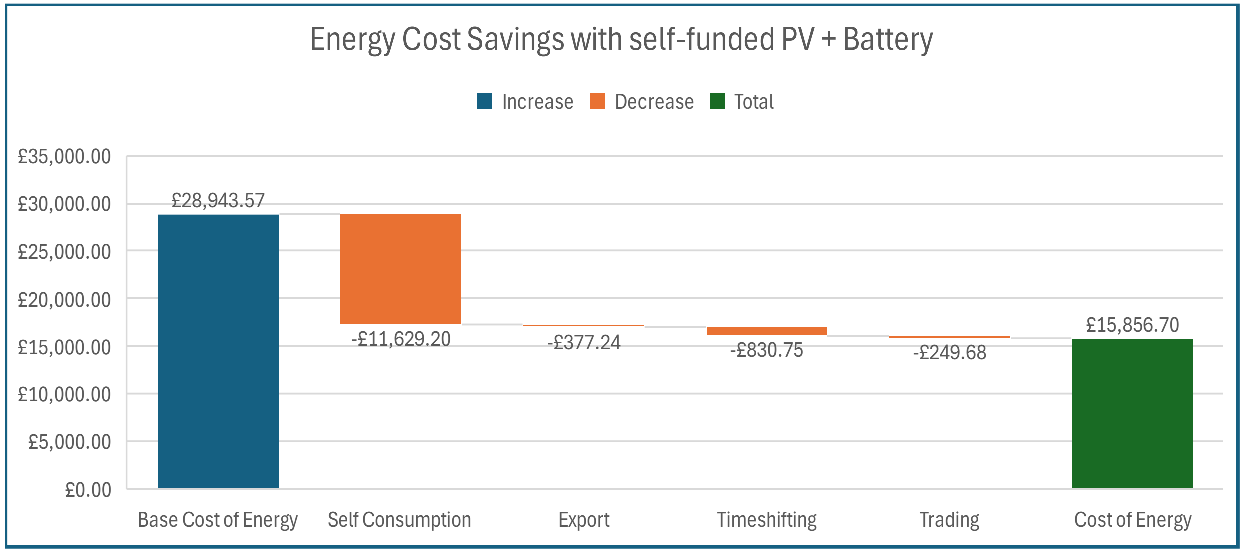
It can be seen that the optimal size for a battery on this site is about 30-40kWh, yielding an additional saving to the site's energy costs of about £2.5k p.a. c.f. the current costs with the PV array. This represents a payback of about 8 years, which is reasonable at current interest rates and not out of line with the expected life of such a battery.

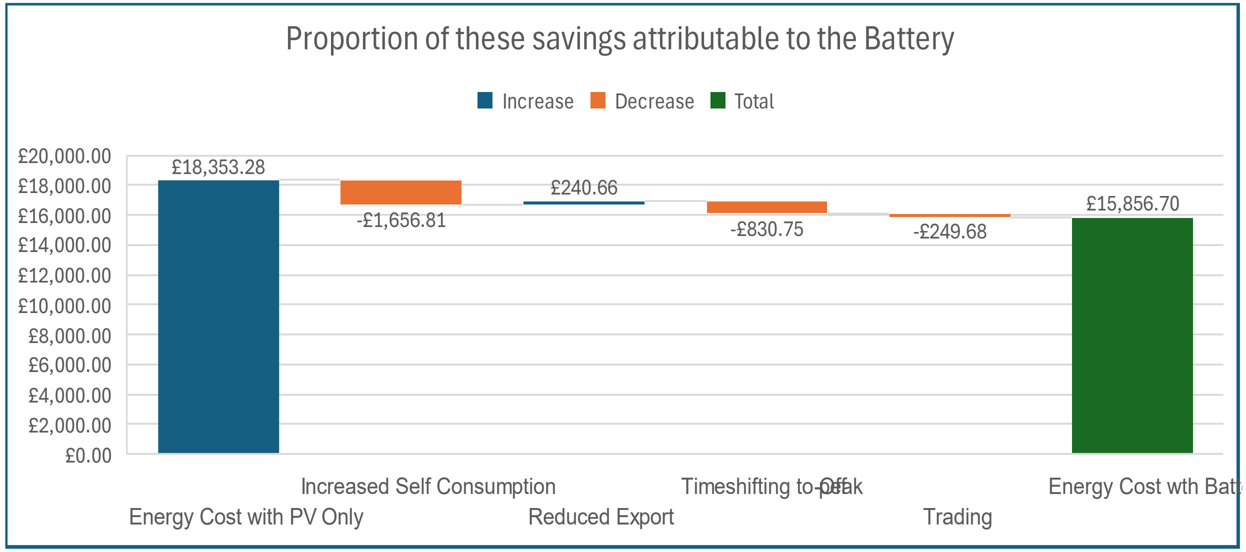
(However, note that this is for a self-funded scenario. The returns diminish when financing costs and sharing of benefits between the site and GMCR are considered, as can be seen in the site viability template in a few slides.)



Site C – Energy Cost Savings for battery purchased with own funds

(does not account for financing costs and cost/benefit split between site and GMCR)



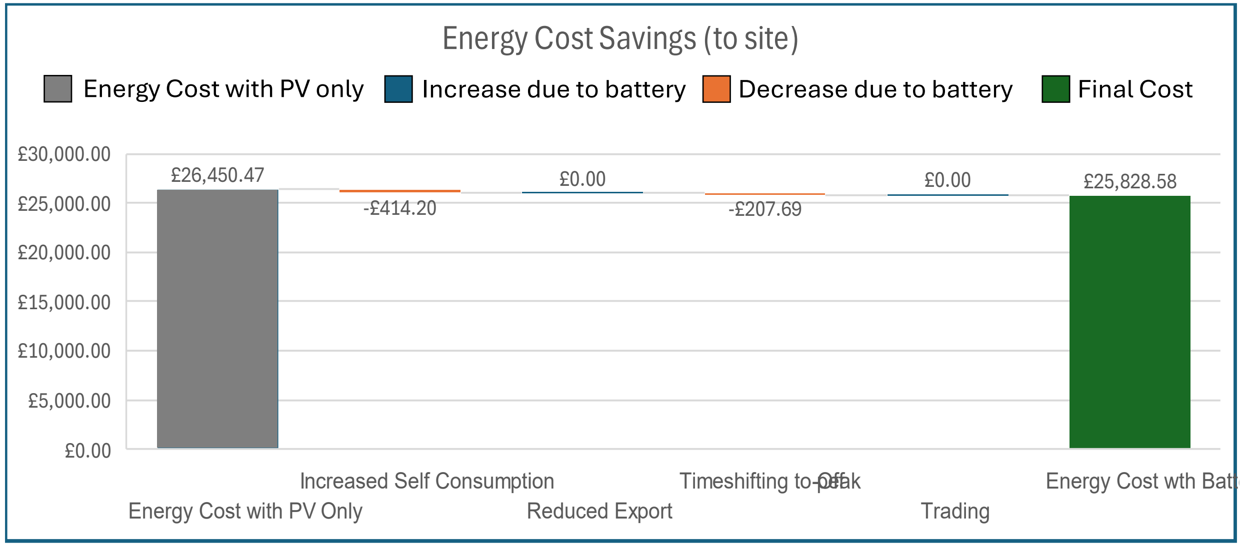


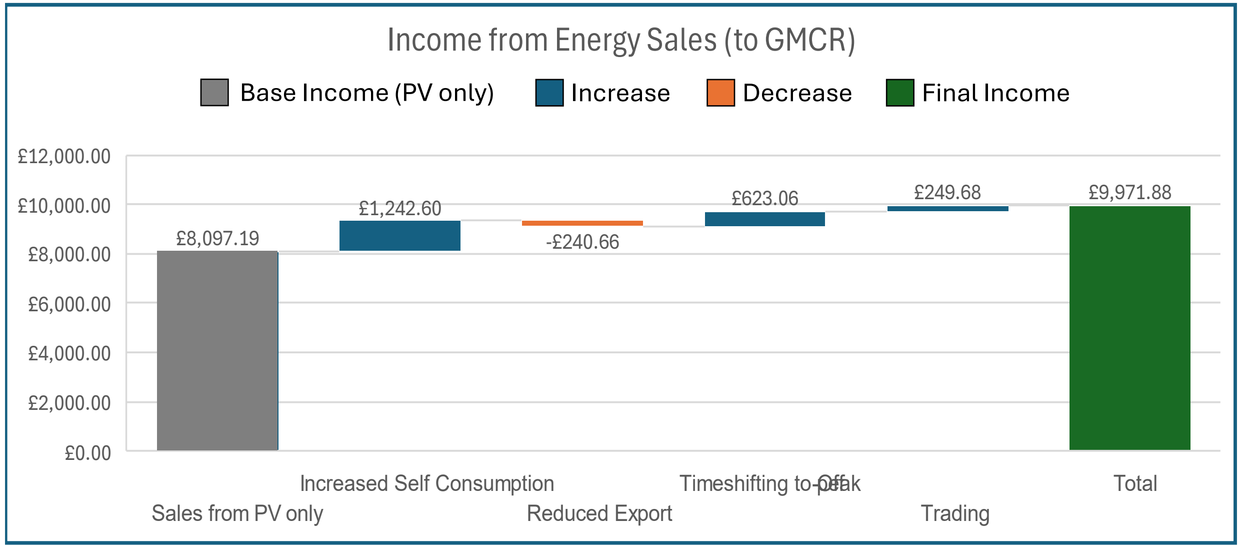
The bulk of the benefit from the PV+battery system comes from self-consumption of the energy generated by the PV array. The principal benefit of the battery is to increase this self-consumption by about £1.7k p.a.

That benefit is achieved at the cost of reducing the array's earnings from exporting to the grid by about £240p.a. Savings from timeshifting consumption to off-peak periods more than compensate for this cost. Then an additional small saving is generated from additional active trading of the battery.

Site C – Allocation of Benefits for GMCR-funded Battery

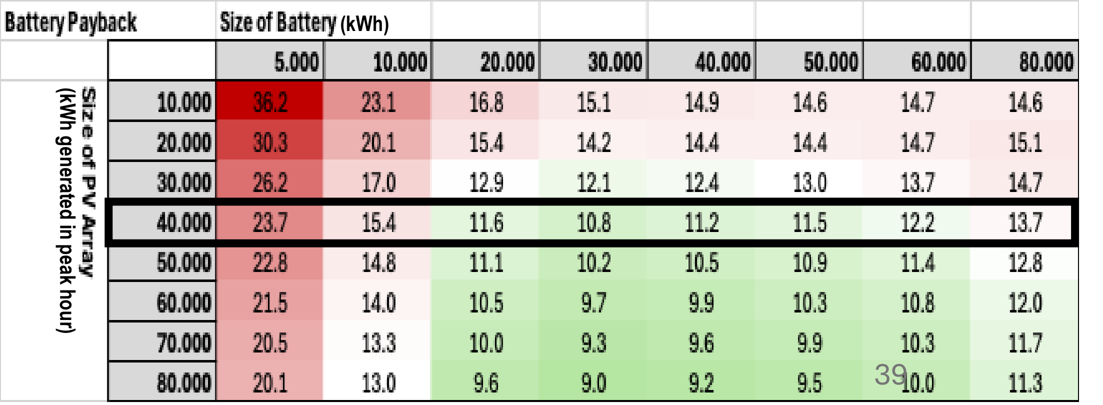
(does not account for financing costs)





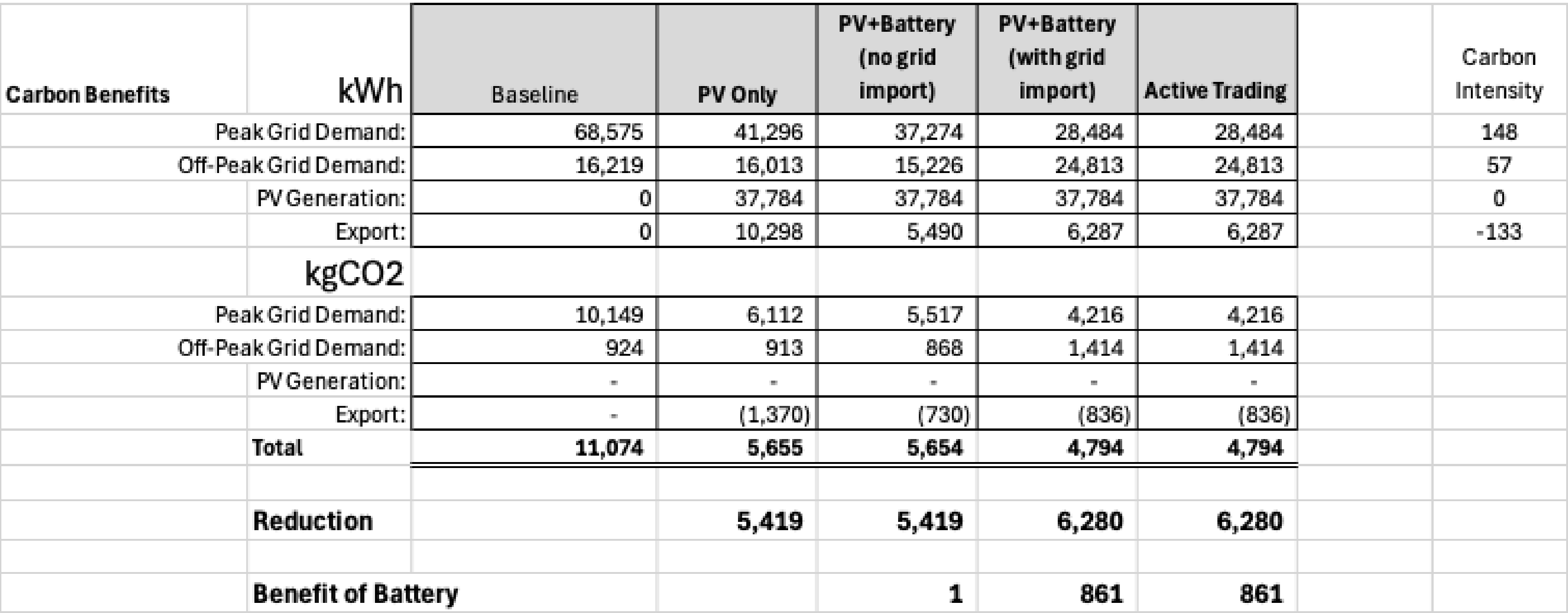
The previous slides identified the "DIY" benefits of the battery, i.e. assuming that the battery is owned by the party incurring the energy costs. In the case where GMCR owns the battery, these benefits will be split between it and the site.

These graphs show what this split might look like if GMCR captures 75% of the self-consumption and time-shifting benefit and 100% of the export and trading revenues. The table below shows the payback GMCR might achieve from these returns: installing a 40kWh battery alongside the current array would pay back after about 11 years. Payback improves for larger array sizes.



Battery Payback		Size of Battery (kWh)							
		5.000	10.000	20.000	30.000	40.000	50.000	60.000	80.000
Size of PV Array (kWh generated in peak hour)	10.000	36.2	23.1	16.8	15.1	14.9	14.6	14.7	14.6
	20.000	30.3	20.1	15.4	14.2	14.4	14.4	14.7	15.1
	30.000	26.2	17.0	12.9	12.1	12.4	13.0	13.7	14.7
	40.000	23.7	15.4	11.6	10.8	11.2	11.5	12.2	13.7
	50.000	22.8	14.8	11.1	10.2	10.5	10.9	11.4	12.8
	60.000	21.5	14.0	10.5	9.7	9.9	10.3	10.8	12.0
	70.000	20.5	13.3	10.0	9.3	9.6	9.9	10.3	11.7
	80.000	20.1	13.0	9.6	9.0	9.2	9.5	10.0	11.3

Site C – Carbon Savings

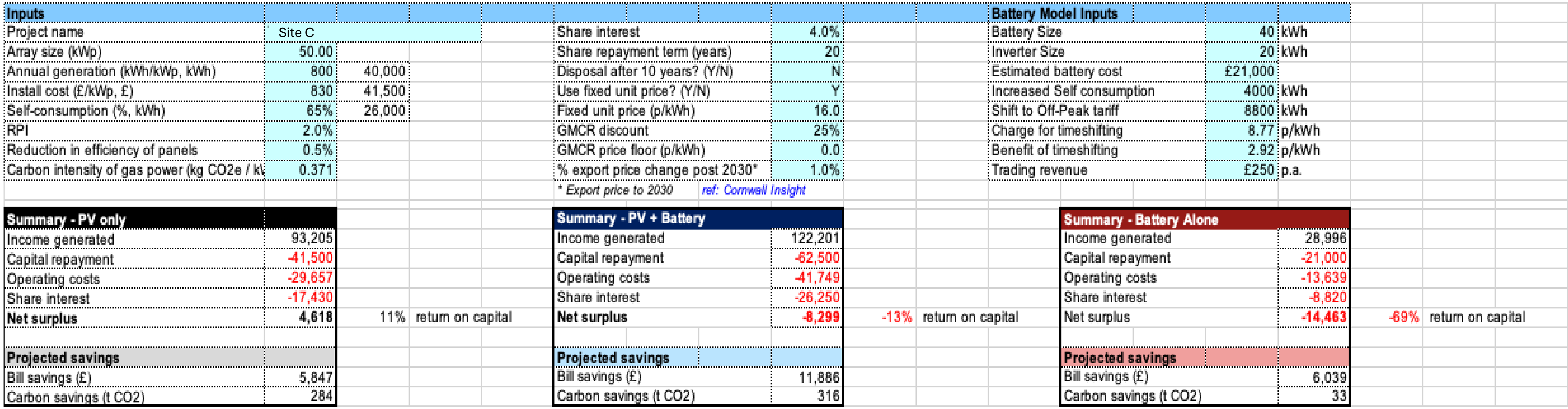


Carbon Benefits	kWh	Baseline	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading		Carbon Intensity
	Peak Grid Demand:	68,575	41,296	37,274	28,484	28,484		148
	Off-Peak Grid Demand:	16,219	16,013	15,226	24,813	24,813		57
	PV Generation:	0	37,784	37,784	37,784	37,784		0
	Export:	0	10,298	5,490	6,287	6,287		-133
	kgCO2							
	Peak Grid Demand:	10,149	6,112	5,517	4,216	4,216		
	Off-Peak Grid Demand:	924	913	868	1,414	1,414		
	PV Generation:	-	-	-	-	-		
	Export:	-	(1,370)	(730)	(836)	(836)		
	Total	**11,074**	**5,655**	**5,654**	**4,794**	**4,794**		
	Reduction		**5,419**	**5,419**	**6,280**	**6,280**		
	Benefit of Battery			**1**	**861**	**861**		

- We estimate that the battery yields an additional carbon saving of approx. 0.9 tCO2e p.a., primarily by time-shifting the site’s consumption to times when grid carbon intensity is lower.
- Note that these calculations are highly dependent on assumptions about grid carbon intensity and how the benefits of the PV array are accounted for. GMCR’s site viability model uses alternative assumptions.
- The calculations also do not account for the embedded carbon within the battery. These are dependent on the manufacturing process, shipping, etc. ChatGPT estimates them at 3.2tCO2e for a 40kWh battery.

Site C – Site Viability

(Based on GMCR’s site viability template for new sites, as updated to include battery storage options.)



Inputs		
Project name	Site C	
Array size (kWp)	50.00	
Annual generation (kWh/kWp, kWh)	800	40,000
Install cost (£/kWp, £)	830	41,500
Self-consumption (%, kWh)	65%	26,000
RPI	2.0%	
Reduction in efficiency of panels	0.5%	
Carbon intensity of gas power (kg CO2e / k	0.371	

Share interest	4.0%
Share repayment term (years)	20
Disposal after 10 years? (Y/N)	N
Use fixed unit price? (Y/N)	Y
Fixed unit price (p/kWh)	16.0
GMCR discount	25%
GMCR price floor (p/kWh)	0.0
% export price change post 2030*	1.0%

** Export price to 2030* *ref: Cornwall Insight*

Battery Model Inputs		
Battery Size	40	kWh
Inverter Size	20	kWh
Estimated battery cost	£21,000	
Increased Self consumption	4000	kWh
Shift to Off-Peak tariff	8800	kWh
Charge for timeshifting	8.77	p/kWh
Benefit of timeshifting	2.92	p/kWh
Trading revenue	£250	p.a.

Summary - PV only			
Income generated	93,205		
Capital repayment	-41,500		
Operating costs	-29,657		
Share interest	-17,430		
Net surplus	**4,618**	11%	return on capital
Projected savings			
Bill savings (£)	5,847		
Carbon savings (t CO2)	284		

Summary - PV + Battery			
Income generated	122,201		
Capital repayment	-62,500		
Operating costs	-41,749		
Share interest	-26,250		
Net surplus	**-8,299**	-13%	return on capital
Projected savings			
Bill savings (£)	11,886		
Carbon savings (t CO2)	316		

Summary - Battery Alone			
Income generated	28,996		
Capital repayment	-21,000		
Operating costs	-13,639		
Share interest	-8,820		
Net surplus	**-14,463**	-69%	return on capital
Projected savings			
Bill savings (£)	6,039		
Carbon savings (t CO2)	33		

- We have updated GMCR’s site viability template to include 3 options – PV only, PV + Battery, and Battery Alone (i.e. as an upgrade to existing PV). Inserting the generic model’s outputs (for battery size and costs, and the self-consumption and energy timeshifting benefits it could deliver) for Site C yields the above results. These now incorporate GMCR’s financing and administrative costs, assumptions about energy prices and carbon intensity, etc.
- Investing in a battery is clearly not viable, even though there are some additional carbon & bill savings for the site. Battery prices would need to reduce significantly, and/or returns would need to increase significantly, before investing in a battery for this site is viable.
- These calculations are very sensitive to the cost of the battery, and to the allocation of benefits between the site and GMCR. Reducing the battery cost by about 25% (which might be achievable if buying at scale, given current trends in battery costs) and allocating all of the timeshifting benefit to GMCR would yield a moderate positive return on the battery.

Site C – Energy usage patterns

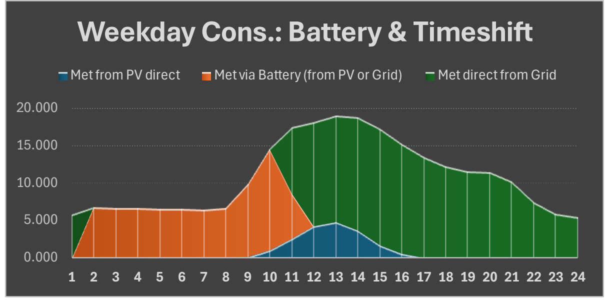
The next 2 slides show the average daily energy usage pattern for each month of the year, for weekdays and weekends respectively. These give a more detailed feel for how the PV energy and battery might be used.

The usage patterns show the following features:

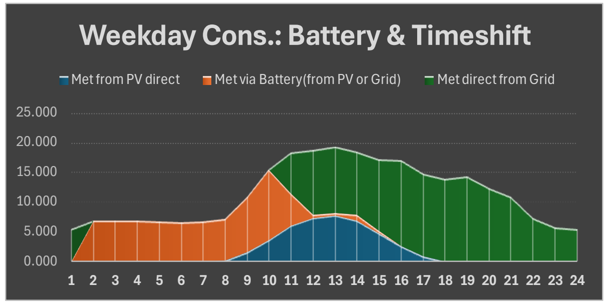
- In winter months, the PV array does not generate enough energy to meet demand on the site. This is true for both weekdays and weekends, even though consumption is slighty lower at weekends. The battery is used almost entirely to take low cost energy from the grid overnight and use it to meet demand during the day. (On weekdays the battery is empty by early afternoon. At weekends it tends to last into the evening.)
- Coming into Spring, the PV starts generating enough to meet demand during the day, especially at weekends. So the battery begins to capture some PV generation during the day, to use in early evening. It than captures a full load of energy from the grid overnight, to power the site in the morning and perhaps into the early afternoon.
- By early summer the PV array is generating enough to meet demand and fill the battery during the day. The stored energy is used to meet demand in the evening, then the battery is topped up from off-peak grid electricity overnight in order to help meet demand the next morning. However, the battery isn’t fully utilised in this second tranche, as the priority is to reserve space to ensure it can capture as much solar as possible the next afternoon. There is also significant export in the afternoon, once the battery is full. (This is sensitive to the specifics – e.g. in July, weekend daily usage goes above weekday usage and it becomes worthwhile to fully charge the battery overnight on weekends, as the PV cannot fully charge the battery during the day. But that applies only to July.)
- Then in Autumn we shift back to the pattern of Spring, where the battery is getting the best part of two cycles per day, charging from PV during the day and off-peak energy from the grid overnight.
- (As for the earlier sites, the model tends to slightly misallocate battery capacity at weekends due to forecasting errors. Again, this reflects real life performance of battery controllers which cannot have perfect foresight. But controllers with advanced AI-driven control algorithms may yield slightly better results.)

Site C – Weekday energy usage

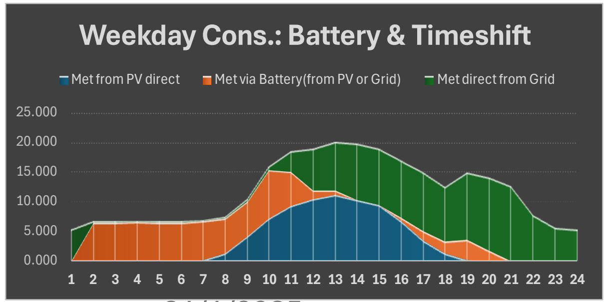
January



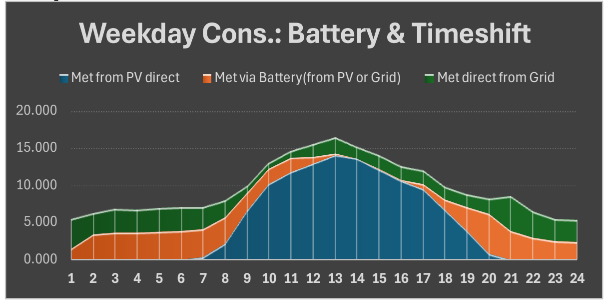
February



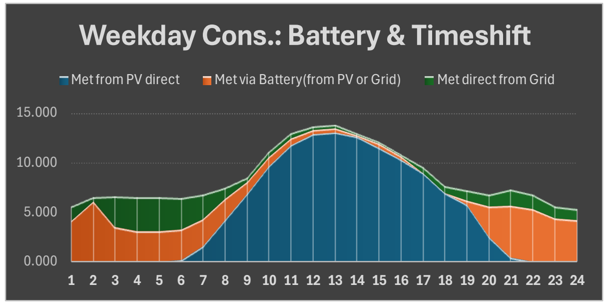
March



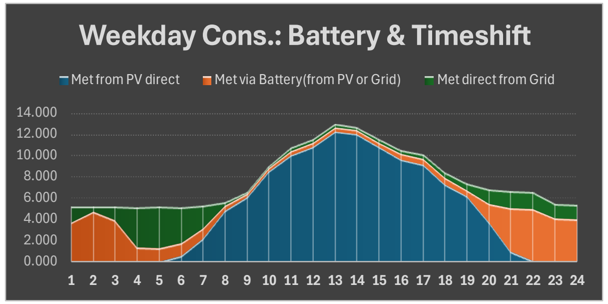
April



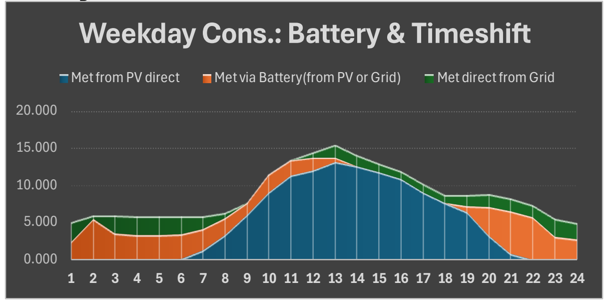
May



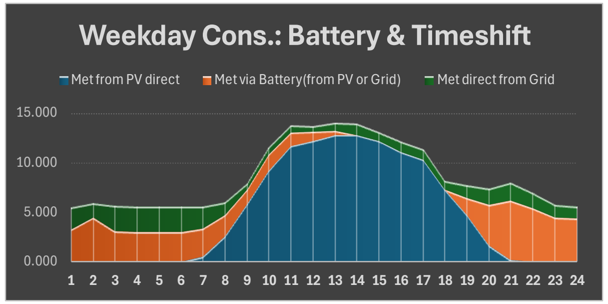
June



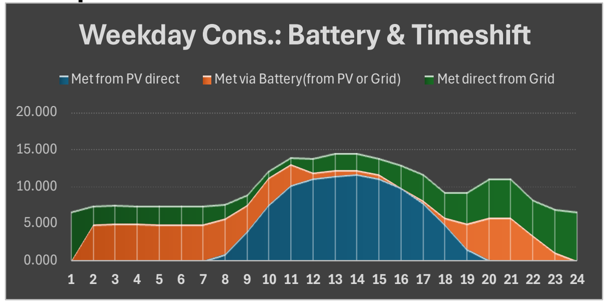
July



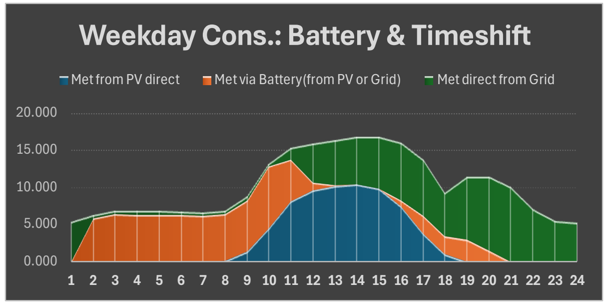
August



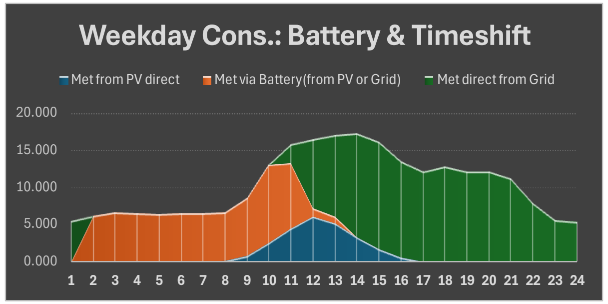
September



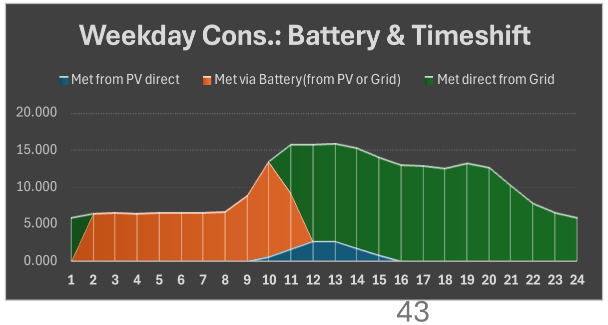
October



November

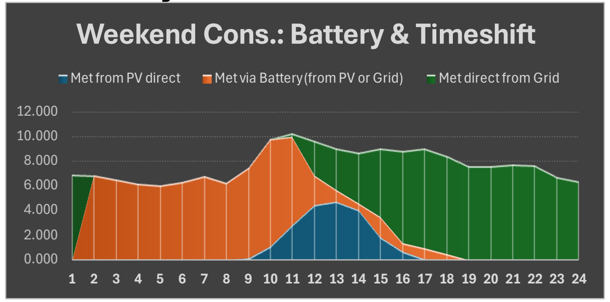


December

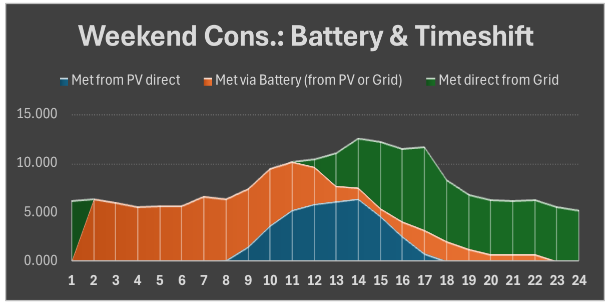


Site C – Weekend energy usage

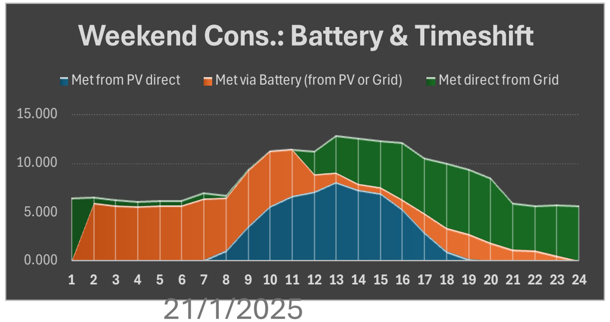
January



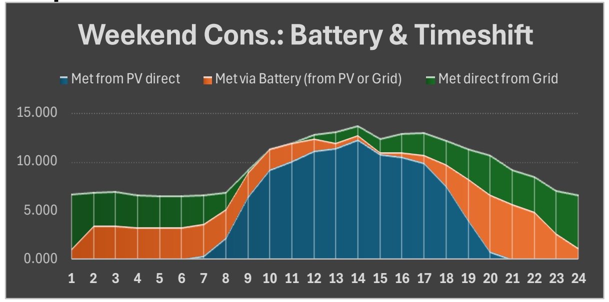
February



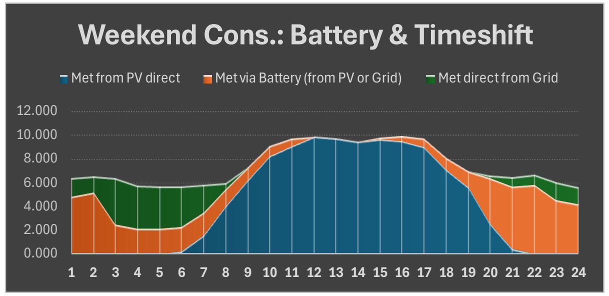
March



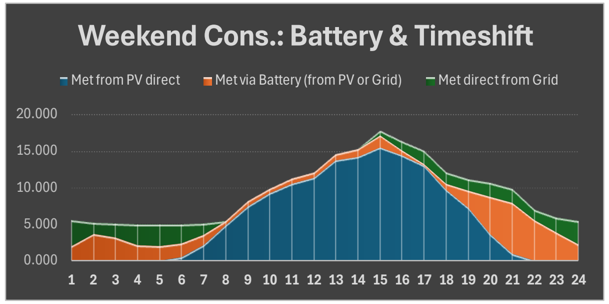
April



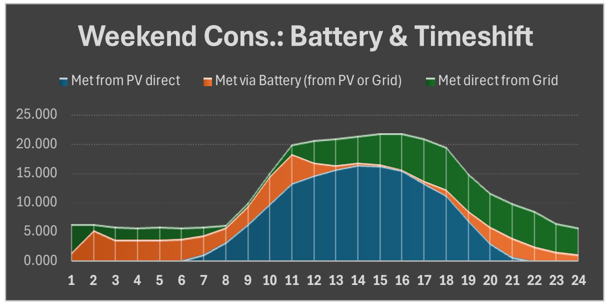
May



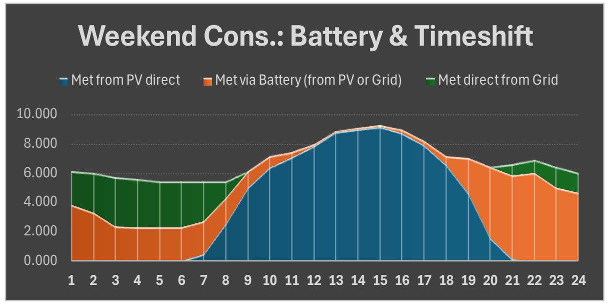
June



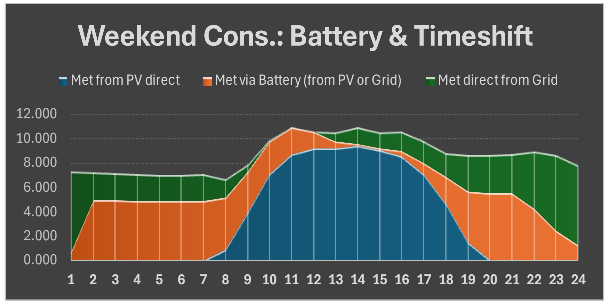
July



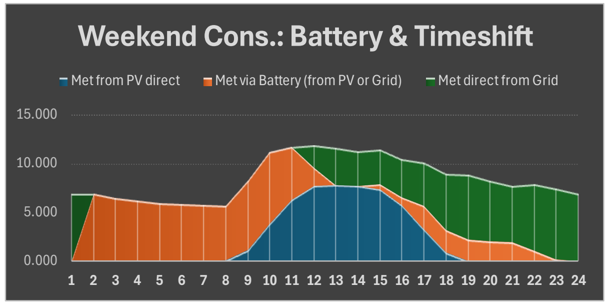
August



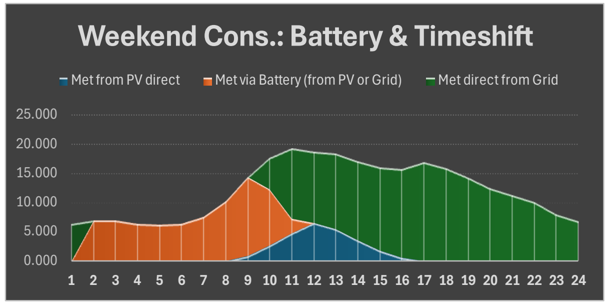
September



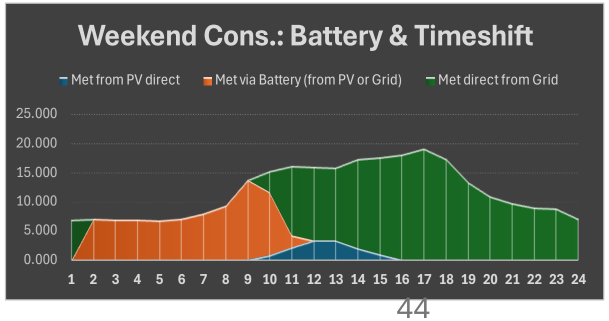
October



November



December



Site D

The following slides show key results for Site D.

Full results are given in the accompanying spreadsheet, which contains the full model , input data, etc.

Note that:

a) We have used energy consumption and generation data for 1 Sep 2021 to 31 Aug 2024, downloaded from the SolarEdge portal for the site's PV system. Hourly data was available for the full 3-year period.

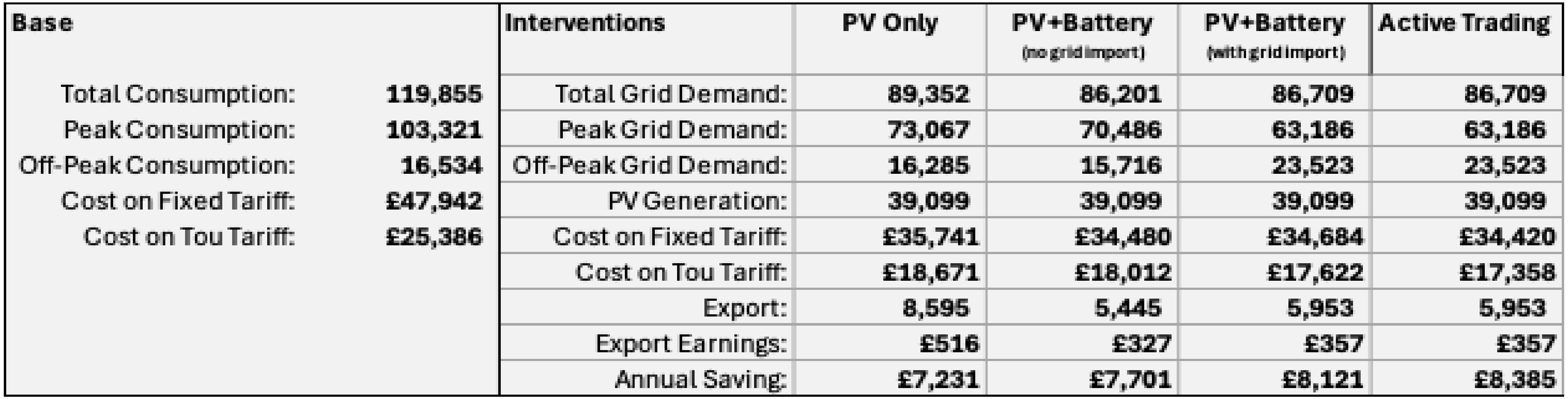
b) We have used actual peak and off-peak tariffs for the site. We have assumed that the off-peak period is from midnight to 7am.

c) We have not modelled a fixed tariff option for the site (i.e. we've set the fixed tariff artificially high so that it is never selected by the algorithm), as we did not have fixed tariff data.

d) We have used an export tariff that aligns to the rate GMCR uses in its site viability template.

Site D – Generic Scenario Summary

(does not account for financing costs and cost/benefit split between site and GMCR)



Base		Interventions	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading
Total Consumption:	119,855	Total Grid Demand:	89,352	86,201	86,709	86,709
Peak Consumption:	103,321	Peak Grid Demand:	73,067	70,486	63,186	63,186
Off-Peak Consumption:	16,534	Off-Peak Grid Demand:	16,285	15,716	23,523	23,523
Cost on Fixed Tariff:	£47,942	PV Generation:	39,099	39,099	39,099	39,099
Cost on Tou Tariff:	£25,386	Cost on Fixed Tariff:	£35,741	£34,480	£34,684	£34,420
		Cost on Tou Tariff:	£18,671	£18,012	£17,622	£17,358
		Export:	8,595	5,445	5,953	5,953
		Export Earnings:	£516	£327	£357	£357
		Annual Saving:	£7,231	£7,701	£8,121	£8,385

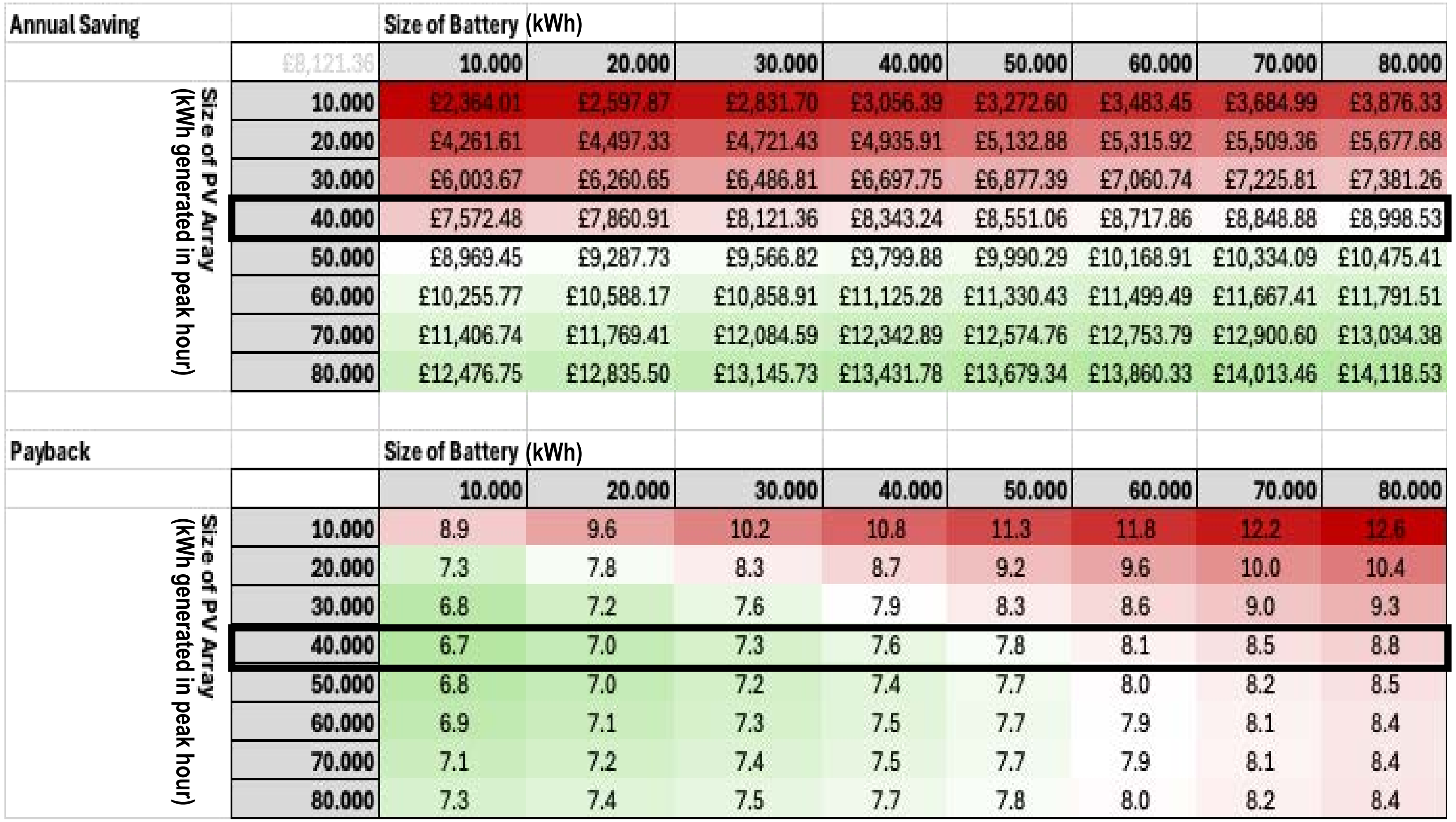
- We estimate the site's current PV array is reducing its energy costs by approx. £7.2k (28%) p.a., from £25k to £18k (after accounting for export earnings). A larger array might reduce these costs further, e.g. doubling the array size might take the saving to ~£12k (48%) p.a., and would be a reasonable investment. However, the current installation is again close to optimal in terms of ROI.
- Adding a 30kWh battery would increase the saving to approx. £8.4k (33%) p.a. This does not represent an especially attractive ROI, giving payback after approx. 15 years. The bulk of this benefit comes from increasing self-consumption of energy generated by the PV array. There is also a reasonable benefit from timeshifting consumption to off-peak tariffs, and from trading the battery actively on energy and flex markets.

Site D – System Sizing for Generic Scenario

(does not account for financing costs and cost/benefit split between site and GMCR)

These tables show the annual saving and payback time (in years) that the site might achieve from a PV plus battery system for a range of array and battery sizes. (Note that they include the benefits of self-consumption and timeshifting but not active trading of the battery – these are explored on the next slide.)

It can be seen that the optimal return is achieved from a PV array that can generate ~40kW[1] at peak and with no battery. Adding a battery increases the optimal size of the array, e.g. pushing it to ~50kW for a 30kWh battery and ~60kW for an 80kWh battery. However, the optimum is broad and shallow, so the batteries will work well with a range of PV array sizes. And again, the actual array that can be installed will also depend on the amount of roof space available, roof pitch and orientation, etc – the generic model does not take this into account.



Annual Saving

Size of PV Array (kWh generated in peak hour)	£8,121.36	Size of Battery (kWh) 10.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000
	10.000	£2,364.01	£2,597.87	£2,831.70	£3,056.39	£3,272.60	£3,483.45	£3,684.99	£3,876.33
	20.000	£4,261.61	£4,497.33	£4,721.43	£4,935.91	£5,132.88	£5,315.92	£5,509.36	£5,677.68
	30.000	£6,003.67	£6,260.65	£6,486.81	£6,697.75	£6,877.39	£7,060.74	£7,225.81	£7,381.26
	40.000	£7,572.48	£7,860.91	£8,121.36	£8,343.24	£8,551.06	£8,717.86	£8,848.88	£8,998.53
	50.000	£8,969.45	£9,287.73	£9,566.82	£9,799.88	£9,990.29	£10,168.91	£10,334.09	£10,475.41
	60.000	£10,255.77	£10,588.17	£10,858.91	£11,125.28	£11,330.43	£11,499.49	£11,667.41	£11,791.51
	70.000	£11,406.74	£11,769.41	£12,084.59	£12,342.89	£12,574.76	£12,753.79	£12,900.60	£13,034.38
	80.000	£12,476.75	£12,835.50	£13,145.73	£13,431.78	£13,679.34	£13,860.33	£14,013.46	£14,118.53

Payback

Size of PV Array (kWh generated in peak hour)		Size of Battery (kWh) 10.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000
	10.000	8.9	9.6	10.2	10.8	11.3	11.8	12.2	12.6
	20.000	7.3	7.8	8.3	8.7	9.2	9.6	10.0	10.4
	30.000	6.8	7.2	7.6	7.9	8.3	8.6	9.0	9.3
	40.000	6.7	7.0	7.3	7.6	7.8	8.1	8.5	8.8
	50.000	6.8	7.0	7.2	7.4	7.7	8.0	8.2	8.5
	60.000	6.9	7.1	7.3	7.5	7.7	7.9	8.1	8.4
	70.000	7.1	7.2	7.4	7.5	7.7	7.9	8.1	8.4
	80.000	7.3	7.4	7.5	7.7	7.8	8.0	8.2	8.4

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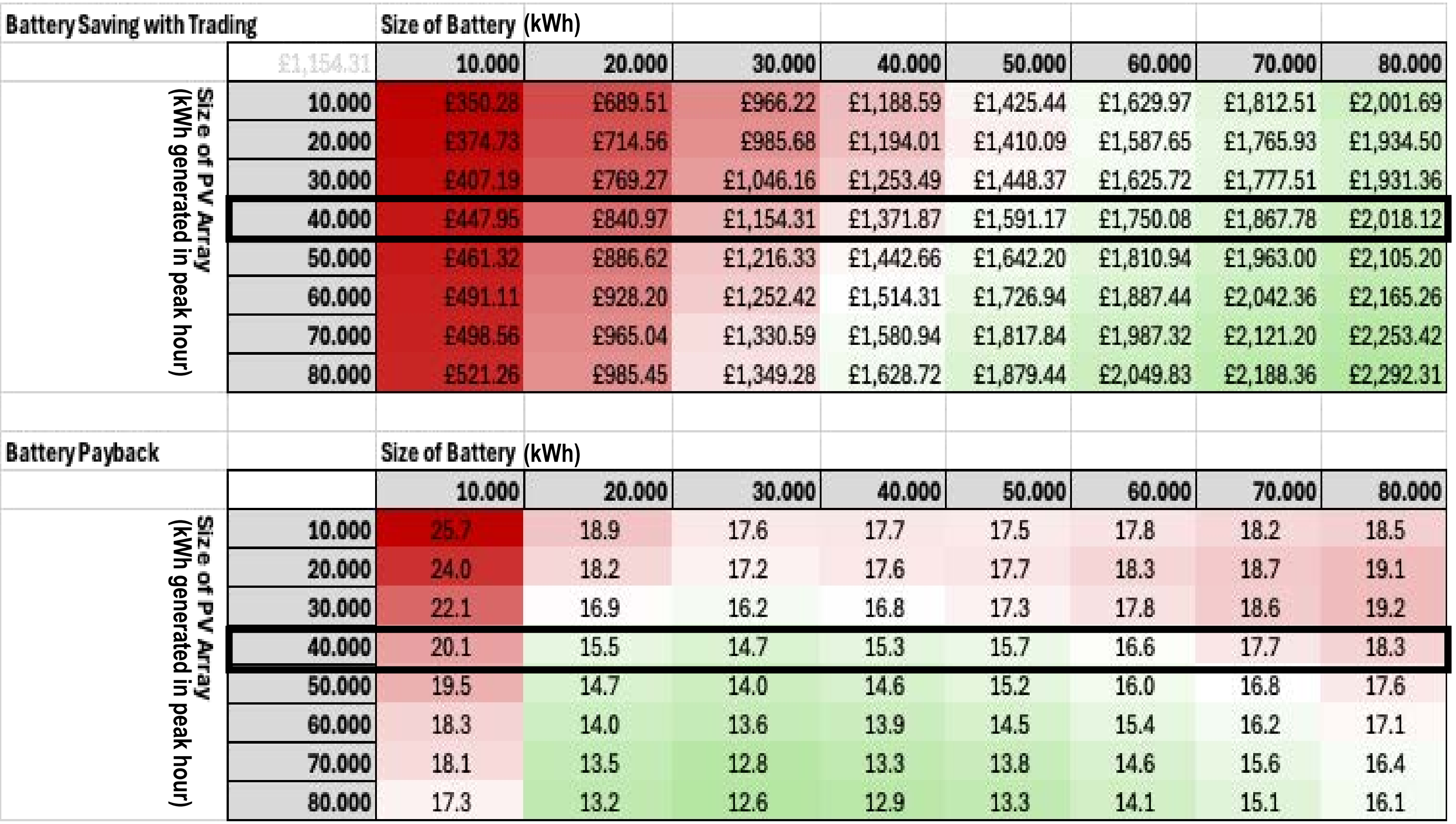
[1] The generic model does not account for site-specific factors such as roof orientation: it calculates the peak generation the array needs to achieve. It is then a separate exercise to design an array that can deliver this output given the site's roof space, orientation and pitch, etc. This array will need a higher rated capacity to achieve the recommended peak generation. Site D's current array produces outputs that are well aligned to the optimum identified by the generic model.

Site D – Battery Sizing for Generic Scenario

(does not account for financing costs and cost/benefit split between site and GMCR)

These tables show the proportion of the annual saving that can be attributed to the battery, and the payback (in years) that this would yield for investing in the battery.

It can be seen that the optimum return is achieved for a 30kWh battery at the current PV array size. Increasing the size of the array improves the return on the battery, but the optimum size remains ~30kWh. However, again the optimum is fairly broad, so there would be little lost if a common battery size were installed across several aites. (This would potentially improve your ability to negotiate discounted pricing on the batteries, and reduce maintenance overheads.)



Battery Saving with Trading		Size of Battery (kWh)							
	£1,154.31	10.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000
Size of PV Array (kWh generated in peak hour)	10.000	£350.28	£689.51	£966.22	£1,188.59	£1,425.44	£1,629.97	£1,812.51	£2,001.69
	20.000	£374.73	£714.56	£985.68	£1,194.01	£1,410.09	£1,587.65	£1,765.93	£1,934.50
	30.000	£407.19	£769.27	£1,046.16	£1,253.49	£1,448.37	£1,625.72	£1,777.51	£1,931.36
	40.000	£447.95	£840.97	£1,154.31	£1,371.87	£1,591.17	£1,750.08	£1,867.78	£2,018.12
	50.000	£461.32	£886.62	£1,216.33	£1,442.66	£1,642.20	£1,810.94	£1,963.00	£2,105.20
	60.000	£491.11	£928.20	£1,252.42	£1,514.31	£1,726.94	£1,887.44	£2,042.36	£2,165.26
	70.000	£498.56	£965.04	£1,330.59	£1,580.94	£1,817.84	£1,987.32	£2,121.20	£2,253.42
	80.000	£521.26	£985.45	£1,349.28	£1,628.72	£1,879.44	£2,049.83	£2,188.36	£2,292.31

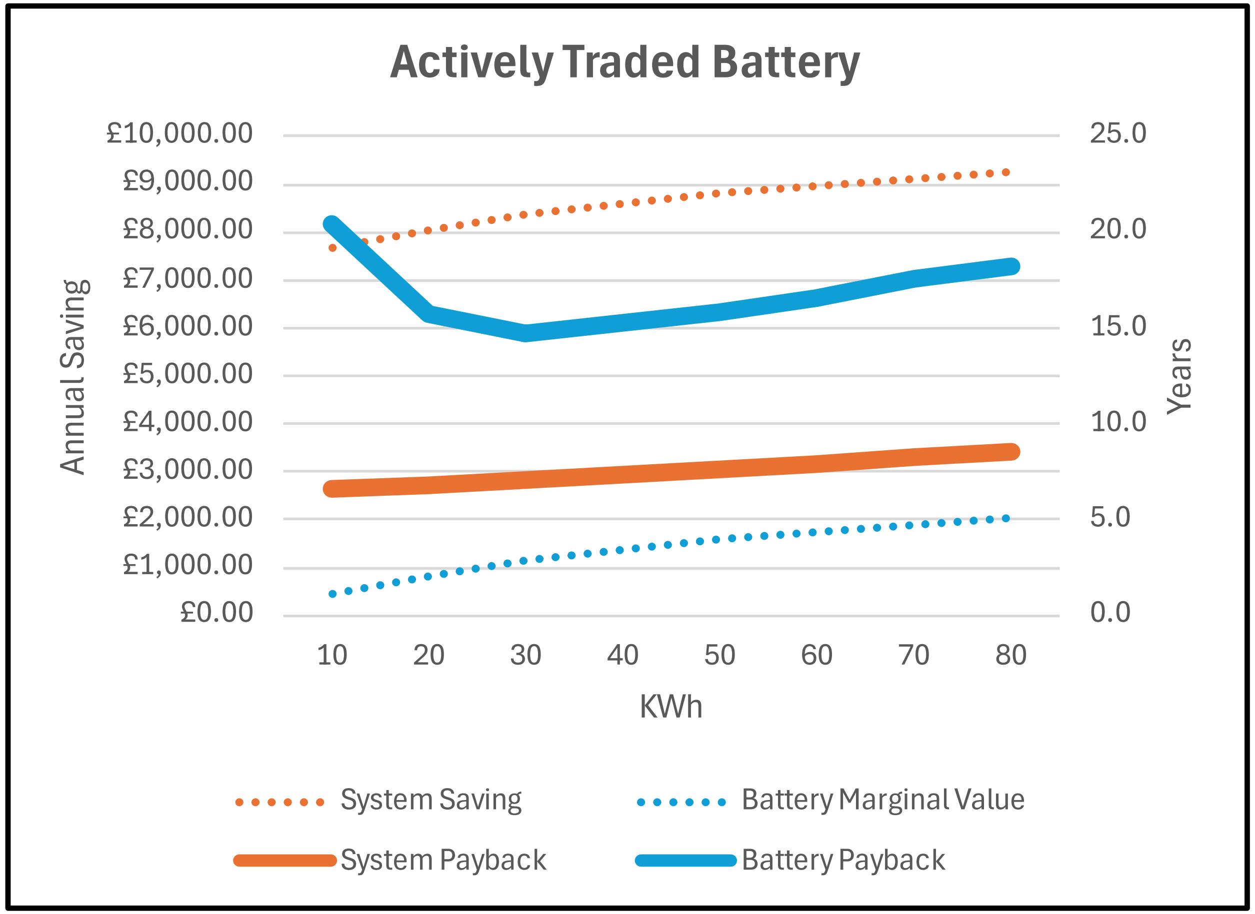
Battery Payback		Size of Battery (kWh)							
		10.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000
Size of PV Array (kWh generated in peak hour)	10.000	25.7	18.9	17.6	17.7	17.5	17.8	18.2	18.5
	20.000	24.0	18.2	17.2	17.6	17.7	18.3	18.7	19.1
	30.000	22.1	16.9	16.2	16.8	17.3	17.8	18.6	19.2
	40.000	20.1	15.5	14.7	15.3	15.7	16.6	17.7	18.3
	50.000	19.5	14.7	14.0	14.6	15.2	16.0	16.8	17.6
	60.000	18.3	14.0	13.6	13.9	14.5	15.4	16.2	17.1
	70.000	18.1	13.5	12.8	13.3	13.8	14.6	15.6	16.4
	80.000	17.3	13.2	12.6	12.9	13.3	14.1	15.1	16.1

Site D – Battery Sizing for Generic Scenario

(does not account for financing costs and cost/benefit split between site and GMCR)

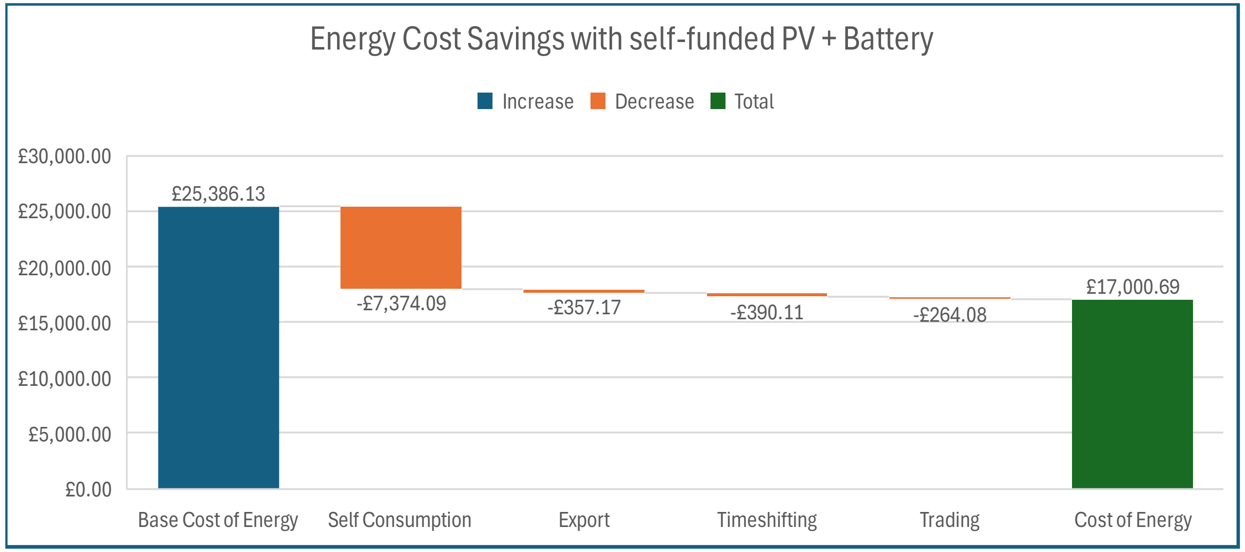
This chart again shows the value of adding a battery to the site's current PV array, separating the marginal value of the battery out from the overall site value.

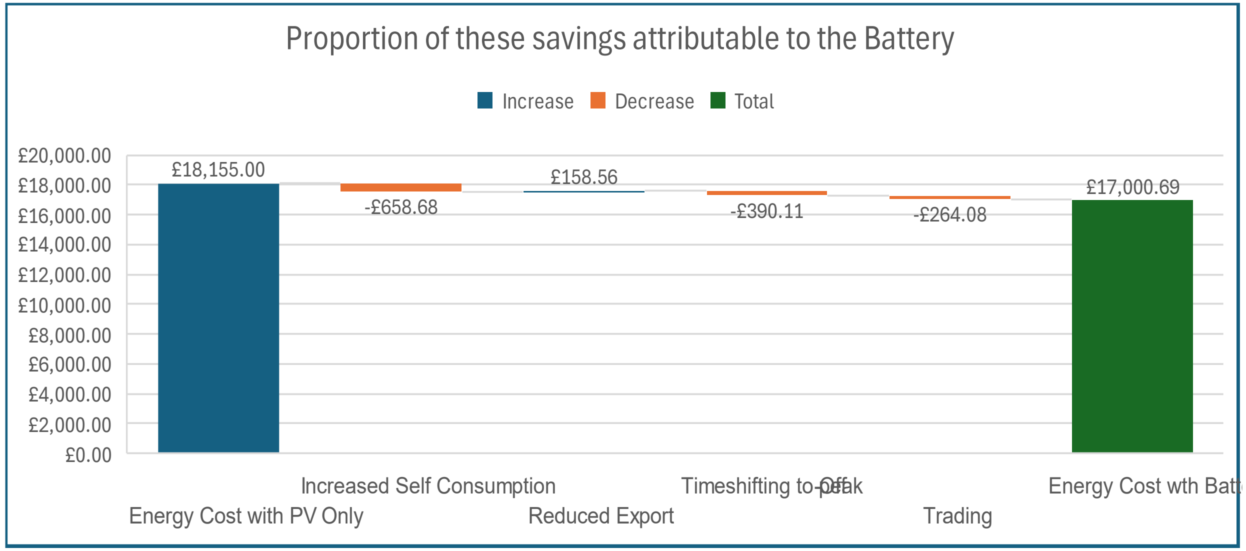
It can be seen that the optimal size for a battery on this site is about 30kWh, yielding an additional saving to the site's energy costs of about £1.1k p.a. c.f. the current costs with the PV array. This represents a payback of about 15 years, which is not especially attractive.



Site D – Energy Cost Savings for battery purchased with own funds

(does not account for financing costs and cost/benefit split between site and GMCR)



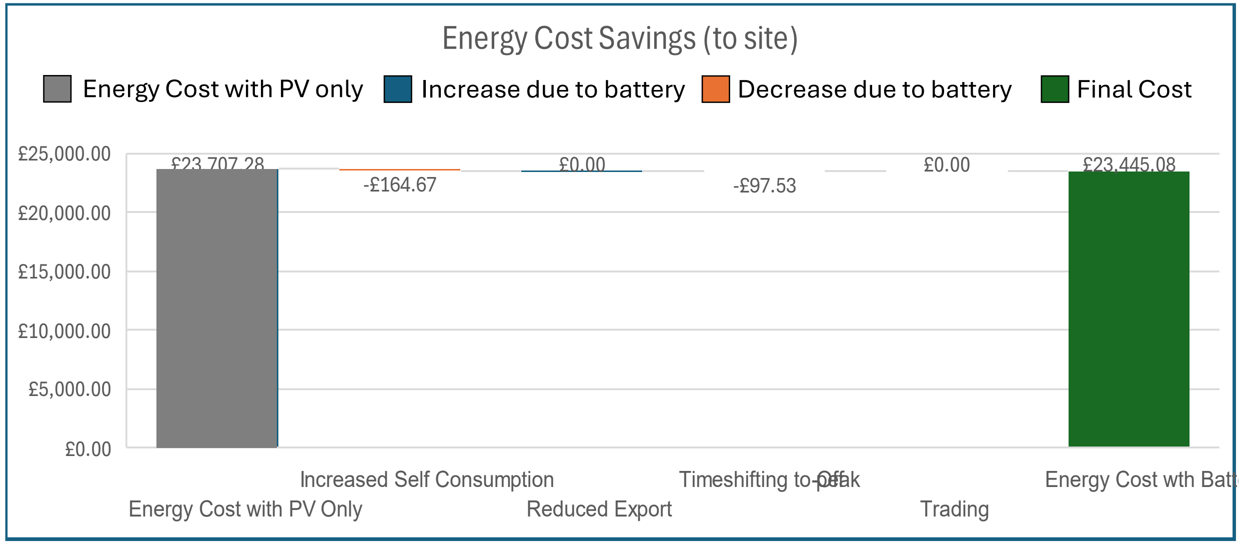


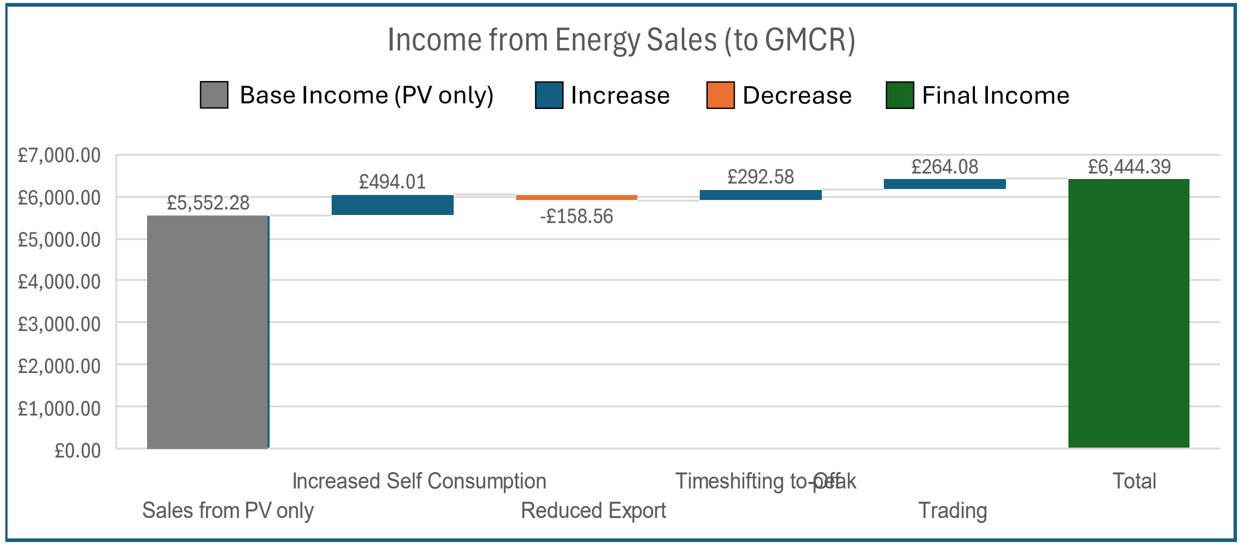
The bulk of the benefit from the PV+battery system comes from self-consumption of the energy generated by the PV array. The principal benefit of the battery is to increase this self-consumption by about £0.7k p.a.

That benefit is achieved at the cost of reducing the array's earnings from exporting to the grid by about £150p.a. Savings from timeshifting consumption to off-peak periods more than compensate for this cost. Then an additional saving is generated from additional active trading of the battery.

Site D – Allocation of Benefits for GMCR-funded Battery

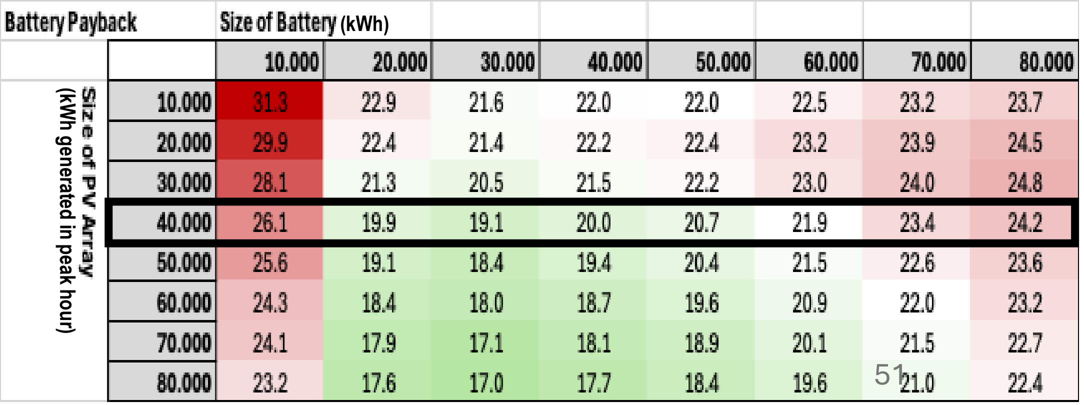
(does not account for financing costs)





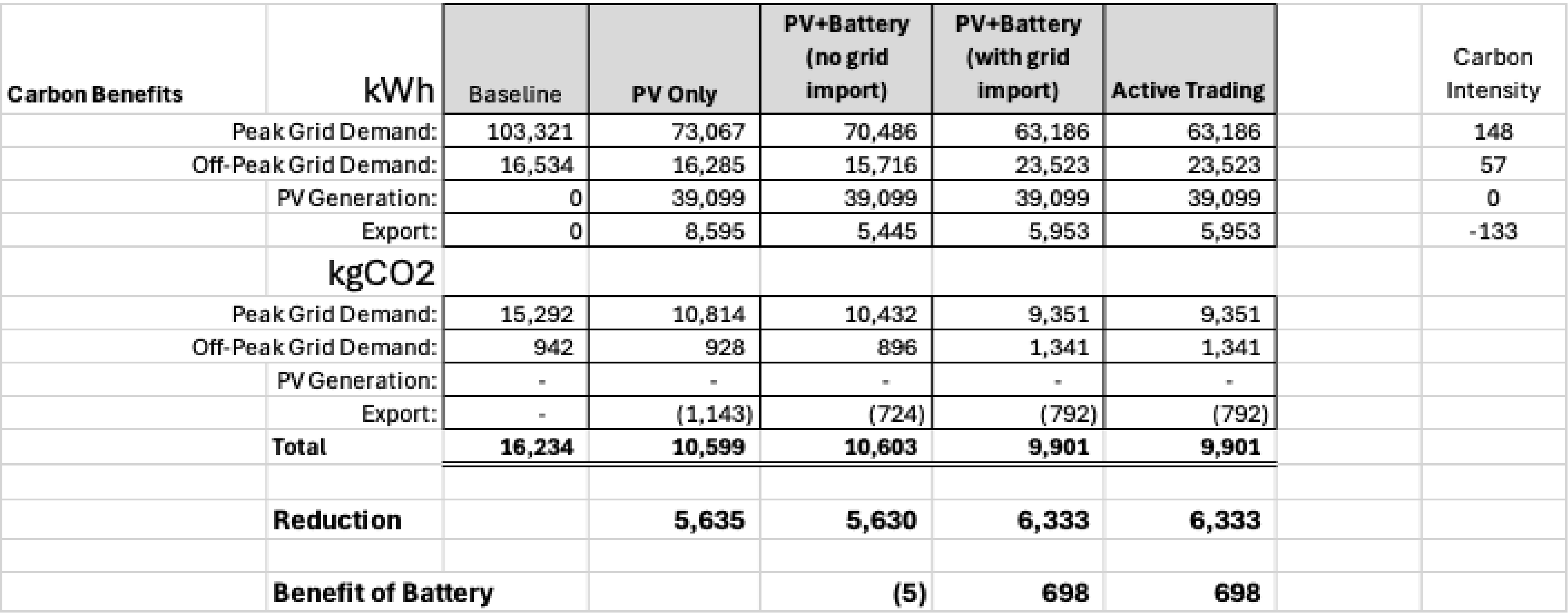
The previous slides identified the "DIY" benefits of the battery, i.e. assuming that the battery is owned by the party incurring the energy costs. In the case where GMCR owns the battery, these benefits will be split between it and the school.

These graphs show what this split might look like if GMCR captures 75% of the self-consumption and time-shifting benefit and 100% of the export and trading revenues. The table below shows the payback GMCR might achieve from these returns: installing a 30kWh battery alongside the current array would pay back after about 19 years. Payback improves for larger array sizes, but is never really viable.



Battery Payback		Size of Battery (kWh)							
		10.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000
Size of PV Array (kWh generated in peak hour)	10.000	31.3	22.9	21.6	22.0	22.0	22.5	23.2	23.7
	20.000	29.9	22.4	21.4	22.2	22.4	23.2	23.9	24.5
	30.000	28.1	21.3	20.5	21.5	22.2	23.0	24.0	24.8
	40.000	26.1	19.9	19.1	20.0	20.7	21.9	23.4	24.2
	50.000	25.6	19.1	18.4	19.4	20.4	21.5	22.6	23.6
	60.000	24.3	18.4	18.0	18.7	19.6	20.9	22.0	23.2
	70.000	24.1	17.9	17.1	18.1	18.9	20.1	21.5	22.7
	80.000	23.2	17.6	17.0	17.7	18.4	19.6	21.0	22.4

Site D – Carbon Savings

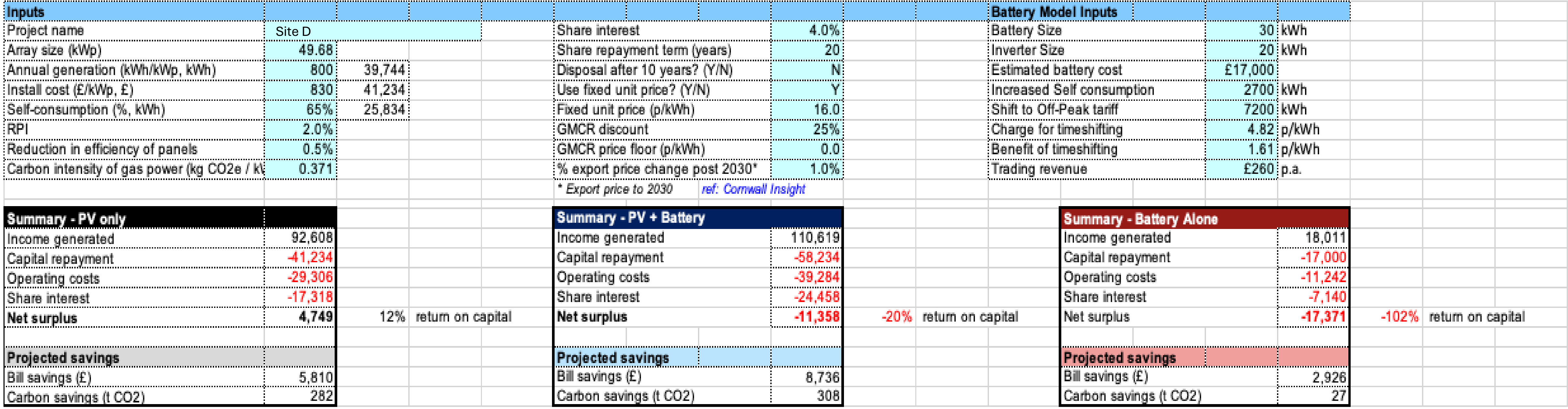


Carbon Benefits	kWh	Baseline	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading		Carbon Intensity
	Peak Grid Demand:	103,321	73,067	70,486	63,186	63,186		148
	Off-Peak Grid Demand:	16,534	16,285	15,716	23,523	23,523		57
	PV Generation:	0	39,099	39,099	39,099	39,099		0
	Export:	0	8,595	5,445	5,953	5,953		-133
	kgCO2							
	Peak Grid Demand:	15,292	10,814	10,432	9,351	9,351		
	Off-Peak Grid Demand:	942	928	896	1,341	1,341		
	PV Generation:	-	-	-	-	-		
	Export:	-	(1,143)	(724)	(792)	(792)		
	Total	**16,234**	**10,599**	**10,603**	**9,901**	**9,901**		
	Reduction		**5,635**	**5,630**	**6,333**	**6,333**		
	Benefit of Battery			**(5)**	**698**	**698**		

- We estimate that the battery yields an additional carbon saving of approx. 0.7 tCO2e p.a., primarily by time-shifting the site's consumption to times when grid carbon intensity is lower.
- Note that these calculations are highly dependent on assumptions about grid carbon intensity and how the benefits of the PV array are accounted for. GMCR's site viability model uses alternative assumptions.
- The calculations also do not account for the embedded carbon within the battery. These are dependent on the manufacturing process, shipping, etc. ChatGPT estimates them at 2.4tCO2e for a 30kWh battery.

Site D – Site Viability

(Based on GMCR's site viability template for new sites, as updated to include battery storage options.)



Inputs		
Project name	Site D	
Array size (kWp)	49.68	
Annual generation (kWh/kWp, kWh)	800	39,744
Install cost (£/kWp, £)	830	41,234
Self-consumption (%, kWh)	65%	25,834
RPI	2.0%	
Reduction in efficiency of panels	0.5%	
Carbon intensity of gas power (kg CO2e / k	0.371	

Share interest	4.0%
Share repayment term (years)	20
Disposal after 10 years? (Y/N)	N
Use fixed unit price? (Y/N)	Y
Fixed unit price (p/kWh)	16.0
GMCR discount	25%
GMCR price floor (p/kWh)	0.0
% export price change post 2030*	1.0%

** Export price to 2030* *ref: Cornwall Insight*

Battery Model Inputs		
Battery Size	30	kWh
Inverter Size	20	kWh
Estimated battery cost	£17,000	
Increased Self consumption	2700	kWh
Shift to Off-Peak tariff	7200	kWh
Charge for timeshifting	4.82	p/kWh
Benefit of timeshifting	1.61	p/kWh
Trading revenue	£260	p.a.

Summary - PV only			
Income generated	92,608		
Capital repayment	-41,234		
Operating costs	-29,306		
Share interest	-17,318		
Net surplus	**4,749**	12%	return on capital
Projected savings			
Bill savings (£)	5,810		
Carbon savings (t CO2)	282		

Summary - PV + Battery			
Income generated	110,619		
Capital repayment	-58,234		
Operating costs	-39,284		
Share interest	-24,458		
Net surplus	**-11,358**	-20%	return on capital
Projected savings			
Bill savings (£)	8,736		
Carbon savings (t CO2)	308		

Summary - Battery Alone			
Income generated	18,011		
Capital repayment	-17,000		
Operating costs	-11,242		
Share interest	-7,140		
Net surplus	**-17,371**	-102%	return on capital
Projected savings			
Bill savings (£)	2,926		
Carbon savings (t CO2)	27		

- We have updated GMCR's site viability template to include 3 options – PV only, PV + Battery, and Battery Alone (i.e. as an upgrade to existing PV). Inserting the generic model's outputs (for battery size and costs, and the self-consumption and energy timeshifting benefits it could deliver) for Site D yields the above results. These now incorporate GMCR's financing and administrative costs, assumptions about energy prices and carbon intensity, etc.
- Investing in a battery is clearly not viable, even though there are some additional carbon & bill savings for the site. Battery prices would need to reduce significantly, and/or returns would need to increase significantly, before investing in a battery for this site is viable.

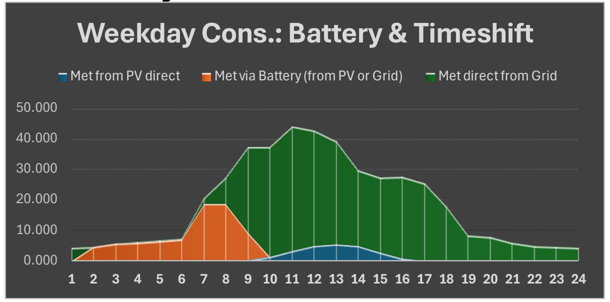
Site D – Energy usage patterns

The next 2 slides show the average daily energy usage pattern for each month of the year, for weekdays and weekends respectively. These give a more detailed feel for how the PV energy and battery might be used.

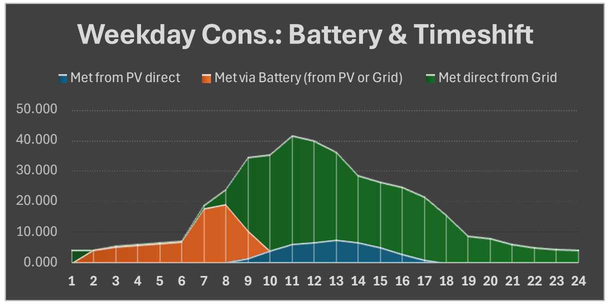
These are broadly in line with the other sites – during winter the battery is used primarily to exploit off-peak tariffs overnight; during summer the emphasis is on capturing excess PC generation with any residual battery capacity used to exploit off-peak tariffs; during spring and autumn the battery may manage to cycle twice per day, exploiting both sources of cheaper energy. (Lower consumption at weekends means that the battery focuses more on capturing excess solar – there may be little need to import further energy overnight in the summer months. And again, the issue with forecasting errors arises for capturing weekend generation.)

Site D – Weekday energy usage

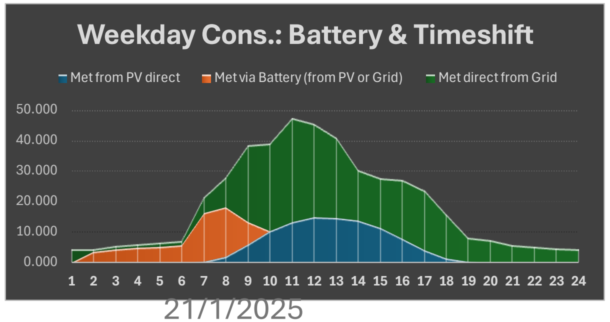
January



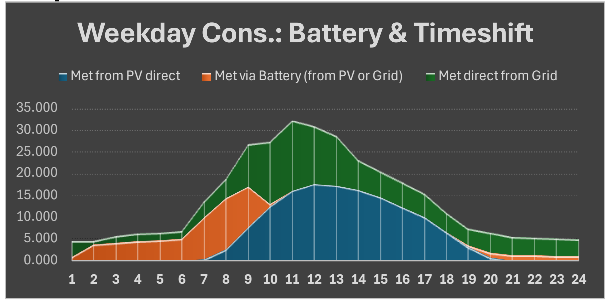
February



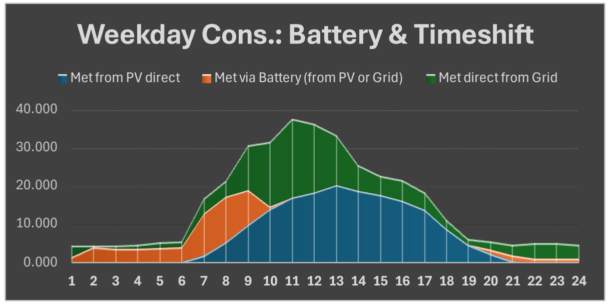
March



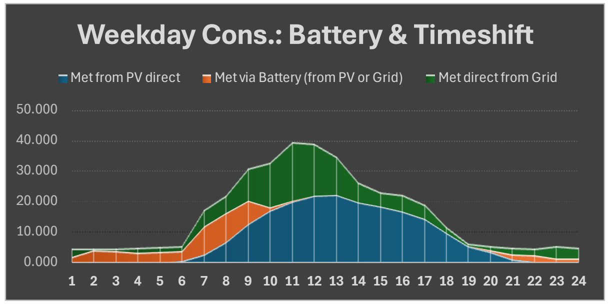
April



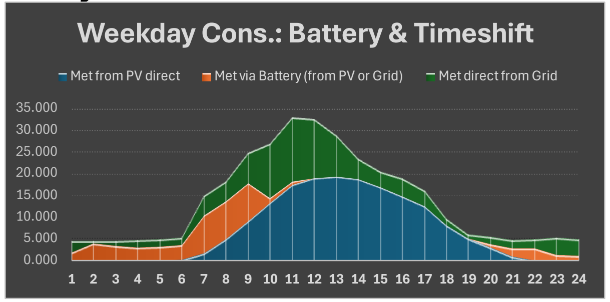
May



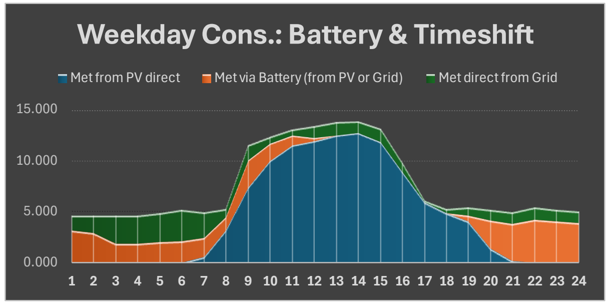
June



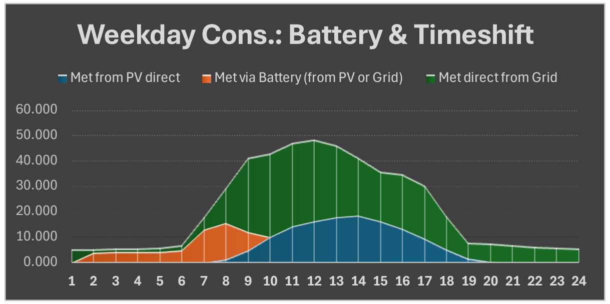
July



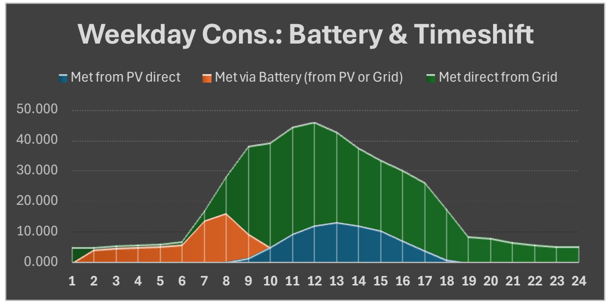
August



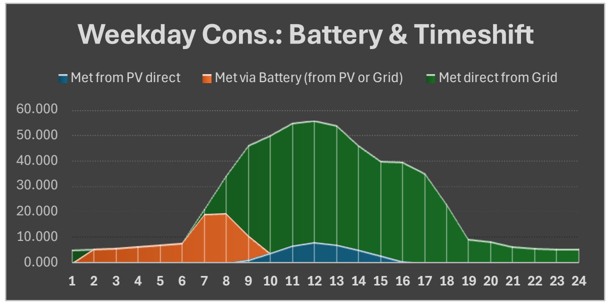
September



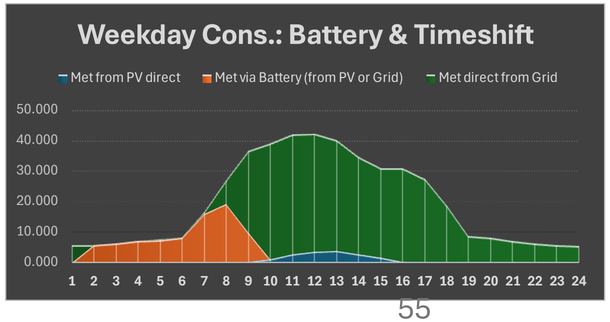
October



November

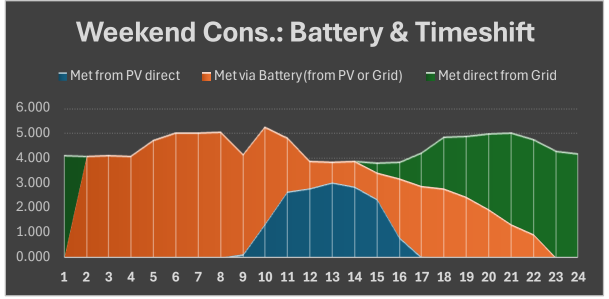


December

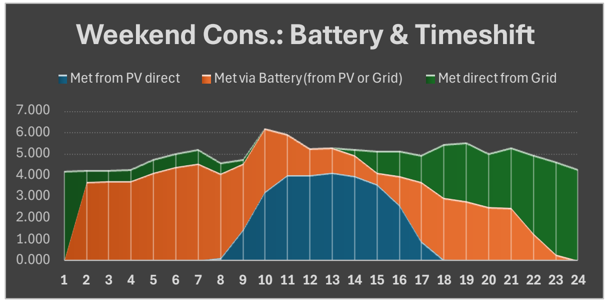


Site D – Weekend energy usage

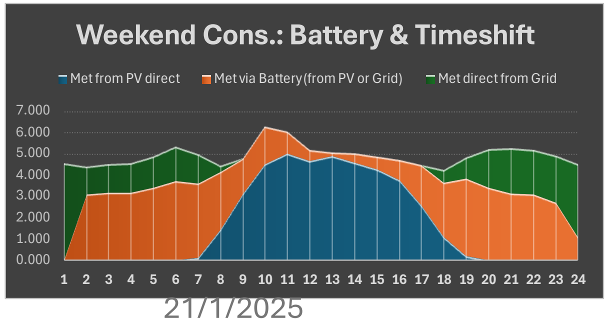
January



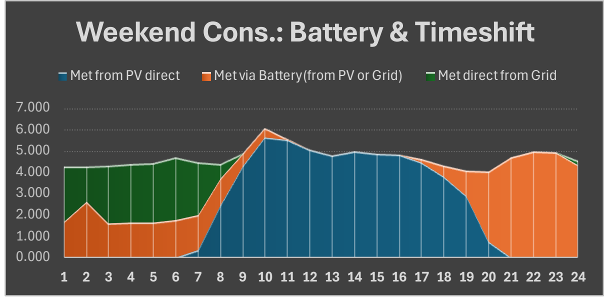
February



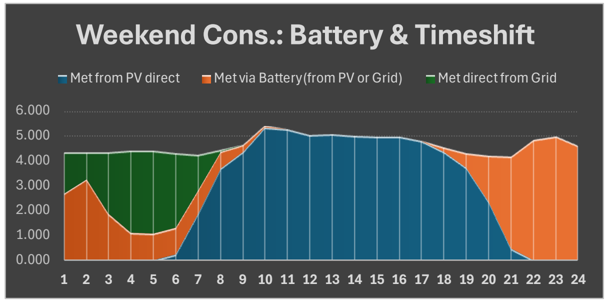
March



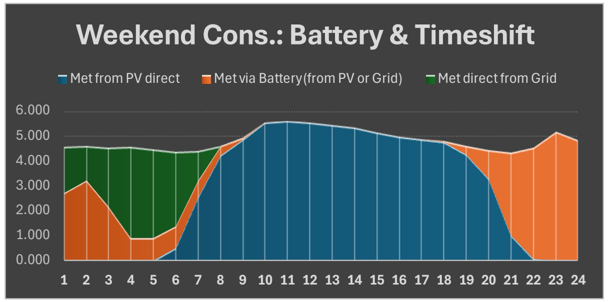
April



May



June



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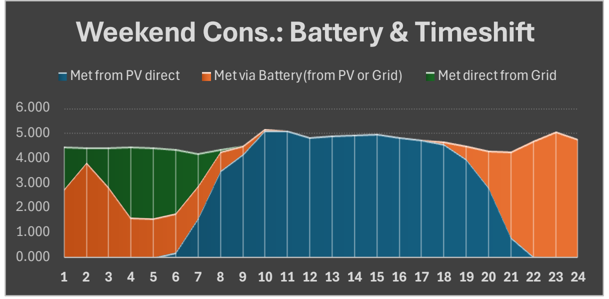

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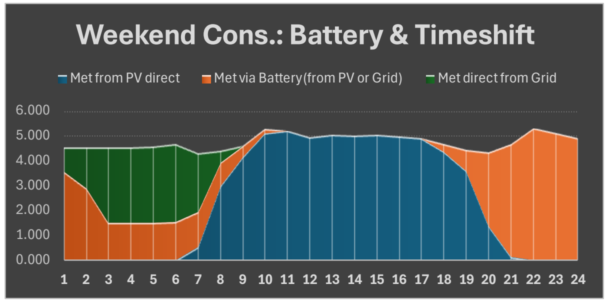

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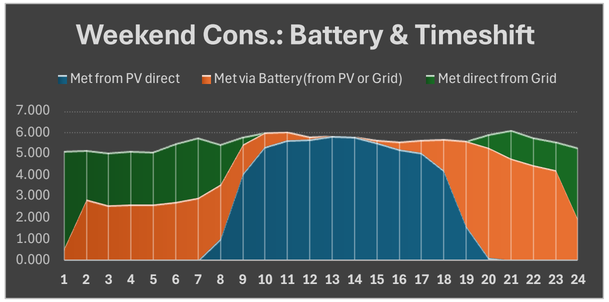

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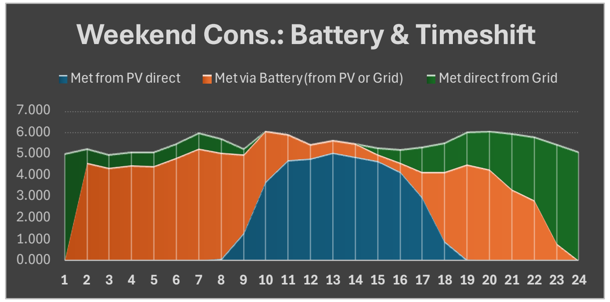

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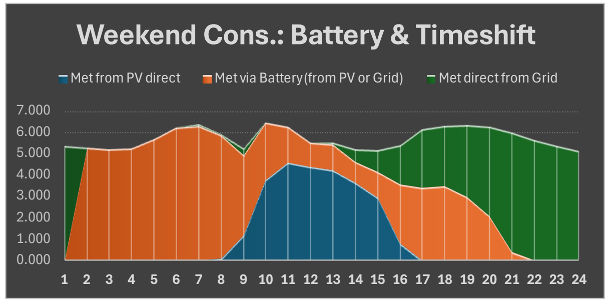
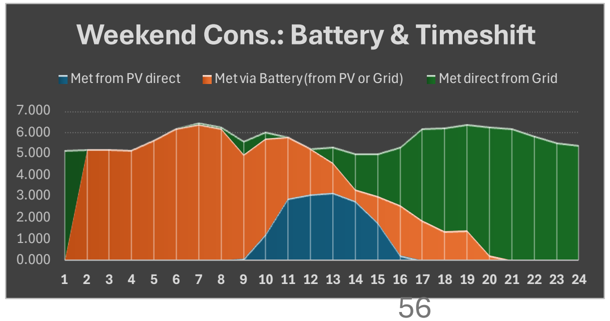


December



Site E

The following slides show key results for Site E.

Full results are given in the accompanying spreadsheet, which contains the full model , input data, etc.

Note that:

a) We have used energy consumption and generation data for 1 Feb 2024 to 31 Aug 2024, downloaded from the SolarEdge portal for the site's PV system. **Hourly data was only available for this 7-month period**, as this appears to be a relatively new installation.

b) For the other 5 months of the year, we have generated consumption and generation profiles for the site by averaging across the other 4 sites and then scaling up to match Site E's consumption and generation for Feb-Aug. This is a critical assumption, and the results of the analysis can only be considered provisional until consumption data for the other months is available. (Generation probably matches reasonably well across the sites, as it's determined primarily by weather. Consumption depends on the how the sites are used, and Site E could well be different to the other sites.)

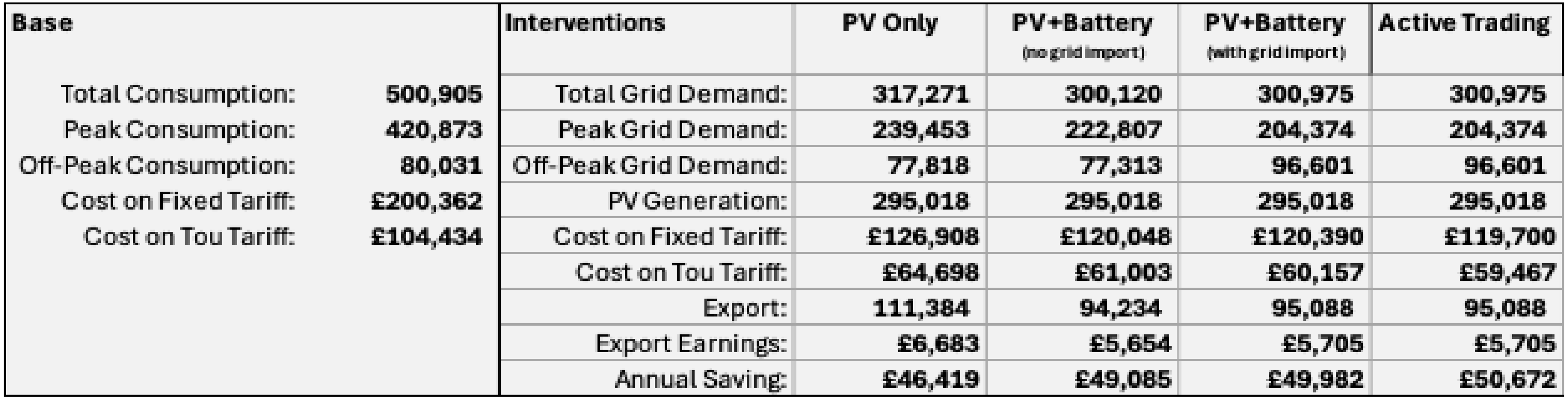
c) We have used actual peak and off-peak tariffs for the site. We have assumed that the off-peak period is from midnight to 7am.

d) We have not modelled a fixed tariff option for the site (i.e. we've set the fixed tariff artificially high so that it is never selected by the algorithm), as the site is already on a variable, Time-of-Use tariff.

e) We have used an export tariff that aligns to the rate GMCR uses in its site viability template.

Site E – Generic Scenario Summary

(does not account for financing costs and cost/benefit split between site and GMCR)



Base		Interventions	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading
Total Consumption:	500,905	Total Grid Demand:	317,271	300,120	300,975	300,975
Peak Consumption:	420,873	Peak Grid Demand:	239,453	222,807	204,374	204,374
Off-Peak Consumption:	80,031	Off-Peak Grid Demand:	77,818	77,313	96,601	96,601
Cost on Fixed Tariff:	£200,362	PV Generation:	295,018	295,018	295,018	295,018
Cost on Tou Tariff:	£104,434	Cost on Fixed Tariff:	£126,908	£120,048	£120,390	£119,700
		Cost on Tou Tariff:	£64,698	£61,003	£60,157	£59,467
		Export:	111,384	94,234	95,088	95,088
		Export Earnings:	£6,683	£5,654	£5,705	£5,705
		Annual Saving:	£46,419	£49,085	£49,982	£50,672

- We estimate the site’s current PV array is reducing its energy costs by approx. £46k (44%) p.a., from £104k to £58k (after accounting for export earnings). A larger array might reduce these costs further, e.g. adding another 100kWp of PV might take the savings to ~£57k (55%) p.a., which would be a reasonable investment. However, the optimal size, in terms of minimising payback time, is probably smaller than the current array unless a good export tariff can be obtained.
- Adding a 100kWh battery would increase the saving to approx. £51k (49%) p.a. This would represent a moderate ROI, giving payback on the investment after approx. 12 years. The bulk of this benefit comes from increasing self-consumption of energy generated by the PV array. There are also small benefits from timeshifting consumption to off-peak and from actively trading the battery on energy and flex markets.

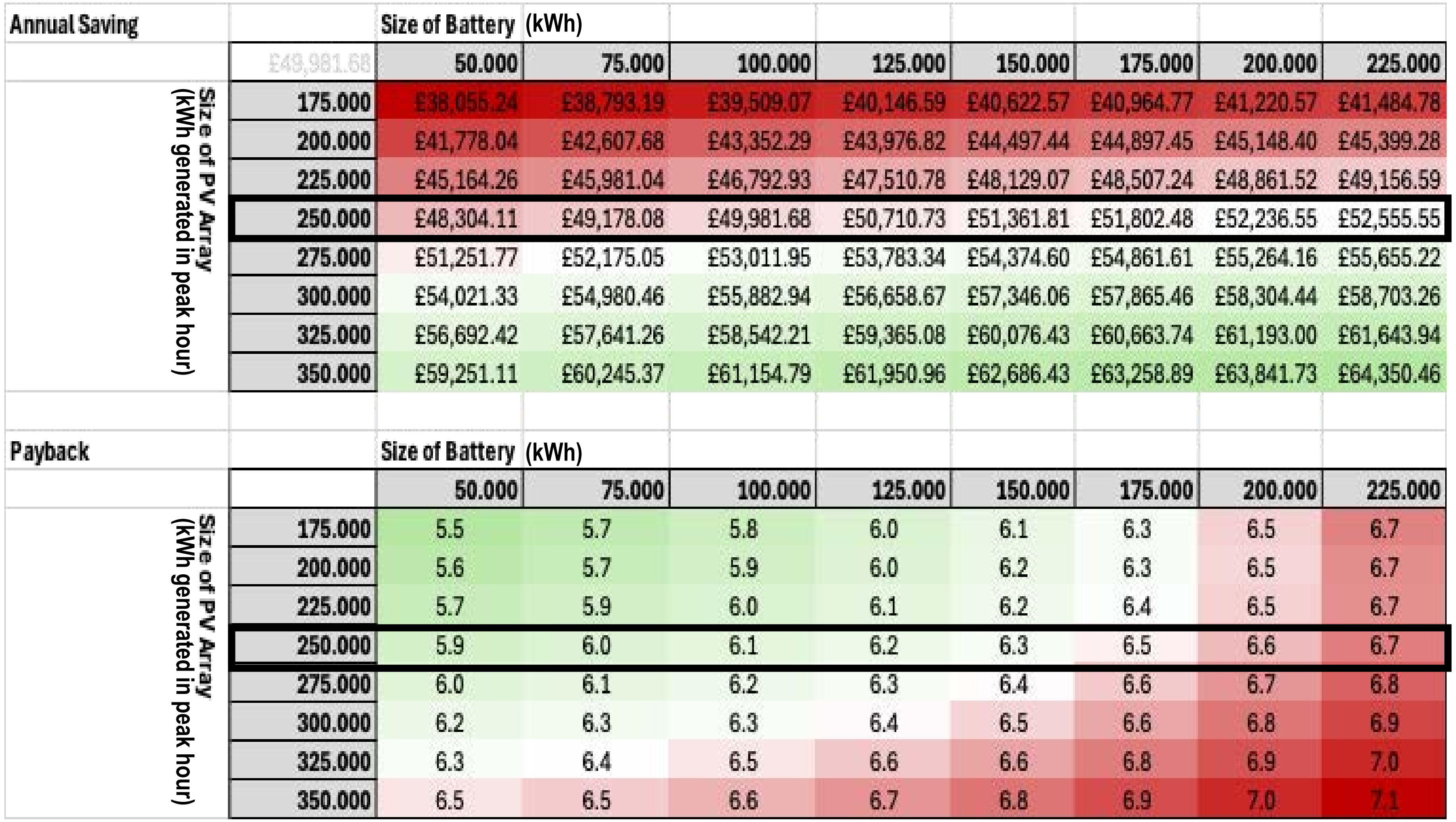
Site E – System Sizing for Generic Scenario

(does not account for financing costs and cost/benefit split between site and GMCR)

These tables show the annual saving and payback time (in years) that the site might achieve from a PV plus battery system for a range of array and battery sizes. (Note that they include the benefits of self-consumption and timeshifting but not active trading of the battery – these are explored on the next slide.)

This analysis suggests that the optimal return would be achieved from a relatively small PV array[1] (smaller than is currently installed) with no battery. Adding further PV or battery capacity yields additional savings but also lengthens the payback time.

However, the change to the payback time is slight, so the return on over-sizing the PV and battery may well be competitive c.f. alternative investment options. Thus, it may be worth investing in a battery.



Annual Saving

Size of PV Array (kWh generated in peak hour) / Size of Battery (kWh)

£49,981.68	50.000	75.000	100.000	125.000	150.000	175.000	200.000	225.000
175.000	£38,055.24	£38,793.19	£39,509.07	£40,146.59	£40,622.57	£40,964.77	£41,220.57	£41,484.78
200.000	£41,778.04	£42,607.68	£43,352.29	£43,976.82	£44,497.44	£44,897.45	£45,148.40	£45,399.28
225.000	£45,164.26	£45,981.04	£46,792.93	£47,510.78	£48,129.07	£48,507.24	£48,861.52	£49,156.59
250.000	£48,304.11	£49,178.08	£49,981.68	£50,710.73	£51,361.81	£51,802.48	£52,236.55	£52,555.55
275.000	£51,251.77	£52,175.05	£53,011.95	£53,783.34	£54,374.60	£54,861.61	£55,264.16	£55,655.22
300.000	£54,021.33	£54,980.46	£55,882.94	£56,658.67	£57,346.06	£57,865.46	£58,304.44	£58,703.26
325.000	£56,692.42	£57,641.26	£58,542.21	£59,365.08	£60,076.43	£60,663.74	£61,193.00	£61,643.94
350.000	£59,251.11	£60,245.37	£61,154.79	£61,950.96	£62,686.43	£63,258.89	£63,841.73	£64,350.46

Payback

Size of PV Array (kWh generated in peak hour) / Size of Battery (kWh)

	50.000	75.000	100.000	125.000	150.000	175.000	200.000	225.000
175.000	5.5	5.7	5.8	6.0	6.1	6.3	6.5	6.7
200.000	5.6	5.7	5.9	6.0	6.2	6.3	6.5	6.7
225.000	5.7	5.9	6.0	6.1	6.2	6.4	6.5	6.7
250.000	5.9	6.0	6.1	6.2	6.3	6.5	6.6	6.7
275.000	6.0	6.1	6.2	6.3	6.4	6.6	6.7	6.8
300.000	6.2	6.3	6.3	6.4	6.5	6.6	6.8	6.9
325.000	6.3	6.4	6.5	6.6	6.6	6.8	6.9	7.0
350.000	6.5	6.5	6.6	6.7	6.8	6.9	7.0	7.1

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[1] The generic model does not account for site-specific factors such as roof orientation: it calculates the peak generation the array needs to achieve. It is then a separate exercise to design an array that can deliver this output given the site's roof space, orientation and pitch, etc. This array will need a higher rated capacity to achieve the recommended peak generation.

Site E – Battery Sizing for Generic Scenario

(does not account for financing costs and cost/benefit split between site and GMCR)

These tables show the proportion of the annual saving that can be attributed to the battery, and the payback (in years) that this would yield for investing in the battery.

It can be seen that the optimum return is achieved for a 100kWh battery at the current PV array size. Increasing the size of the array improves the return on the battery, but the optimum size remains 100kWh. However, again the optimum is fairly broad, so there would be little lost if a common battery size were installed across several sites. (This would potentially improve your ability to negotiate discounted pricing on the batteries and reduce maintenance overheads.)

Battery Saving with Trading | Size of Battery (kWh)

	£4,252.98	50.000	75.000	100.000	125.000	150.000	175.000	200.000	225.000
Size of PV Array (kWh generated in peak hour)	175.000	£2,166.92	£3,037.70	£3,774.87	£4,398.00	£4,836.27	£5,129.37	£5,381.27	£5,633.98
	200.000	£2,244.87	£3,208.20	£3,975.52	£4,576.74	£5,065.27	£5,417.37	£5,670.03	£5,921.41
	225.000	£2,331.82	£3,294.15	£4,116.34	£4,818.29	£5,406.58	£5,735.65	£6,080.53	£6,375.60
	250.000	£2,413.54	£3,434.28	£4,252.98	£4,968.04	£5,585.61	£5,980.08	£6,399.45	£6,714.86
	275.000	£2,474.89	£3,542.07	£4,396.07	£5,150.36	£5,714.42	£6,160.33	£6,557.38	£6,944.74
	300.000	£2,498.81	£3,606.47	£4,525.85	£5,292.78	£5,950.17	£6,424.37	£6,859.15	£7,248.67
	325.000	£2,558.92	£3,655.14	£4,566.59	£5,379.46	£6,062.11	£6,608.22	£7,132.98	£7,579.72
	350.000	£2,575.55	£3,722.38	£4,636.41	£5,421.47	£6,131.34	£6,668.40	£7,241.64	£7,744.17

Battery Payback | Size of Battery (kWh)

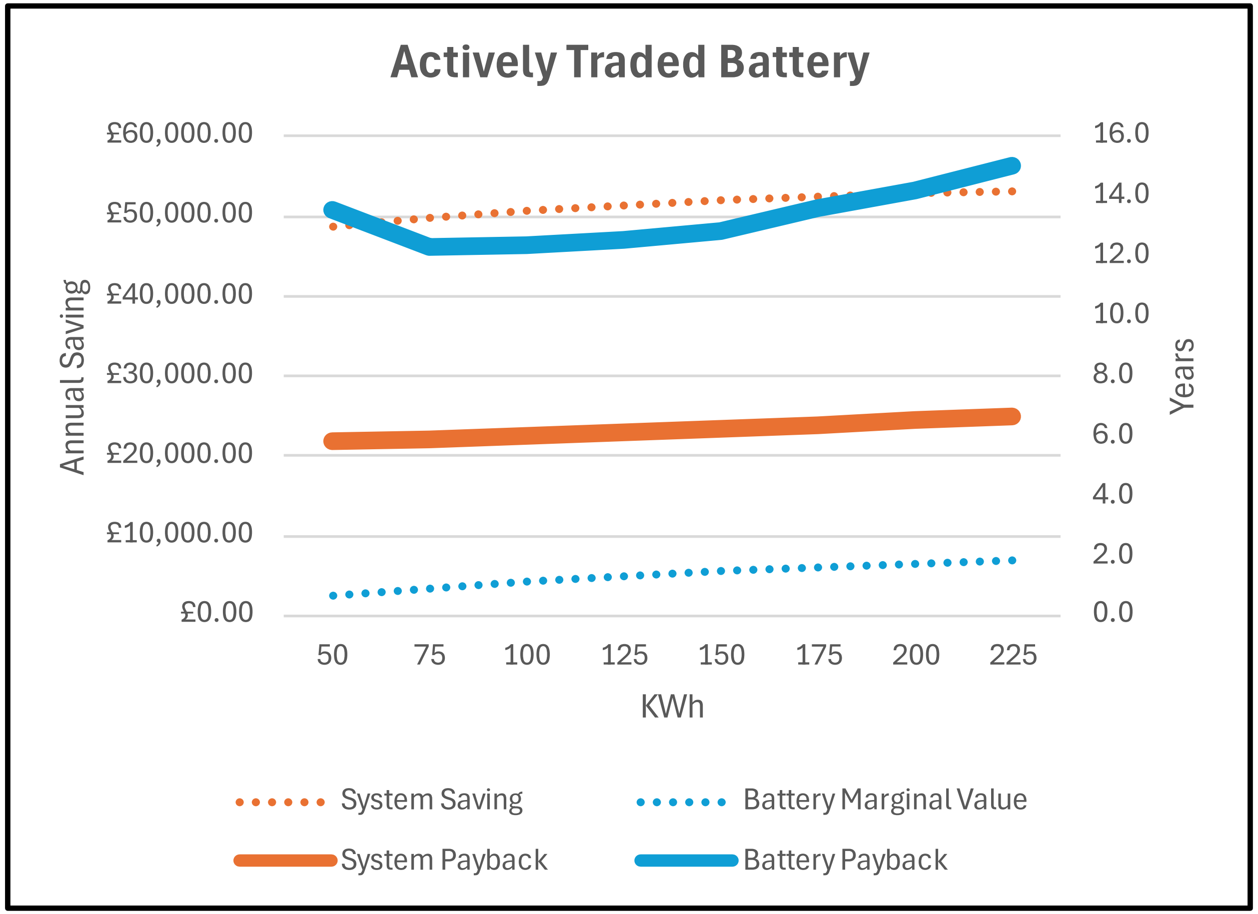
		50.000	75.000	100.000	125.000	150.000	175.000	200.000	225.000
Size of PV Array (kWh generated in peak hour)	175.000	15.0	14.0	13.9	14.2	15.0	16.1	17.2	18.2
	200.000	14.5	13.2	13.2	13.7	14.3	15.2	16.3	17.3
	225.000	13.9	12.9	12.8	13.0	13.4	14.4	15.2	16.1
	250.000	13.5	12.4	12.3	12.6	13.0	13.8	14.5	15.3
	275.000	13.1	12.0	11.9	12.1	12.7	13.4	14.1	14.8
	300.000	13.0	11.8	11.6	11.8	12.2	12.8	13.5	14.1
	325.000	12.7	11.6	11.5	11.6	12.0	12.5	13.0	13.5
	350.000	12.6	11.4	11.3	11.5	11.8	12.4	12.8	13.2

Site E – Battery Sizing for Generic Scenario

(does not account for financing costs and cost/benefit split between site and GMCR)

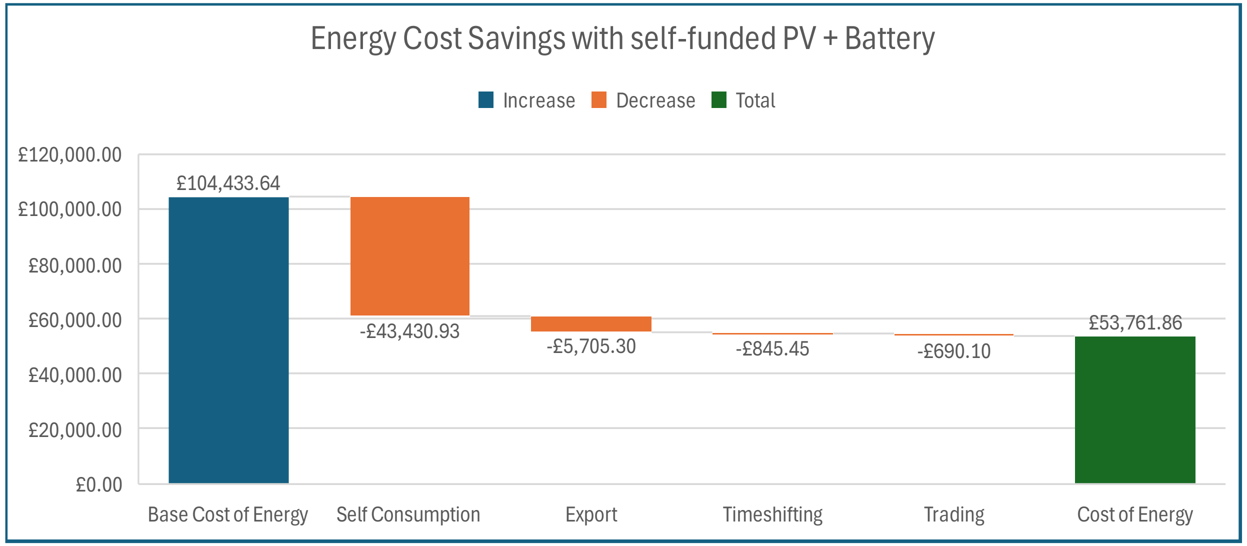
This chart again shows the value of adding a battery to the site's current PV array, separating the marginal value of the battery out from the overall site value.

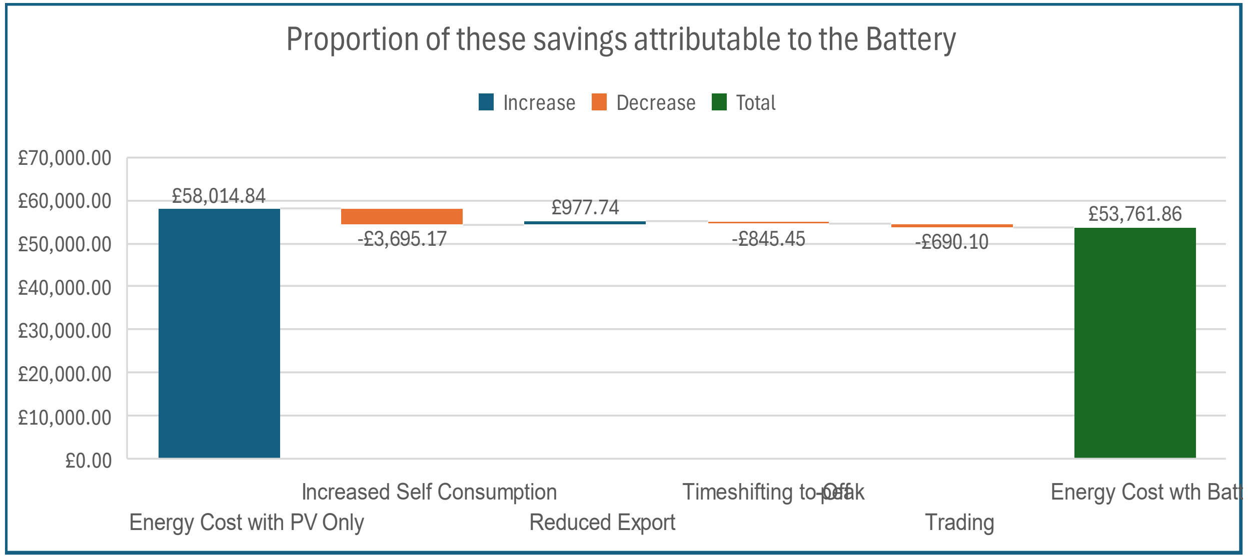
It can be seen that the optimal size for a battery on this site is about 75-100kWh, yielding an additional saving to the site's energy costs of about £4k p.a. c.f. the current costs with the PV array. This represents a payback of about 12 years, which is reasonable at current interest rates. (But again, this is for a self-funded scenario. Returns diminish when financing costs and sharing of benefits between the site and GMCR are considered.)



Site E – Energy Cost Savings for battery purchased with own funds

(does not account for financing costs and cost/benefit split between site and GMCR)



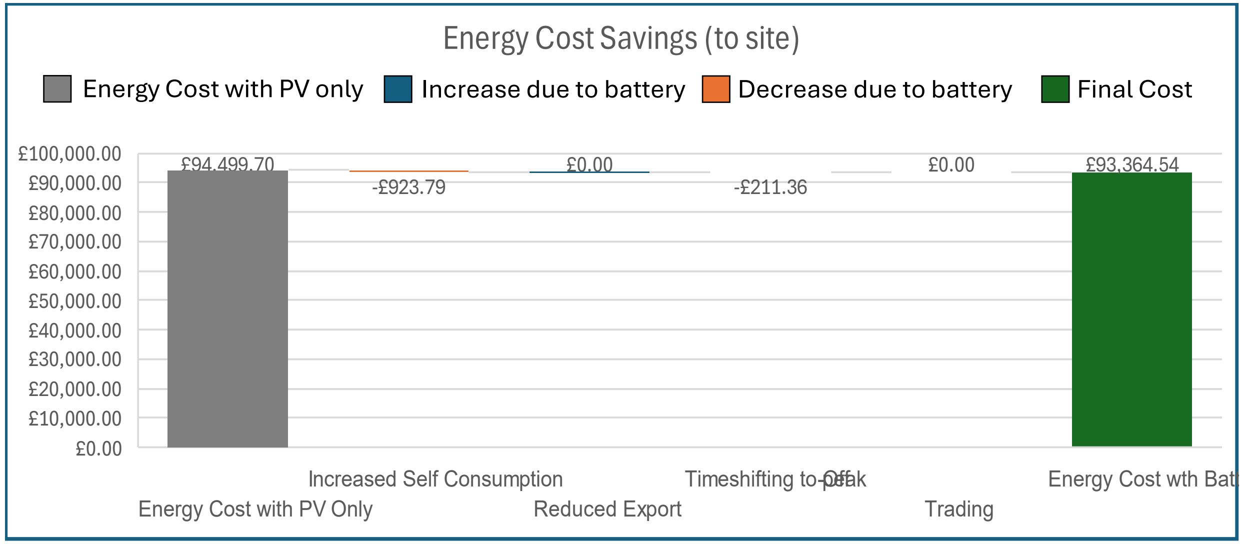


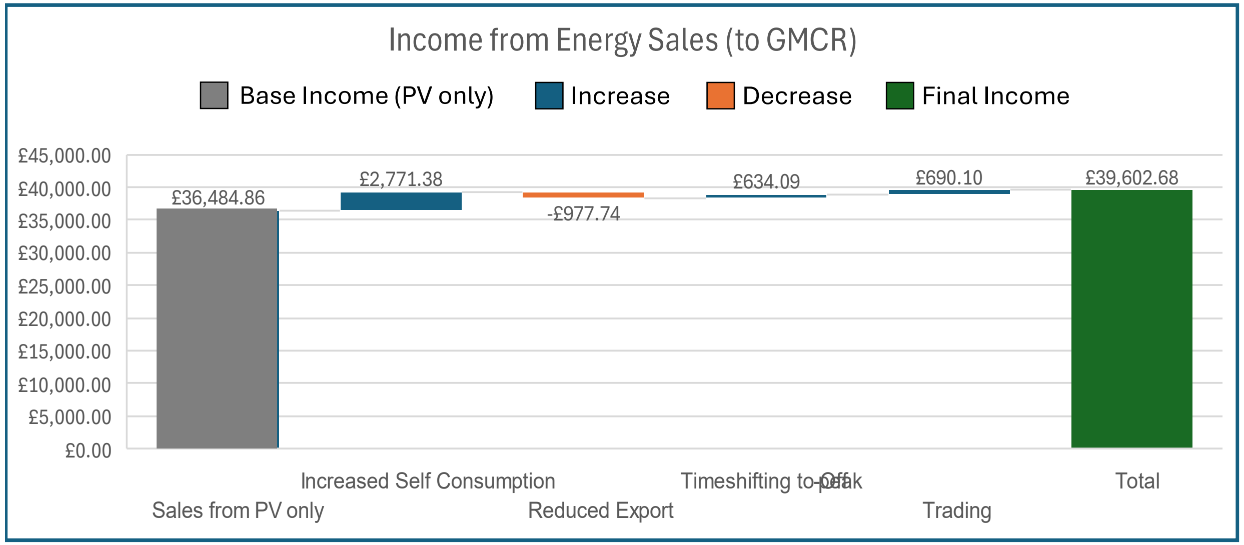
The bulk of the benefit from the PV+battery system comes from self-consumption of the energy generated by the PV array. The principal benefit of the battery is to increase this self-consumption by about £4k p.a.

That benefit is achieved at the cost of reducing the array’s earnings from exporting to the grid by about £1kp.a. Savings from timeshifting consumption to off-peak periods and actively trading the battery more than compensate for this cost.

Site E – Allocation of Benefits for GMCR-funded Battery

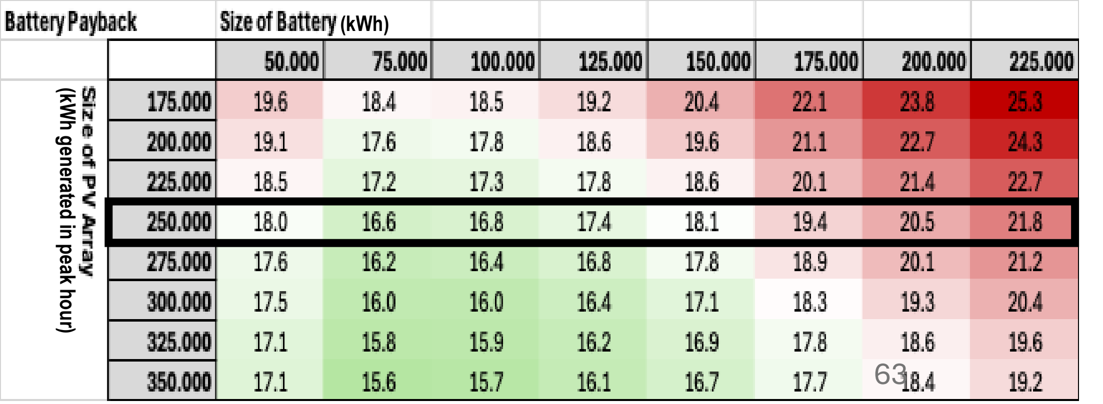
(does not account for financing costs)





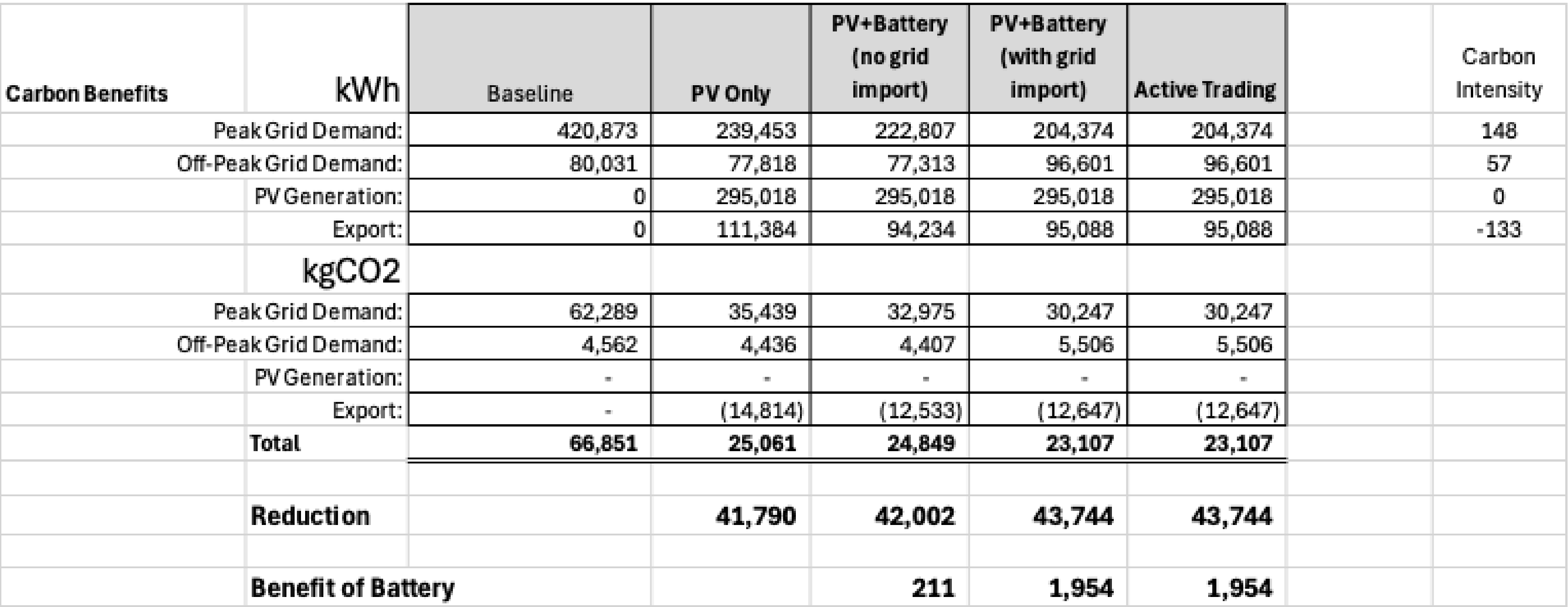
The previous slides identified the "DIY" benefits of the battery, i.e. assuming that the battery is owned by the party incurring the energy costs. In the case where GMCR owns the battery, these benefits will be split between it and the site.

These graphs show what this split might look like if GMCR captures 75% of the self-consumption and time-shifting benefit and 100% of the export and trading revenues. The table below shows the payback GMCR might achieve from these returns: installing a 100kWh battery alongside the current array would pay back after about 17 years. Payback improves for larger array sizes, but is never especially attractive.



Battery Payback		Size of Battery (kWh)							
		50.000	75.000	100.000	125.000	150.000	175.000	200.000	225.000
Size of PV Array (kWh generated in peak hour)	175.000	19.6	18.4	18.5	19.2	20.4	22.1	23.8	25.3
	200.000	19.1	17.6	17.8	18.6	19.6	21.1	22.7	24.3
	225.000	18.5	17.2	17.3	17.8	18.6	20.1	21.4	22.7
	250.000	**18.0**	**16.6**	**16.8**	**17.4**	**18.1**	**19.4**	**20.5**	**21.8**
	275.000	17.6	16.2	16.4	16.8	17.8	18.9	20.1	21.2
	300.000	17.5	16.0	16.0	16.4	17.1	18.3	19.3	20.4
	325.000	17.1	15.8	15.9	16.2	16.9	17.8	18.6	19.6
	350.000	17.1	15.6	15.7	16.1	16.7	17.7	18.4	19.2

Site E – Carbon Savings

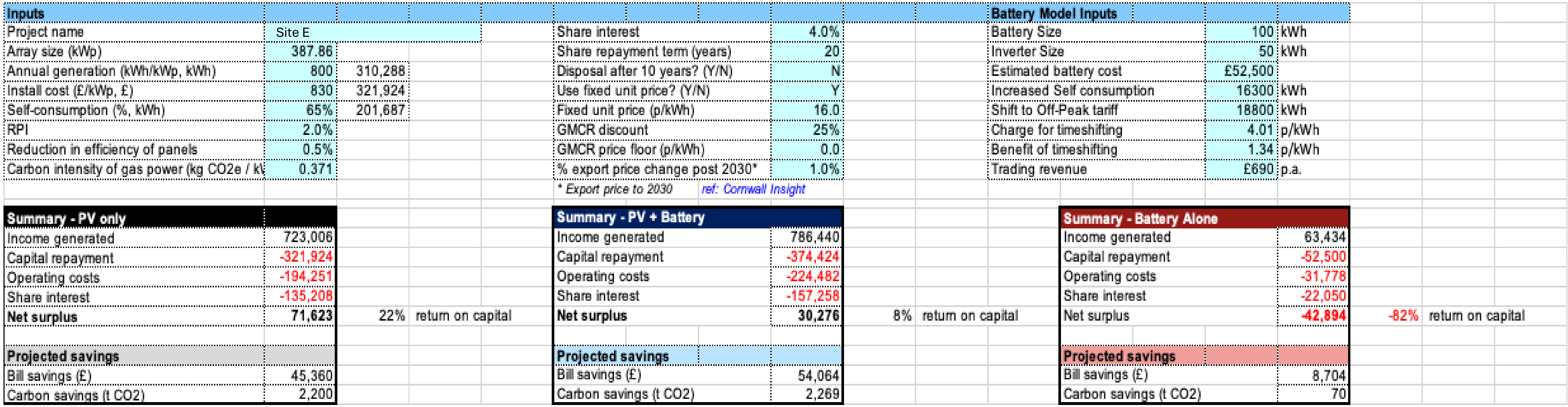


Carbon Benefits	kWh	Baseline	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading		Carbon Intensity
	Peak Grid Demand:	420,873	239,453	222,807	204,374	204,374		148
	Off-Peak Grid Demand:	80,031	77,818	77,313	96,601	96,601		57
	PV Generation:	0	295,018	295,018	295,018	295,018		0
	Export:	0	111,384	94,234	95,088	95,088		-133
	kgCO2							
	Peak Grid Demand:	62,289	35,439	32,975	30,247	30,247		
	Off-Peak Grid Demand:	4,562	4,436	4,407	5,506	5,506		
	PV Generation:	-	-	-	-	-		
	Export:	-	(14,814)	(12,533)	(12,647)	(12,647)		
	Total	**66,851**	**25,061**	**24,849**	**23,107**	**23,107**		
	Reduction		**41,790**	**42,002**	**43,744**	**43,744**		
	Benefit of Battery			**211**	**1,954**	**1,954**		

- We estimate that the battery yields an additional carbon saving of approx. 2 tCO2e p.a., primarily by time-shifting the site's consumption to times when grid carbon intensity is lower.
- Note that these calculations are highly dependent on assumptions about grid carbon intensity and how the benefits of the PV array are accounted for. GMCR's site viability model uses alternative assumptions.
- The calculations also do not account for the embedded carbon within the battery. These are dependent on the manufacturing process, shipping, etc.

Site E – Site Viability

(Based on GMCR’s site viability template for new sites, as updated to include battery storage options.)



Inputs		
Project name	Site E	
Array size (kWp)	387.86	
Annual generation (kWh/kWp, kWh)	800	310,288
Install cost (£/kWp, £)	830	321,924
Self-consumption (%, kWh)	65%	201,687
RPI	2.0%	
Reduction in efficiency of panels	0.5%	
Carbon intensity of gas power (kg CO2e / k	0.371	

Share interest	4.0%
Share repayment term (years)	20
Disposal after 10 years? (Y/N)	N
Use fixed unit price? (Y/N)	Y
Fixed unit price (p/kWh)	16.0
GMCR discount	25%
GMCR price floor (p/kWh)	0.0
% export price change post 2030*	1.0%

** Export price to 2030* *ref: Cornwall Insight*

Battery Model Inputs		
Battery Size	100	kWh
Inverter Size	50	kWh
Estimated battery cost	£52,500	
Increased Self consumption	16300	kWh
Shift to Off-Peak tariff	18800	kWh
Charge for timeshifting	4.01	p/kWh
Benefit of timeshifting	1.34	p/kWh
Trading revenue	£690	p.a.

Summary - PV only			
Income generated	723,006		
Capital repayment	-321,924		
Operating costs	-194,251		
Share interest	-135,208		
Net surplus	**71,623**	22%	return on capital
Projected savings			
Bill savings (£)	45,360		
Carbon savings (t CO2)	2,200		

Summary - PV + Battery			
Income generated	786,440		
Capital repayment	-374,424		
Operating costs	-224,482		
Share interest	-157,258		
Net surplus	**30,276**	8%	return on capital
Projected savings			
Bill savings (£)	54,064		
Carbon savings (t CO2)	2,269		

Summary - Battery Alone			
Income generated	63,434		
Capital repayment	-52,500		
Operating costs	-31,778		
Share interest	-22,050		
Net surplus	**-42,894**	-82%	return on capital
Projected savings			
Bill savings (£)	8,704		
Carbon savings (t CO2)	70		

- We have updated GMCR’s site viability template to include 3 options – PV only, PV + Battery, and Battery Alone (i.e. as an upgrade to existing PV). Inserting the generic model’s outputs (for battery size and costs, and the self-consumption and energy timeshifting benefits it could deliver) for Site E yields the above results. These now incorporate GMCR’s financing and administrative costs, assumptions about energy prices and carbon intensity, etc.
- Investing in a battery is clearly not viable, even though there are some additional carbon & bill savings for the site. Battery prices would need to reduce significantly, and/or returns would need to increase significantly, before investing in a battery for this site is viable.

Site E – Energy usage patterns

We have not analysed the average daily usage patterns for this site, as the data for much of the year has been generated by averaging across the other sites so this analysis will tell us little new. (The patterns are available in the detailed spreadsheet for the site.)

Methodology for further modelling

Our modelling for the sites goes through 4 stages:

1) Enter site consumption and generation data into our PV & Battery model
2) Set up initial estimate for PV and battery configuration, alongside other parameters (tariffs, etc)
3) Use model sensitivities to iterate and refine the configuration
4) Transfer parameters to GMCR’s Site Viability template to calculate expected returns

The next few slides outline each of these stages.

1) Site consumption and generation data (1 of 2)

This stage tends to entail the most work, as data availability and formatting varies widely. However, the quality of the final estimates is strongly driven by the quality of the input site data: the amount of self-consumption and time-shifting a battery can achieve is determined by the site's generation and consumption patterns.

Our PV & Battery model takes generation and consumption data at hourly or better granularity and creates a "generic year" of hourly generation and consumption. It does this by calculating the site's average hourly consumption for each day of the week and month of the year by averaging across several years of data. It then generates a generic consumption profile for the analysis year. Likewise, it calculates hourly PV generation for each month of the year, breaks it down by quartiles to account for weather variation, then builds a generic annual generation profile for the site. Both profiles, consumption and generation, are then normalised against the site's typical (or expected) total annual consumption/generation.

Five spreadsheet tabs are relevant to this process:

1) **PV Generation Data**: Input generation data for the site. Should be at hourly or better granularity, ideally covering several years.
2) **PV Profiles**: This gives average PV generation by hour-of-day and month-of-year, broken down by quartiles. It is derived from the first tab. If no site generation data is available, then a generic profile calculated from another site or generic solar irradiance data could be inserted in its place (provided the exact format of this tab is retained).
3) **Consumption Data**: Input consumption data for the site. Again, should be at hourly or better granularity and cover several years.
4) **Consumption Profiles**: Average hourly energy consumption by weekday versus weekend, and by month of year. As with the PV Profiles, this is derived from the input consumption data. It can also be substituted with a generic profile, e.g. from Elexon's standard settlement class profiles, if site-specific data is not available. (This will mean that the resulting self-consumption and time-shifting estimates can only be broad estimates. This is a bigger issue for consumption than generation, as consumption patterns are more likely to vary significantly between sites.)
5) **Annual Energy Model**: Columns G & J are derived from the PV Profiles and Consumption Profiles. These are then used to calculate the energy flows between the site, PV array, battery and grid, and hence self-consumption and time-shifting values.

1) Site consumption and generation data (2 of 2)

The following process is used to enter site generation and consumption data:

a) **Generation data**: Create a spreadsheet with raw data in two columns – date/time and energy consumption – as per columns A & B of the PV Generation Data tab. Copy-and-paste this raw data over the top of the data in columns A & B of this tab, starting at row 6. If there is further data from the current spreadsheet beyond the end of this input data, delete it. Or if the input data goes beyond the end of the data currently in the spreadsheet, fill columns C through G down to match this data.

b) **Normalised generation**: Adjust the formulas in cells B2, B3, B4, B5, C2 and C5 to cover the full extent of the input data. The spreadsheet will then normalise the generation data to 1KW (so the Annual Energy Model can easily normalise it to match the size of the PV array being modelled).

c) **Consumption data**: Similarly to the generation data, create a spreadsheet with raw data in two columns, date/time and energy consumption. Copy-and-paste this over the top of columns A & B of the Consumption Data tab, starting at row 3. Adjust the rows at the end of the data to match the input data, as for the generation data.

d) **Normalised consumption**: Adjust the formula in cell B2 to cover the full extent of the data. This will then be used to normalise the data in the Consumption Profile tab, and hence in the Annual Energy Model.

The most likely issues with this process are:

1) **Date formats**: Data imported from US sites via CSV files may have a different format to the UK formats the spreadsheet uses. If this is the case, you may need to adjust the data format.

2) **Lack of data**: If you don't have a full year's generation data for the site, you can probably use data from another nearby site without too much loss of accuracy, as PV generation is driven mostly by weather. If that isn't available, then you could use a more distant site and probably still retain reasonable accuracy. In extremis, you could use generic solar irradiance data, but this will lose the effect of weather variations – the results will probably still be OK, but the degree of confidence will go down somewhat.

   Lack of consumption data is a bigger issue. Half hourly data from a smart meter is ideal. If that's not available, the best fallback is probably to copy data from another site with similar consumption patterns. However, the calculations of self-consumption and time-shifting, and hence of the returns on a battery, can only be provisional in this case. In the worst case, standard Elexon settlement profiles could be inserted into the Consumption Profiles tab.

The calculations in the model can always only be estimates, as consumption patterns and market conditions change over time, so any forward-looking model is subject to significant uncertainty. Uncertainty in the input data just adds to this.

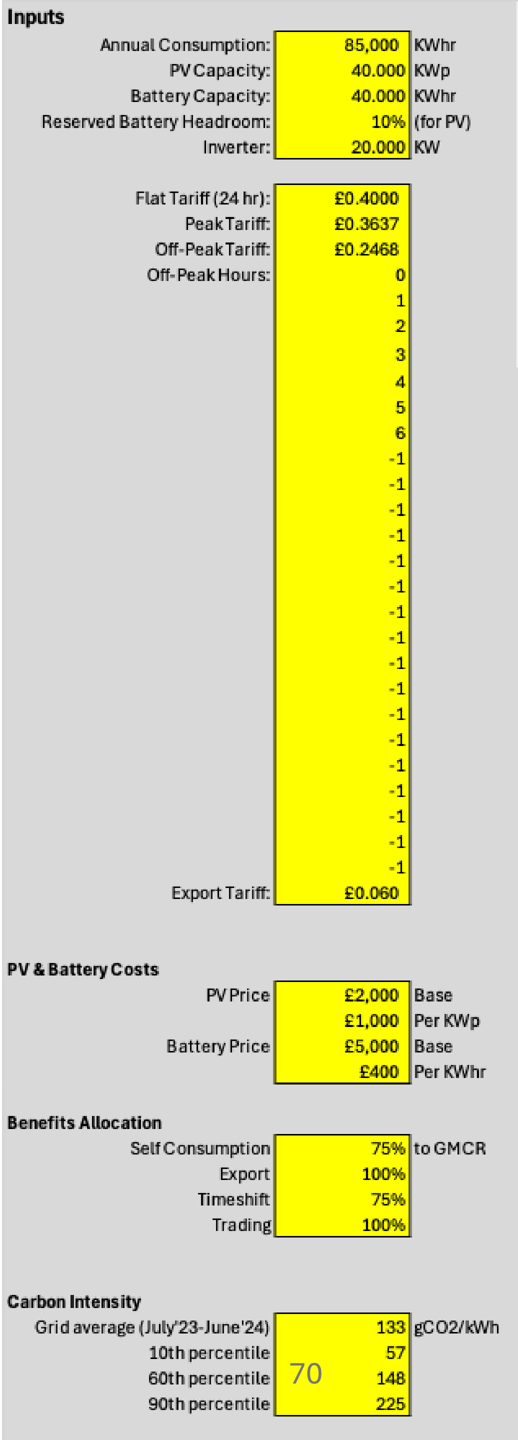
2) Initial configuration and other parameters (tariffs, etc) (1 of 2)

The PV & Battery model uses the algorithm outlined earlier in this deck (slide 7) to calculate the site's energy costs under the 5 scenarios outlined earlier (slide 6):

1) **Base energy costs**: The site's energy costs before installing PV or battery.
2) **PV only**: Energy costs with a solar array but no battery.
3) **Battery for self-consumption**: A battery is installed alongside the PV array, but is used only to maximise self-consumption.
4) **Battery for self-consumption and timeshifting**: The battery is also now used for time-shifting also. The site needs a time-of-use tariff for this to add any value.
5) **Actively traded battery**: The battery is also used to trade actively on energy and flexibility markets.

These calculations are driven by the following parameters, which can be entered from the Inputs & Outputs tab of the spreadsheet:

- **Annual Consumption**: Expected total annual consumption for the site (kWh). This is generally available for most sites (e.g. from bills). It's used to normalise the input consumption data.
- **PV Capacity**: Size of the PV array (kWp). If there isn't currently an array / the goal is to determine what size array to install, enter an initial guess and then iterate and refine as outlined in the next section.
- **Battery Capacity**: Capacity of the battery (kWh). Again, enter an initial estimate and iterate.
- **Reserved Battery headroom**: The algorithm reserves some battery capacity to cover forecasting errors for the site's generation and consumption. This also creates an allowance to account for battery degradation over time. The starting value, 10%, is going to be good enough for most cases.
- **Inverter**: Size of the inverter (kW). The outputs usually aren't especially sensitive to this. Entering a value about half that of the battery capacity should suffice for most cases.



Inputs

Annual Consumption:	85,000	KWhr
PV Capacity:	40.000	KWp
Battery Capacity:	40.000	KWhr
Reserved Battery Headroom:	10%	(for PV)
Inverter:	20.000	KW
Flat Tariff (24 hr):	£0.4000	
Peak Tariff:	£0.3637	
Off-Peak Tariff:	£0.2468	
Off-Peak Hours:	0	
	1	
	2	
	3	
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	-1	
Export Tariff:	£0.060	

PV & Battery Costs

PV Price	£2,000	Base
	£1,000	Per KWp
Battery Price	£5,000	Base
	£400	Per KWhr

Benefits Allocation

Self Consumption	75%	to GMCR
Export	100%	
Timeshift	75%	
Trading	100%	

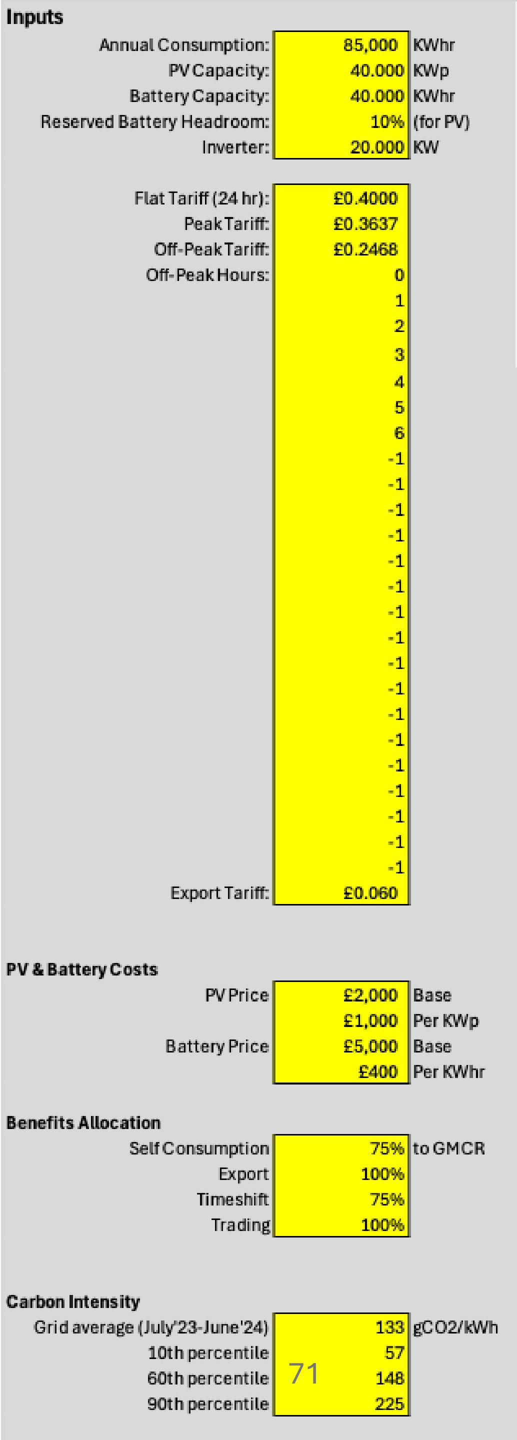
Carbon Intensity

Grid average (July'23-June'24)	133	gCO2/kWh
10th percentile	57	
60th percentile	148	
90th percentile	225	

2) Initial configuration and other parameters (tariffs, etc) (2 of 2)

Input parameters (continued):

- **Flat tariff**: Price per kWh for energy consumption, where a flat tariff is offered.
- **Peak tariff**: Price per kWh for energy consumed at peak times, where a 2-tier time-of use tariff is offered.
- **Off-Peak Tariff**: Price per kWh for energy consumed at off-peak times.
- **Off-Peak Hours**: List of hours that are considered off-peak for tariff purposes. Entered as a list of integers – midnight to 1am is 0; 1am-2am is 1; etc. (Off-peak will typically be contiguous hours overnight, as for Economy-7 tariffs, but this format allows for several off-peak periods per day, etc.)
- **Export Tariff**: Payment received per kWh for energy exported to the grid.
- **PV Price**: This gives a base price and cost per kWp for the PV array. If you have data for this, then you can override these parameters here.
- **Battery Price**: Base price and cost per kWh for the battery. Note that the base price is linked to the size of the inverter. Again, if you have specific data, enter it here. Otherwise, the starting numbers will probably suffice. (PV Price and Battery Price can be refined in the Site Viability template, and that's where final calculations of returns should be made, ideally based on quoted figures from installers / OEMs. The numbers here will generally be good enough to run sensitivities on the payback periods and hence identify a PV and battery configuration to use for the site.)
- **Benefits Allocation**: The percent of the benefits of self-consumption, export, time-shifting and active trading respectively that is retained by GMCR to cover the costs of installing and operating the system.
- **Carbon Intensity**: Grid carbon intensity, used to calculate the carbon savings made by the system. Data for July 2023 – June 2024, taken from the ESO's website, have been entered and should be good enough for most purposes. Again, these will be overridden by calculations in the Site Viability template.



Inputs		
Annual Consumption:	85,000	KWhr
PV Capacity:	40.000	KWp
Battery Capacity:	40.000	KWhr
Reserved Battery Headroom:	10%	(for PV)
Inverter:	20.000	KW
Flat Tariff (24 hr):	£0.4000	
Peak Tariff:	£0.3637	
Off-Peak Tariff:	£0.2468	
Off-Peak Hours:	0	
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Export Tariff:	£0.060	
PV & Battery Costs		
PV Price	£2,000	Base
	£1,000	Per KWp
Battery Price	£5,000	Base
	£400	Per KWhr
Benefits Allocation		
Self Consumption	75%	to GMCR
Export	100%	
Timeshift	75%	
Trading	100%	
Carbon Intensity		
Grid average (July'23-June'24)	133	gCO2/kWh
10th percentile	57	
60th percentile	148	
90th percentile	225	

3) Using sensitivities to iterate and refine

The model does not attempt to automatically configure the PV and Battery sizes. It relies on you to enter initial values. It then calculates the savings this configuration creates and undertakes a sensitivity analysis either side of these values. This allows you to enter new starting values and broad, as necessary. (We've found that 1 or 2 iterations generally suffice.)

Starting values for the PV size will be driven by the site's annual consumption (and by what is physically possible on the site). The anticipated annual generation from the array should probably be matched roughly to the site's annual consumption, as a decent starting point. Matching the capacity of the battery (kWh) to the peak generation of the array (kWp) is then probably a good starting point for the battery size. I'd then set the inverter size (kW) at roughly half the battery capacity (kWh).

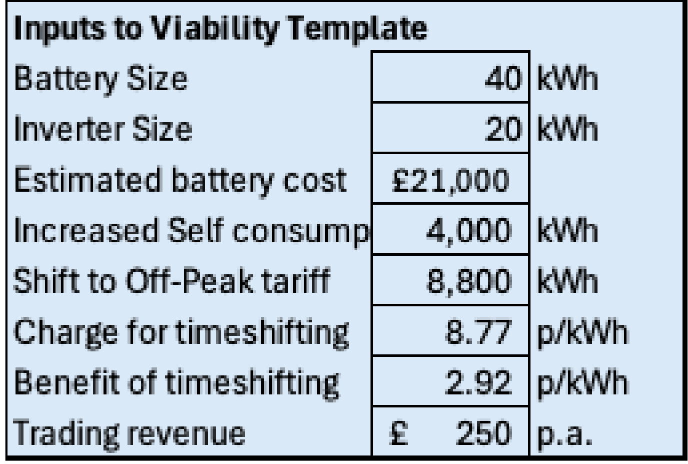
Sensitivity calculations are then driven by the values broad, cells H16 to H23 (for PV array size) and I25 to I33 (for battery size). These should be set either side of the starting values for the configuration. These then drive the following sensitivity calculations:

- **Payback versus PV capacity, for the starting battery size**: Graph across cells R11 to Q24. This gives a good feel for the ”sweet spot” on PV size.
- **Payback versus battery capacity, for the starting PV size**: Graph across cells R25 to Q38. Gives a feel for the "sweet spot" on battery size.
- **Full payback table by PV and battery size**: Table in cells H111 to Q120. Drills into how PV and battery size interact.
- **Battery payback by PV and battery size**: The above bullets show the payback on the full system (PV + Battery). The table in cells H136 to Q145 separates out the payback for the battery alone, to help determine whether it's worth adding a battery to the PV.

These graphs and tables can be used to set new starting values and sensitivities as necessary. Aa above, 1-2 iterations generally suffice. (The optimal points tend to be fairly broad, and the calculations are necessarily only estimates, given their dependency on forward energy prices and suchlike, so there isn't a lot to gain by trying to tune too finely. In any event, there is probably more to gain by using a standard configuration across multiple sites, e.g. in terms of negotiating leverage with OEMs and simplifying maintenance, than by trying to fine tune to each site.)

Note that the sensitivity analysis is time consuming – it needs to rerun the Annual Energy Model for each cell in the sensitivity tables. This can take 10 mins or so on a reasonably powerful laptop. The spreadsheet calculation parameter (under Calculation Options on the Formulas tab) is set to "Automatic Except for Data Tables" so that you only run these when you need them. This means that you need to select the Calculate Now button on the Formulas tab when you want to recalculate the sensitivities. (Excel also recalculates when you save. That's why the spreadsheet is set to read-only be default, so you don't incur this delay unless you really want it.)

4) Transfer parameters to Site Viability template



Inputs to Viability Template		
Battery Size	40	kWh
Inverter Size	20	kWh
Estimated battery cost	£21,000	
Increased Self consump	4,000	kWh
Shift to Off-Peak tariff	8,800	kWh
Charge for timeshifting	8.77	p/kWh
Benefit of timeshifting	2.92	p/kWh
Trading revenue	£ 250	p.a.

Once a preferred PV and battery configuration has been determined, key parameters can be transferred to GMCR's Site Viability template to calculate returns according to its standard model.

The relevant parameters are in the Outputs to Viability Template tab:

- **Battery Size**: The chosen battery size (kWh), resulting from the sensitivity analysis and iteration process of step (3).
- **Inverter Size**: The chosen inverter size (kW).
- **Estimate battery cost**: Estimated cost of the selected battery + inverter configuration (including installation costs). The spreadsheet gives an estimate based on generic cost parameters. If specific quotes / estimates are available from OEMs or installers, then these should be used in the Site Viability template instead of the estimates here.
- **Increased Self-Consumption**: Estimated annual increase to self-consumption from the site's PV array (kWh). We give an absolute figure rather than %, as this directly drives the value calculations. The Site Viability template uses this figure to determine how much additional energy GMCR can sell to the site via its standard charging model.
- **Shift to Off-Peak tariff**: Estimated annual amount of consumption that the battery can shift from peak to off-peak hours (kWh).
- **Charge for timeshifting**: The charge (p/kWh) that GMCR makes to the site for enabling energy to be shifted to cheaper times. This is calculated as a percentage (as entered in the Benefits Allocation inputs) of the difference between the peak and off-peak tariff.
- **Benefit of timeshifting**: The benefit the site gains from shifting consumption to off-peak hours (p/kWh). This is the remainder of the difference between the peak and off-peak tariff.
- **Trading revenue**: Estimate additional revenue (£ p.a.) that can be gained from actively trading the battery on markets such as NESO Demand Flexibility Service and Balancing Mechanism when it is not being used to optimise self-consumption or timeshift consumption to off-peak hours.

These can be copy-and-pasted from cells C3-C10 into the relevant cells (P3-P10) in the viability template.

5) Technical requirements to enable trading

Aggregator / VPP operator - to take the batteries to flex markets, GMCR will need to partner with an aggregator of some sort. For the simplest markets (DSO flex markets, possibly DFS although it's changing), it could conceivably do this itself, but to get maximum value from the various markets that have developed in UK, it'll need to work with a specialist. This partner will also bring the necessary technical platform. (GMCR might be able to work with open-source platforms that parties like Carbon Co-op have developed, but this will require skills and entail costs to run the platform. Again, the best option is most likely going to be to work with a partner.)

Technical requirements - the site systems will need to integrate with the aggregation platform. There has been a lot of discussion of interoperability standards for this (e.g. PAS 1878/1879 developed by DESNZ; project Mercury sponsored by Octopus), but none of these is yet widely adopted. So, the requirement is either to select aggregator and battery systems in a linked pair of decisions, requiring that the preferred aggregator will support the batteries and vice versa, or to select either an aggregator or battery supplier who is prepared to underwrite the technical work needed to integrate batteries and platform.

Administrative requirements - accessing flex markets entails registering with each flex buyer, demonstrating creditworthiness, assigning MPANs to flex units, tendering / bidding into auctions for flexibility, declaring availability, etc. One advantage of partnering with an aggregator is that they will manage this, across all the markets you are accessing. Note that the requirements are different for each market, and still evolving, so this can be a substantial task in its own right.

5) Technical requirements to enable trading

Commercial/Legal requirements - Flex buyers (e.g. DSOs, NESO) will probably write a framework agreement with each aggregator, then a schedule for each specific service for which they win a tender; or they might write a separate contract for each tender. This contract will define pricing, penalties for non-delivery, indemnities, etc. The aggregator will then pass these terms through to the flex providers from which it constructs its portfolio for any tender. The original terms from the flex buyer may not be suitable for domestic consumers (although the HomeFlex project is working on this), so the aggregator may need to adapt them to make them consumer-friendly. They'll also probably take on some of the portfolio risk (for non-delivery, indemnities, etc) themselves. There is no real standard for this, although the HomeFlex terms may eventually pass through in some way. In selecting an aggregator, you need to pay attention their commercial terms as well as their technical ability and market expertise.

NB there's scope for a community organisation (CIC, co-op, etc) to mediate between consumers and the aggregator. In that case, the contractual chain will be similar to flex buyer -> aggregator -> community org -> consumer, with each party taking on terms and risk it can accommodate. Small businesses like GMCR and schools aren't consumers, so don't enjoy the same protections, but for this discussion, it's advisable to see them as such.

NB this may change if aggregators become licensed entities, as below. (This is another reason GMCR may want to look for a partner - even if the licensing regime is 'light touch' by Ofgem's standards, it will create more overheads.) The contractual chain will probably remain the same, but the terms may change…

(Note also that GMCR will need a contract with the site to cover arrangements for it to install a battery on their land, import and pay for energy from the system, gain access for maintenance, etc.)

Regulatory requirements — the regulatory requirements for flex markets are currently very light. The complexities are all currently technical, commercial, market and administrative. There has been a move to bring in licensing for aggregators and this was re-affirmed in last week's CP2030 Action Plan from the government. The main objective here is to ensure that consumers are adequately protected. Again, this is something that is advisable to leave for the aggregators.

In selecting an aggregator, it is advisable to look for one that has expressed support for HomeFlex, as regulation will probably be influenced by that, or its parent FlexAssure. (FlexAssure is for C&I customers; HomeFlex extends it for domestic ones. FlexAssure was set up by ADE based on its Heat Trust model for distract heating providers, so it has a decent track record of bulding self-assurance schemes for sectors before they get pulled into Ofgem's sphere.) Note that "expressed support" is a weak requirement — FlexAssure has a degree of audit built in (but it's still really getting that ramped up in practice); HomeFlex isn't yet that solid. So, there won't be any real weight behind this expression.

6) Legislation and Health & Safety Requirements for Installing Battery Storage on School Premises

Key Legislation and Standards

1. **Health and Safety at Work Act 1974 (UK):** This act places a duty on schools to ensure the safety of anyone on their premises, including the safe installation and maintenance of battery storage systems.

2. **Electricity at Work Regulations 1989:** These regulations require that electrical installations are maintained to prevent danger.

3. **The Control of Major Accident Hazards (COMAH) Regulations 2015:** Depending on the size of the battery storage system, schools may need to comply with COMAH regulations to manage risks associated with hazardous substances.

4. **Building Regulations:**

Part B (Fire Safety): Fire safety measures must address risks related to battery systems, including fire suppression systems and safe positioning of batteries. (Many battery casings have built-in fire suppression systems)

Part P (Electrical Safety): Electrical installations must be designed and tested by qualified professionals.

6) Legislation and Health & Safety Requirements for Installing Battery Storage on School Premises

Key Legislation and Standards

5. **Battery-Specific Standards and Guidelines**

   BS EN IEC 62485-2:2018 (Safety Requirements for Secondary Batteries and Battery Installations)
   Provides safety standards for battery systems, including ventilation, fire suppression, and operational safety.

   BS 7671 (IET Wiring Regulations)
   Governs electrical safety for battery storage installations **Fire Safety Regulations: Fire safety must be considered, with guidance provided by the Fire Safety Risk Assessment for Educational Premises.**

6. **Fire and Building Safety**

   Fire Safety Order 2005
   Schools must conduct a fire risk assessment and ensure that battery systems are included in fire safety plans, considering storage location and emergency response protocols.

6) Legislation and Health & Safety Requirements for Installing Battery Storage on School Premises

Technical and Safety Considerations

1. **Ingress Protection (IP) Ratings**:
    1. **IP55**: Protected against limited dust ingress and water jets from any direction.
    2. **IP65**: Fully protected against dust ingress and low-pressure water jets from any direction. These ratings determine the suitability of battery enclosures in various environments. For outdoor installations, an IP65 rating is typically recommended to provide adequate protection against the elements.
2. **Location**:
    1. **Indoor Storage**: Batteries can be stored inside provided there is proper ventilation, and the area is free from flammable materials. Compliance with specific room designations, fire safety measures, and ventilation is required to manage potential hazards such as heat buildup or gas emissions.
    2. **Outdoor Storage**: Outdoor storage is often preferred for large battery systems to mitigate risks associated with heat and flammable gases. IP65-rated enclosures are recommended to protect the batteries from weather conditions. Battery performance is reduced in colder temperatures, and some may not fuction in sub-zero environments. If the battery is being installed outside, consider an installation with a built-in heating system.
    3. **Playground Areas**: Installing battery storage in playgrounds is generally discouraged unless securely enclosed and placed in areas where students cannot access them, ensuring compliance with child safety standards.
    4. **Car Parks**: Car parks can be suitable locations for battery storage, provided that the installation is secure, protected from vehicle collisions, and compliant with fire safety and IP ratings for outdoor environments.
3. **Safety Measures**:
    1. **Signage**: Proper signage indicating high voltage and safety hazards should be placed around the battery storage area.
    2. **Emergency Procedures**: Schools must have clear emergency procedures, including fire response plans, for incidents involving battery storage systems.
    3. **Maintenance**: Regular maintenance and inspection are required to ensure the system operates safely and efficiently. Installers may offer monitoring and maintenance services as part of their contract.

6) Legislation and Health & Safety Requirements for Installing Battery Storage on School Premises

Other practical considerations

- **Noise and Disruption:** Systems must comply with noise limits and avoid disrupting school activities.
- **Emergency Planning:** Procedures should cover battery failure, chemical leaks, or fire, with regular staff training.
- **Insurance Requirements:** Schools should consult their insurers to ensure coverage for new installations.

Battery Viability Assessment

Thank You

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