Solar for GM Faiths

15 May 2025

Data from three sites partially redacted to conceal commercially sensitive data.

In these cases all costs and savings are expressed as percentage of current electricity bill.

Contents

Summary

- We have modelled the potential returns of installing solar PV and batteries at several places of worship in Greater Manchester. Such systems have potential to reduce the sites' electricity costs by using free electricity generated by the PV array ("self-consumption") rather than buying it from the grid. Adding batteries can increase the level of self-consumption. They can also enable the site to buy from the grid at times when energy prices are lowest, for consumption later, when prices are higher ("timeshifting"). There is also potential to earn some additional returns by using the batteries to participate in markets for energy flexibility. (Noting that doing this will require the sites to partner with a suitable aggregator.)
- Our modelling[1] suggests that the optimum system for each site is as follows:

	PV	Battery	Annual Saving	Payback (years)
Site A - current	**30kW**	**-**	~£6,900	~5
Site A – added daytime load	**30kW**	**-**	~£7,600	~5
Site A – added evening load	**30kW**	**-**	~£6,900	~5
Site B	**6kW**	**4kWh**	~£1,500	~7
Site C	**8kW**	**4kWh**	~ 47%	~5
Site D	**10kW**	**4kWh**	~ 43%	~5
Site E	**8kW**	**6kWh**	~£2,200	~6
Site F	**10kW**	**15kWh**	~ 35%	~6

- Note that this modelling is dependent on assumptions about the the sites' energy consumption patterns, future energy prices and tariffs, PV and battery prices, etc, so cannot be guaranteed. However, the payback times given above are in line with results elsewhere in the UK. For example, ChatGPT reports that "*the typical payback period for a 30 kWp solar PV system on a commercial rooftop in the UK is usually between 5 and 8 years, depending on the specific conditions of the installation and business. After that, the system continues to generate savings for the remainder of its 25+ year lifespan.*" Thus we would recommend that these sites consider installing PV arrays. The next step would be to obtain specific quotes for installing these systems at each of the sites.
- Our modelling suggests that installing small batteries alongside these PV arrays yields a decent payback in some cases but gives very marginal returns (with paybacks exceeding 10 years) in others. However, batteries would also help mitigate the risk of future energy cost price increases, so it may be worth considering them at additional sites.

[1] Further details of our modelling approach are given in the appendices. The model spreadsheets have been supplied separately.

Site A – Current Load

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 the site's half-hourly energy consumption data for Dec 2022 to Dec 2023, and applied the (fixed) tariff paid by the site at the end of this period to estimate future electricity costs.

b) We have used the PV generation profile from a similar site (in terms of total energy consumption) in Greater Manchester. We have also used peak and off-peak tariffs from that site, as representative examples of the type of Time of Use (ToU) tariff that the Site A might be able to obtain. We have assumed that the off-peak period is from midnight to 7am.

c) We have estimated an export tariff based on web research plus experience at other sites in Greater Manchester, as we did not have an export tariff for the site.

d) Energy costs are likely to be volatile over the life of the systems being modelled. It is also possible that the site's energy consumption patterns will change over time. So our results should be seen as estimates. We cannot guarantee that specific levels of return will be obtained over the life of the systems.

Site A – Current Load – Summary

Base		Interventions	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading
Total Consumption:	58,138	Total Grid Demand:	39,965	35,631	36,141	36,141
Peak Consumption:	45,294	Peak Grid Demand:	27,276	23,789	17,956	17,956
Off-Peak Consumption:	12,844	Off-Peak Grid Demand:	12,689	11,842	18,185	18,185
Cost on Fixed Tariff:	£18,040	PV Generation:	28,338	28,338	28,338	28,338
Cost on Tou Tariff:	£19,643	Cost on Fixed Tariff:	£12,401	£11,056	£11,215	£10,963
		Cost on Tou Tariff:	£13,052	£11,575	£11,019	£10,767
		Export:	10,165	5,831	6,341	6,341
		Export Earnings:	£1,220	£700	£761	£761
		Annual Saving:	£6,859	£7,684	£7,782	£8,034

- We estimate a PV array could reduce the site's energy costs by approx. £6.9k (35%) p.a., from £18k to £11k (after accounting for export earnings). This is for an array sized at about 30kWp. A larger array would give further benefit (e.g. doubling the array size might increase the savings by about 50%), but the best return on investment (ROI) is at 20-30kWp. This array would pay back its costs in about 5-6 years.
- Adding a 30kWh battery would increase the saving to approx. £8k (41%) p.a. This would give a very marginal return on investment, paying back after about 14 years. The bulk of this benefit comes from increasing the self-consumption of energy generated by the PV array. The benefits of timeshifting are marginal, only just exceeding the cost of moving to a Time-of-Use tariff (which would increase the cost of energy consumed during the day c.f. the current fixed tariff).

Site A – Current Load – System Sizing

These tables show the annual cost saving (i.e. reduction to energy costs) that the system could deliver, and hence the payback (in years) that the site might achieve from a PV plus battery system for a range of array and battery sizes.

It can be seen that the optimal return[1] is achieved from a 20-30kW PV array with no battery. Adding a battery increases the optimal size of the array, e.g. pushing it to 40kW for a 60kWh battery. However, the optimum is broad and shallow, so there is a fairly wide range of battery and PV sizes that work reasonably well.

Although the optimum system has no battery, adding a battery does not increase the payback time dramatically and the overall return is still decent for many configurations. Thus it may be worth investing in a battery as this could yield reasonable returns, even if not as high as for PV alone. (Noting also that, by increasing self-consumption, the battery will help mitigate the risk of future energy price increases.)

Full System Saving p.a.		Size of Battery							
	£8,034.05	0.000	5.000	10.000	20.000	30.000	40.000	60.000	80.000
Size of PV Array	10.000	£2,878.60	£2,961.30	£3,020.09	£3,107.42	£3,196.84	£3,551.03	£4,201.32	£4,767.89
	20.000	£5,096.27	£5,266.99	£5,414.48	£5,624.13	£5,925.67	£6,242.59	£6,753.68	£7,183.82
	30.000	£6,858.83	£7,078.87	£7,269.35	£7,603.51	£8,034.05	£8,394.81	£8,887.43	£9,265.07
	40.000	£8,395.13	£8,643.56	£8,878.63	£9,301.22	£9,816.91	£10,180.66	£10,730.59	£11,087.40
	50.000	£9,818.68	£10,090.59	£10,337.90	£10,854.47	£11,393.91	£11,775.67	£12,331.03	£12,639.11
	60.000	£11,166.10	£11,460.35	£11,732.90	£12,325.90	£12,883.42	£13,300.20	£13,855.55	£14,181.36
	70.000	£12,465.18	£12,767.96	£13,059.57	£13,717.25	£14,296.38	£14,721.57	£15,282.41	£15,623.48
	80.000	£13,737.16	£14,045.78	£14,346.13	£15,039.44	£15,634.55	£16,072.49	£16,632.82	£16,963.29

Full System Payback		Size of Battery							
(years - excludes financing)		0.000	5.000	10.000	20.000	30.000	40.000	60.000	80.000
Size of PV Array	10.000	5.9	6.4	7.0	8.0	9.1	9.3	9.8	10.3
	20.000	5.3	5.5	5.7	6.2	6.6	6.9	7.6	8.2
	30.000	5.4	5.5	5.6	5.9	6.1	6.3	6.9	7.4
	40.000	5.6	5.7	5.7	5.9	6.0	6.2	6.6	7.1
	50.000	5.8	5.8	5.9	6.0	6.1	6.2	6.6	7.0
	60.000	6.0	6.0	6.1	6.1	6.1	6.2	6.6	7.0
	70.000	6.2	6.2	6.2	6.2	6.2	6.3	6.6	7.0
	80.000	6.3	6.3	6.3	6.3	6.3	6.4	6.7	7.0

[1] We calculate return as simple payback – capital cost of the system / annual energy cost saving – in years. This is the starting point for more sophisticated financial analysis, which requires assumptions on cost of capital, time value of money, etc, and is dependent on the asset ownership model, e.g. whether the system is owned by the site or by a separate investor. If the simple payback suggests the asset is viable, then it is worthwhile obtaining more detailed price estimates and undertaking full financial analysis.

Site A – Current Load – Battery Sizing

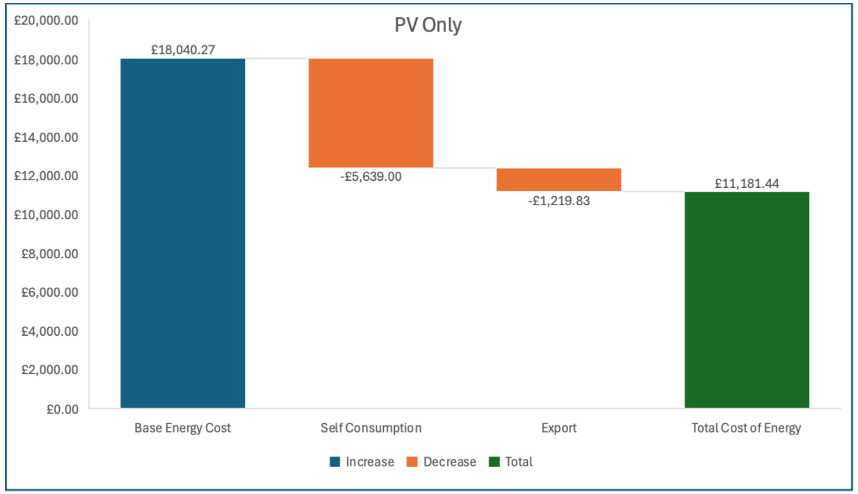
These tables show the proportion of the annual saving that can be attributed to the battery, and the payback (in years) that this would yield for investing in the battery.

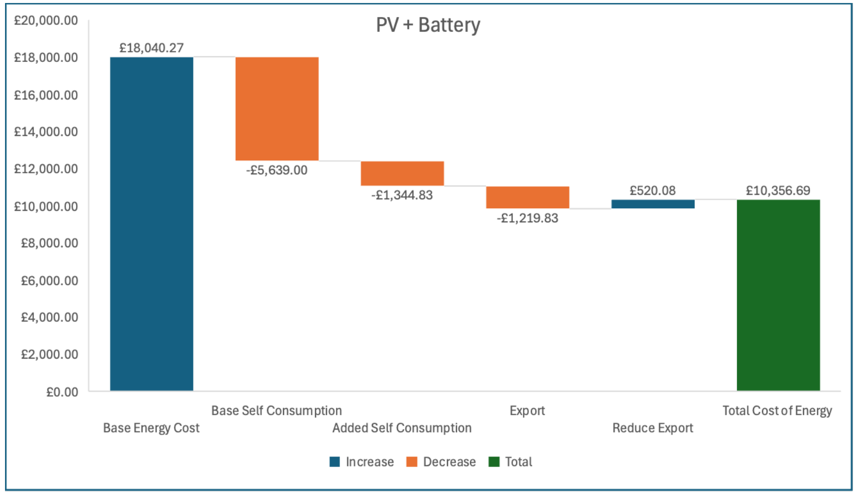
It can be seen that the optimum return is achieved for a 30-40kWh battery for most PV array sizes, and that the return improves as the size of the array grows. For the recommended PV size on this site (30kWp), the payback on a 30-40kWh battery would be about 14 years. This is not particularly attractive, as it aligns to the expected life of the battery. Nonetheless, it might worth installing such a battery for the risk mitigation benefits mentioned earlier.

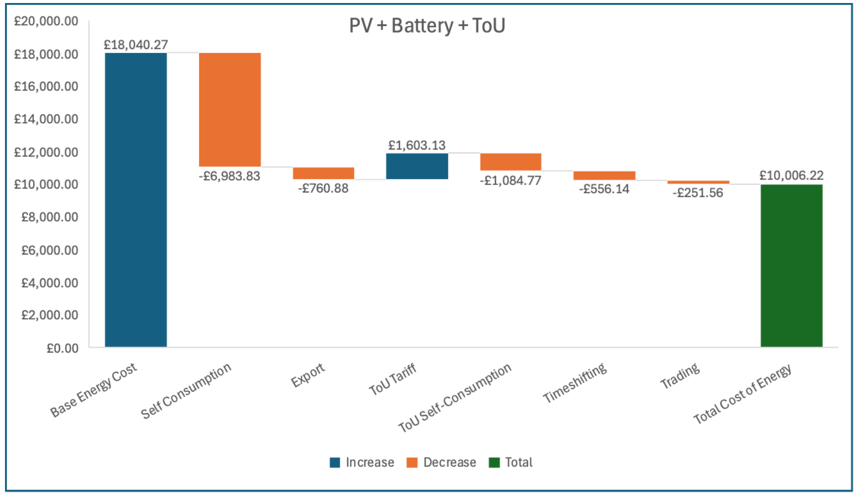
Battery Savings		Size of Battery							
	£1,175.22	0.000	5.000	10.000	20.000	30.000	40.000	60.000	80.000
Size of PV Array	10.000	£0.00	£82.69	£141.49	£228.82	£318.24	£672.43	£1,322.72	£1,889.28
	20.000	£0.00	£170.72	£318.21	£527.86	£829.40	£1,146.32	£1,657.41	£2,087.55
	30.000	£0.00	£220.04	£410.52	£744.68	£1,175.22	£1,535.98	£2,028.60	£2,406.24
	40.000	£0.00	£248.42	£483.50	£906.09	£1,421.77	£1,785.53	£2,335.46	£2,692.27
	50.000	£0.00	£271.91	£519.22	£1,035.79	£1,575.23	£1,956.99	£2,512.35	£2,820.43
	60.000	£0.00	£294.25	£566.80	£1,159.80	£1,717.32	£2,134.10	£2,689.45	£3,015.26
	70.000	£0.00	£302.77	£594.38	£1,252.07	£1,831.20	£2,256.39	£2,817.23	£3,158.29
	80.000	£0.00	£308.62	£608.96	£1,302.27	£1,897.39	£2,335.33	£2,895.65	£3,226.13

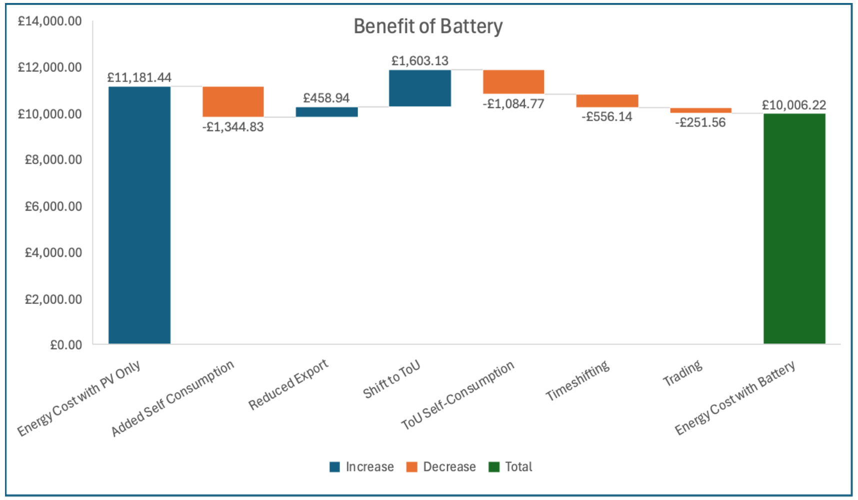
Battery Payback		Size of Battery							
		0.000	5.000	10.000	20.000	30.000	40.000	60.000	80.000
Size of PV Array	10.000	5000.0	84.7	63.6	56.8	53.4	31.2	21.9	19.6
	20.000	5000.0	41.0	28.3	24.6	20.5	18.3	17.5	17.7
	30.000	5000.0	31.8	21.9	17.5	14.5	13.7	14.3	15.4
	40.000	5000.0	28.2	18.6	14.3	12.0	11.8	12.4	13.7
	50.000	5000.0	25.7	17.3	12.6	10.8	10.7	11.5	13.1
	60.000	5000.0	23.8	15.9	11.2	9.9	9.8	10.8	12.3
	70.000	5000.0	23.1	15.1	10.4	9.3	9.3	10.3	11.7
	80.000	5000.0	22.7	14.8	10.0	9.0	9.0	10.0	11.5

Site A – Current Load – Benefits Breakdown









The bulk of the benefit from the PV array comes from allowing the site to use free solar energy rather than buying electricity from the grid (“self-consumption”). This yields a saving of about £5.6k p.a. from the PV array alone. Adding a battery increases this by a further £1.3k.

There is also a small benefit from exporting excess PV generation to the grid (typically during the summer). Adding a battery reduces this benefit, as it enables some of the excess generation to be self-consumed, which is generally more valuable.

The battery could also be used to shift some of the site’s consumption from peak to off-peak times. This is only worthwhile if the site switches to a Time-of-Use tariff, which would entail some cost (as it increases the cost of energy consumed at peak times). The time-shifting benefit only just compensates for this cost.

Finally, spare capacity in the battery could be used to trade on wholesale & flexibility markets. The returns on such trading can be volatile, but we have estimated that they could generate revenue of the order of £250p.a. for the site.

Site A – Current Load – 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:	45,294	27,276	23,789	17,956	17,956		148
	Off-Peak Grid Demand:	12,844	12,689	11,842	18,185	18,185		57
	PV Generation:	0	28,338	28,338	28,338	28,338		0
	Export:	0	10,165	5,831	6,341	6,341		-133
	kgCO2							
	Peak Grid Demand:	6,704	4,037	3,521	2,658	2,658		
	Off-Peak Grid Demand:	732	723	675	1,037	1,037		
	PV Generation:	-	-	-	-	-		
	Export:	-	(1,352)	(776)	(843)	(843)		
	Total	**7,436**	**3,408**	**3,420**	**2,851**	**2,851**		
	Reduction		**4,027**	**4,015**	**4,585**	**4,585**		
	Benefit of Battery			**(12)**	**557**	**557**		

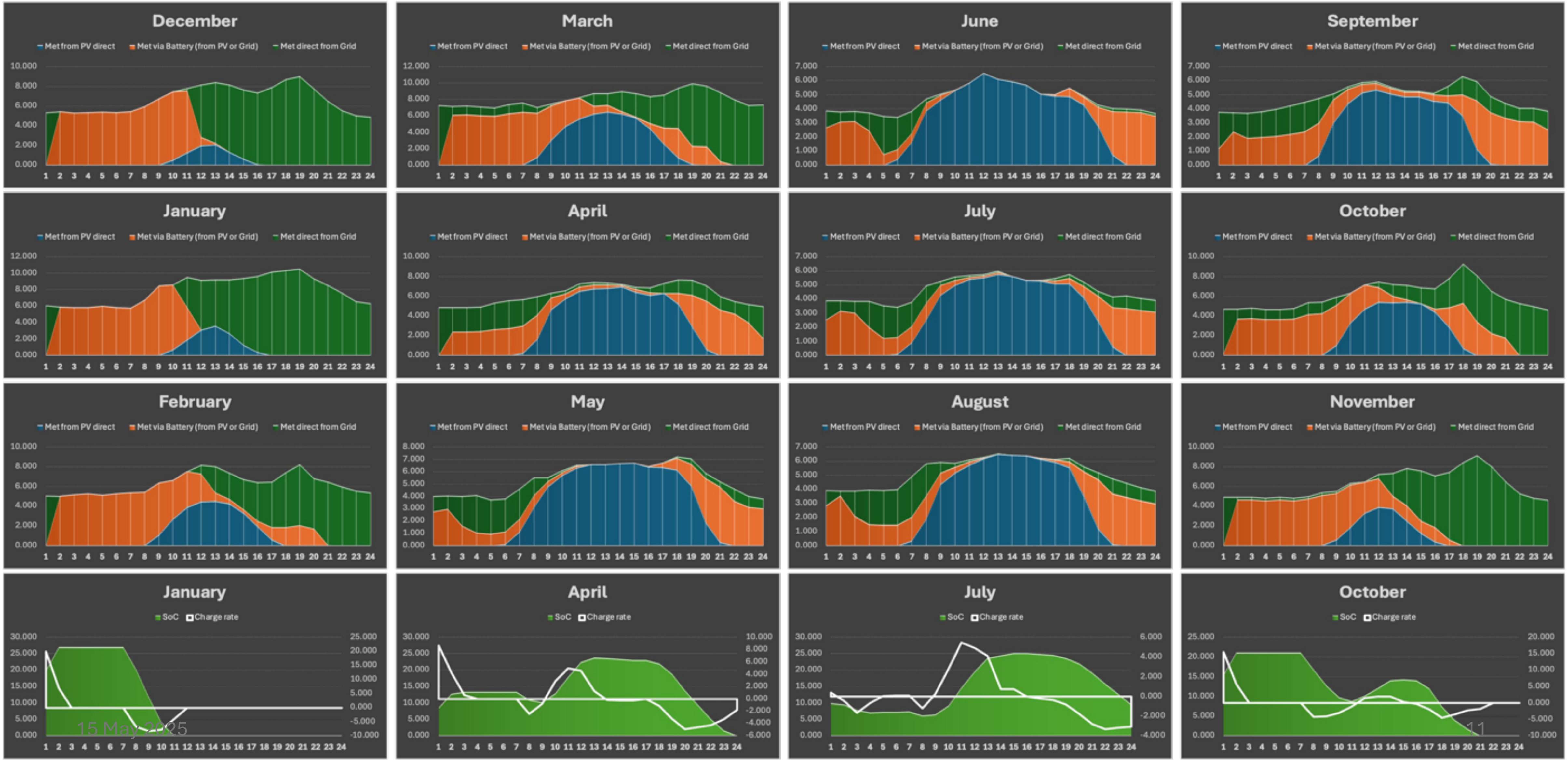
- Adding a PV array would enable the site to reduce its carbon footprint by about 4 tCO2e p.a. Adding a battery would yield an additional carbon saving of approx. 0.5 tCO2e p.a., primarily by time-shifting the site's consumption to times when grid carbon intensity is lower.
- Note that these calculations are highly dependent on assumptions about grid carbon intensity and how the benefits of the PV array are accounted for. We tend to use fairly conservative assumptions, as the grid's carbon intensity is declining rapidly and so the future benefit of avoiding importing from the grid will decline.

Site A – Current Load – Energy usage patterns

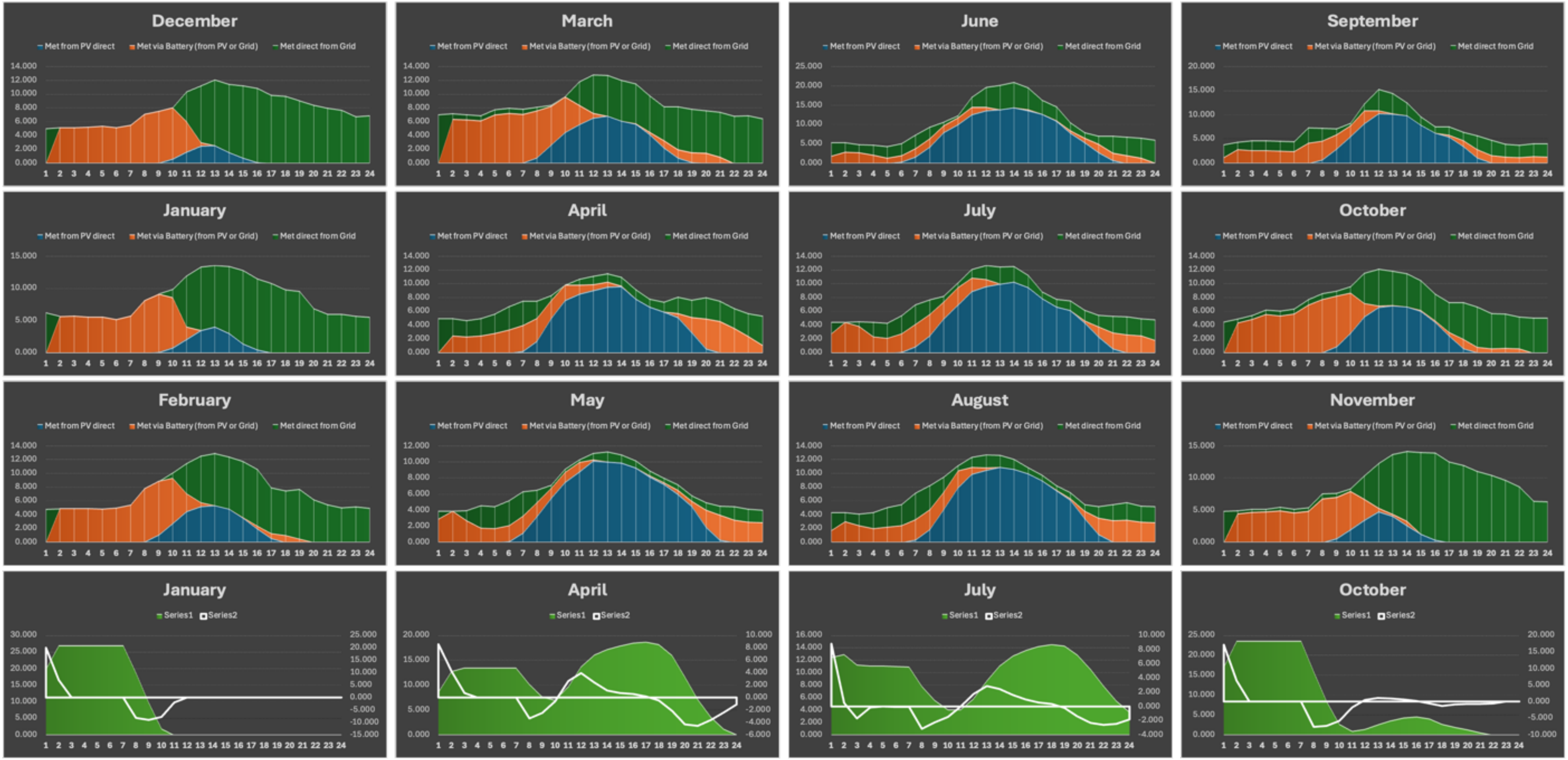
The next 2 slides show the average daily energy usage pattern for each month of the year, for weekdays and weekends respectively. These give a more detailed feel for how the PV energy and battery might be used. Features of the usage patterns include:

- 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 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. 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 generally outweighs that of using off-peak energy from the grid, so it forgoes some of the latter.)
- By June, the PV is meeting demand during the day most weekdays, and the excess is sufficient to meet evening demand on those days and some of the morning demand the next day. The battery may also capture some energy overnight and use it to meet some of the morning demand, but this is much reduced compared to the Spring months.
- In Autumn, the pattern goes back to that of the Spring months, with the battery cycling twice per day, once from the solar PV and once from cheap overnight electricity from the grid.
- Consumption at weekends is higher, especially in the middle of the day. The generation and consumption patterns are broadly similar to weekdays, however – the differences are in degree rather than in the overall shape of the energy usage.

Site A – Current Load – Weekday energy usage



Site A – Current Load – Weekend energy usage



Site A – Added Daytime Load

We have modelled the effect of adding approximately 20% additional electrical load at the Site A, e.g. by running 3kW of electrical cooking appliances for 10hrs per day (8am-6pm) throughout the year (giving a total added load of 10,920kWh). All other assumptions (e.g. about generation profile and tariffs) remain the same.

Site A – Added Daytime Load – Summary

Base		Interventions	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading
Total Consumption:	69,088	Total Grid Demand:	47,263	43,962	44,514	44,514
Peak Consumption:	56,244	Peak Grid Demand:	34,574	31,936	24,812	24,812
Off-Peak Consumption:	12,844	Off-Peak Grid Demand:	12,689	12,026	19,702	19,702
Cost on Fixed Tariff:	£21,438	PV Generation:	28,338	28,338	28,338	28,338
Cost on Tou Tariff:	£23,626	Cost on Fixed Tariff:	£14,666	£13,641	£13,813	£13,562
		Cost on Tou Tariff:	£15,706	£14,583	£13,887	£13,636
		Export:	6,513	3,212	3,764	3,764
		Export Earnings:	£782	£385	£452	£452
		Annual Saving:	£7,554	£8,182	£8,077	£8,327

- A 30kW PV array now reduces the sites energy costs by about £7.6k p.a. (c.f. £6.9k for the base case), i.e. it offsets about £700 of the cooking costs. However, the site's costs would still be increased by approx. £2k p.a., as the array cannot offset a significant amount of the cooking load, especially during mornings, evenings and winter months. A larger array would yield larger savings, but the optimum payback remains at about 30kW.
- Adding a 30kWh battery would increase the saving to approx. £8.3k p.a. However, the payback period on this battery has gone from ~14 years in the base case to ~22 years. This is because much of the added load is during peak PV generation, so there is less need for a battery to timeshift the generated energy. Likewise, timeshifting generation from the overnight low-cost period into the morning peak does not compensate for the cost of moving to a Time-of-Use tariff for this load profile, with so much of the consumption in the middle of the day.

Site A – Added Daytime Load – System Sizing

These tables show the annual saving and payback (in years) that the site might now achieve from a PV plus battery system for a range of array and battery sizes.

It can be seen that the optimal return is still achieved from a 20-30kW PV array with no battery. The payback period has reduced by ~6 months, making a PV array even more attractive in this scenario. (Not surprisingly, given the added load in the middle of the day.) However, the benefit is not sufficient to justify buying a larger array on financial savings alone.

Note also that this scenario does not include the cost and emission savings created by shifting from gas to electric cooking. If the Site A were to shift to electric cooking for environmental reasons, then a PV array would be highly attractive.

Full System Saving p.a.		Size of Battery							
	£8,327.31	0.000	5.000	10.000	20.000	30.000	40.000	60.000	80.000
Size of PV Array	10.000	£2,931.09	£2,980.50	£3,031.62	£3,128.58	£3,191.73	£3,183.65	£3,769.66	£4,459.99
	20.000	£5,527.67	£5,654.44	£5,760.46	£5,903.17	£5,981.35	£6,112.59	£6,726.27	£7,273.49
	30.000	£7,553.84	£7,737.26	£7,903.48	£8,162.73	£8,327.31	£8,604.03	£9,151.83	£9,585.09
	40.000	£9,276.24	£9,495.36	£9,693.11	£10,044.87	£10,297.03	£10,615.34	£11,165.78	£11,557.86
	50.000	£10,824.62	£11,068.97	£11,298.61	£11,691.07	£12,024.72	£12,399.07	£12,956.22	£13,344.99
	60.000	£12,274.36	£12,534.03	£12,782.15	£13,226.31	£13,622.36	£14,006.22	£14,575.31	£14,923.52
	70.000	£13,652.82	£13,931.24	£14,188.34	£14,664.29	£15,118.88	£15,537.63	£16,092.26	£16,474.21
	80.000	£14,977.28	£15,272.98	£15,549.51	£16,052.96	£16,560.99	£16,979.77	£17,547.11	£17,939.07

Full System Payback		Size of Battery							
(years - excludes financing)		0.000	5.000	10.000	20.000	30.000	40.000	60.000	80.000
Size of PV Array	10.000	5.8	6.4	6.9	8.0	9.1	10.4	10.9	11.0
	20.000	4.9	5.1	5.4	5.9	6.5	7.0	7.6	8.1
	30.000	4.9	5.0	5.2	5.5	5.9	6.2	6.7	7.2
	40.000	5.1	5.2	5.3	5.5	5.7	5.9	6.4	6.8
	50.000	5.3	5.3	5.4	5.6	5.7	5.9	6.3	6.7
	60.000	5.5	5.5	5.6	5.7	5.8	5.9	6.2	6.6
	70.000	5.6	5.7	5.7	5.8	5.9	6.0	6.3	6.6
	80.000	5.8	5.8	5.9	5.9	6.0	6.1	6.3	6.6

Site A – Added Daytime Load – Battery Sizing

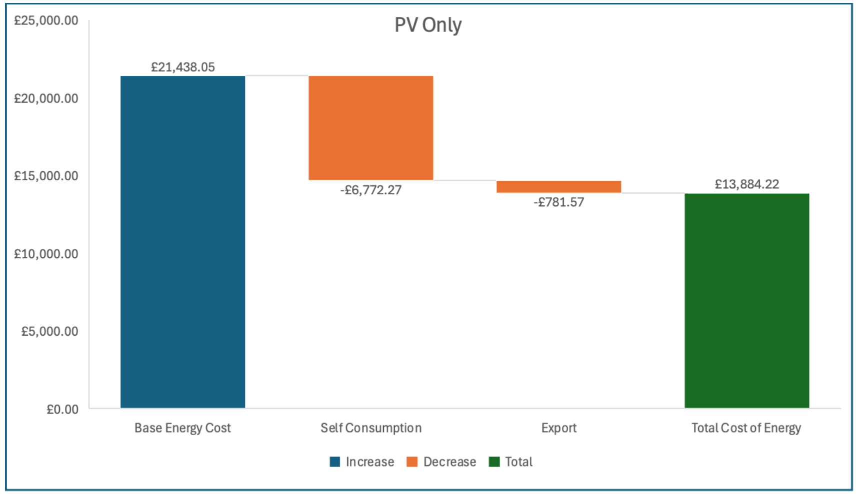
These tables show the proportion of the annual saving that can be attributed to the battery, and the payback (in years) that this would yield for investing in the battery under this scenario.

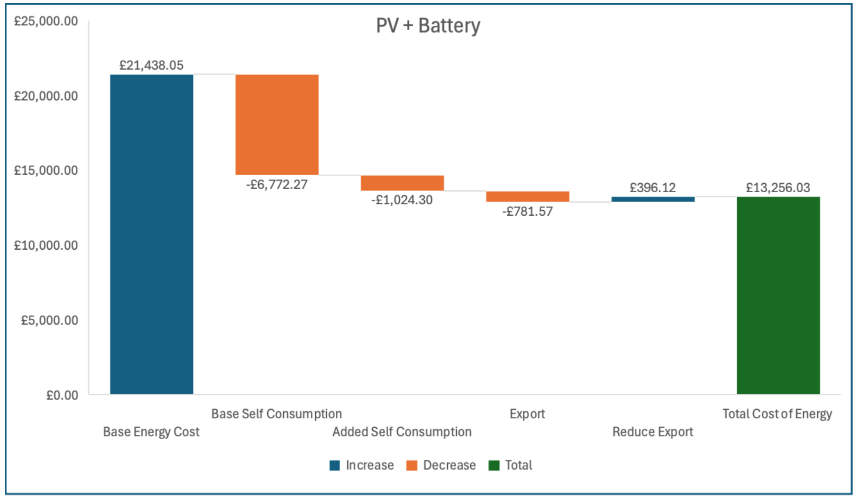
The optimum return may be for a slightly larger battery than the base case, 40kWh or even slightly larger. However, the payback period has lengthened (from 14 to 20 years) because, as noted earlier, there is less need to timeshift solar generation with so much added load in the middle of the day.

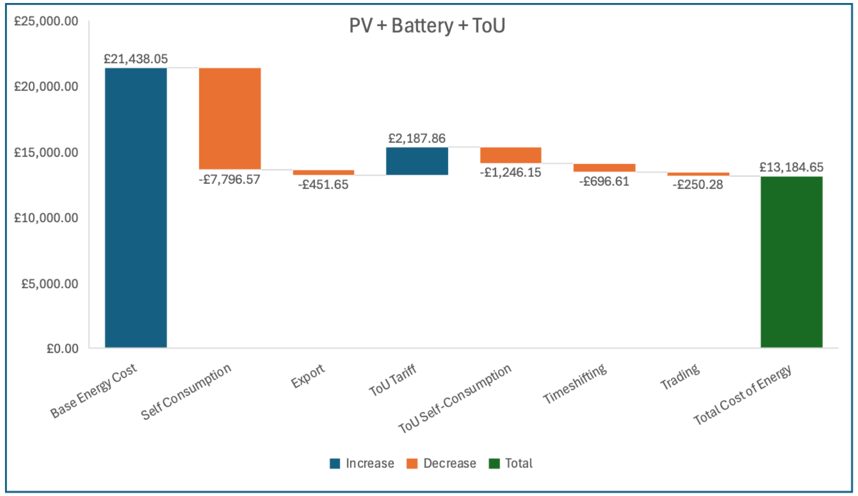
Battery Savings		Size of Battery							
	£773.47	0.000	5.000	10.000	20.000	30.000	40.000	60.000	80.000
Size of PV Array	10.000	£0.00	£49.41	£100.53	£197.49	£260.64	£252.56	£838.57	£1,528.90
	20.000	£0.00	£126.77	£232.79	£375.51	£453.69	£584.93	£1,198.60	£1,745.82
	30.000	£0.00	£183.42	£349.64	£608.89	£773.47	£1,050.19	£1,597.99	£2,031.26
	40.000	£0.00	£219.12	£416.87	£768.63	£1,020.79	£1,339.10	£1,889.54	£2,281.62
	50.000	£0.00	£244.35	£473.99	£866.45	£1,200.10	£1,574.45	£2,131.59	£2,520.37
	60.000	£0.00	£259.68	£507.80	£951.95	£1,348.00	£1,731.86	£2,300.96	£2,649.16
	70.000	£0.00	£278.42	£535.52	£1,011.47	£1,466.06	£1,884.81	£2,439.44	£2,821.39
	80.000	£0.00	£295.70	£572.23	£1,075.68	£1,583.71	£2,002.49	£2,569.84	£2,961.79

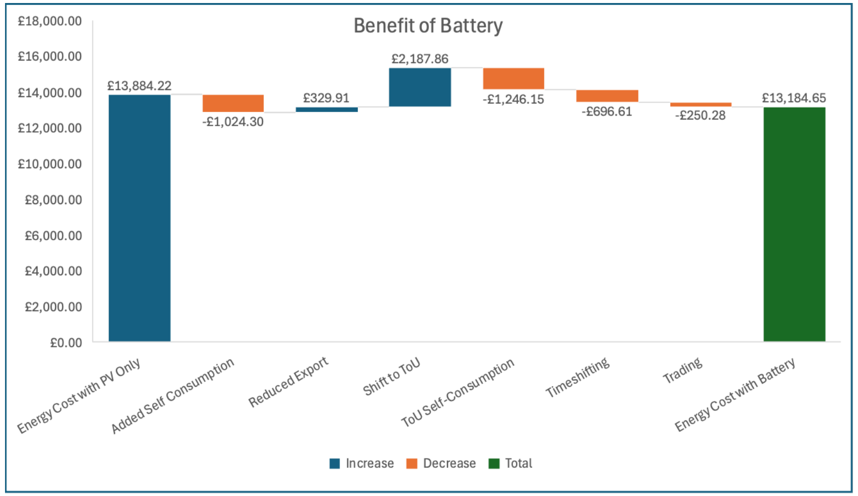
Battery Payback		Size of Battery							
		0.000	5.000	10.000	20.000	30.000	40.000	60.000	80.000
Size of PV Array	10.000	5000.0	141.7	89.5	65.8	65.2	83.1	34.6	24.2
	20.000	5000.0	55.2	38.7	34.6	37.5	35.9	24.2	21.2
	30.000	5000.0	38.2	25.7	21.4	22.0	20.0	18.1	18.2
	40.000	5000.0	31.9	21.6	16.9	16.7	15.7	15.3	16.2
	50.000	5000.0	28.6	19.0	15.0	14.2	13.3	13.6	14.7
	60.000	5000.0	27.0	17.7	13.7	12.6	12.1	12.6	14.0
	70.000	5000.0	25.1	16.8	12.9	11.6	11.1	11.9	13.1
	80.000	5000.0	23.7	15.7	12.1	10.7	10.5	11.3	12.5

Site A – Added Daytime Load – Benefits Breakdown









Again, the bulk of the benefit comes from self-consuming energy generated by the PV array, yielding a cost saving of about £6.8k p.a. Adding a battery increases this by about £1k p.a.

There is a small additional benefit from exporting excess energy to the grid.

Shifting to a Time-of-Use tariff and using the battery to timeshift energy from off-peak times has little or no additional value – the increased peak time costs of the tariff outweigh the benefits of timeshifting from the off-peak tariff. (This balance might shift if a larger differential between peak and off-peak rates could be negotiated.)

Site A – Added Daytime Load – Carbon Savings

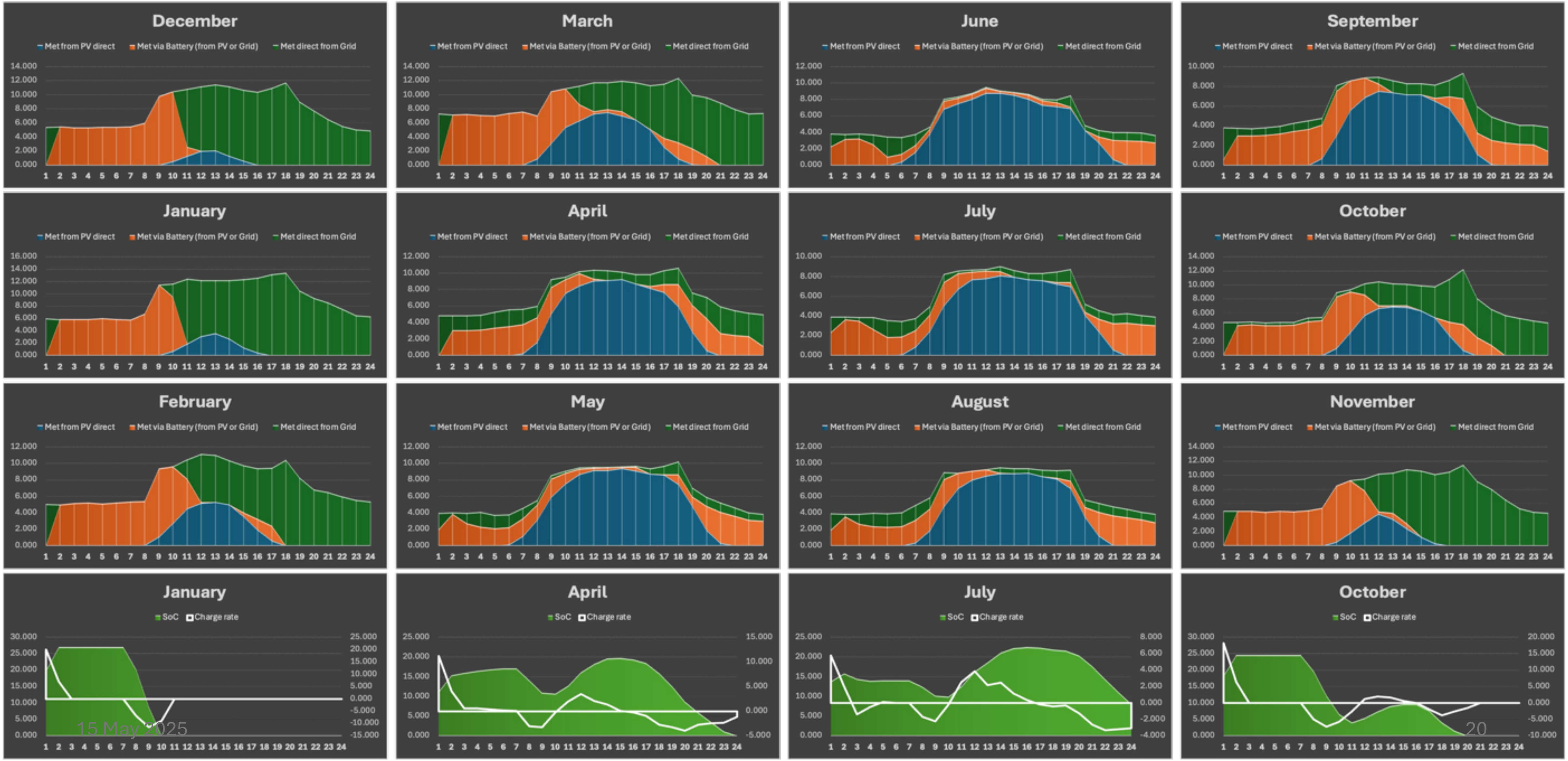
Carbon Benefits	kWh	Baseline	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading		Carbon Intensity
	Peak Grid Demand:	56,244	34,574	31,936	24,812	24,812		148
	Off-Peak Grid Demand:	12,844	12,689	12,026	19,702	19,702		57
	PV Generation:	0	28,338	28,338	28,338	28,338		0
	Export:	0	6,513	3,212	3,764	3,764		-133
	kgCO2							
	Peak Grid Demand:	8,324	5,117	4,727	3,672	3,672		
	Off-Peak Grid Demand:	732	723	685	1,123	1,123		
	PV Generation:	-	-	-	-	-		
	Export:	-	(866)	(427)	(501)	(501)		
	Total	**9,056**	**4,974**	**4,985**	**4,295**	**4,295**		
	Reduction		**4,082**	**4,071**	**4,762**	**4,762**		
	Benefit of Battery			**(11)**	**679**	**679**		

- The PV array yields marginal additional environmental benefit c.f. the base case. But again, note that this does not include the benefit of shifting from gas cooking – that would yield a substantial reduction to the carbon footprint.

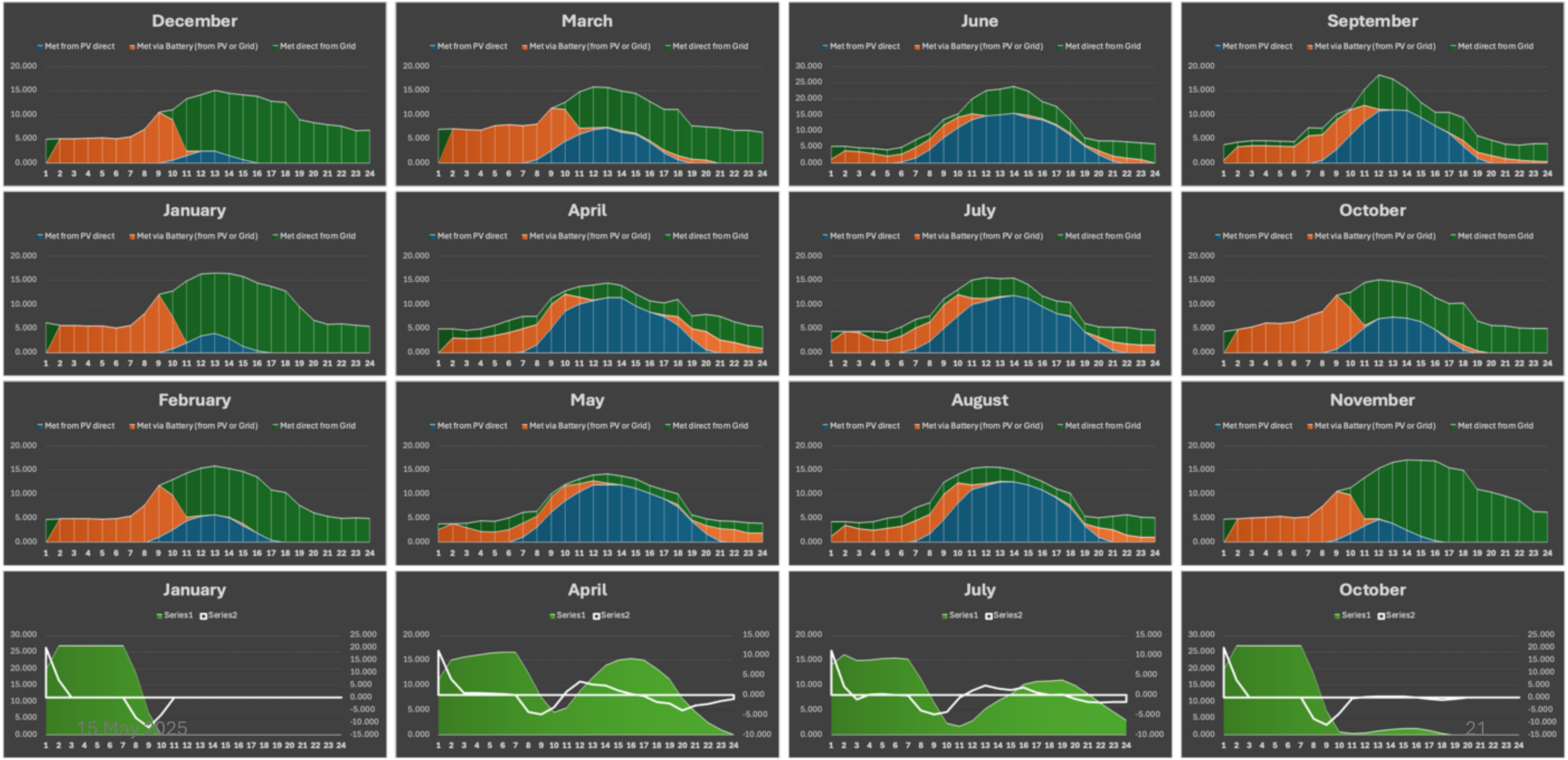
Site A – Added Daytime Load – Energy usage patterns

The next 2 slides show the average daily energy usage pattern for each month of the year, for weekdays and weekends respectively. The patterns are broadly similar to those for the base case, with some variations in the details due to the added daytime load.

Site A – Added Daytime Load – Weekday energy usage



Site A – Added Daytime Load – Weekend energy usage



Site A – Added Evening Load

We also modelled the effect of adding approximately 20% additional electrical load at the Site A, e.g. by running 3-6kW of electrical cooking appliances for 4hrs each evening (5-9pm) throughout the year, again giving a total added load of 10,920kWh. All other assumptions (e.g. about generation profile and tariffs) remain the same.

Site A – Added Evening Load – Summary

Base		Interventions	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading
Total Consumption:	69,088	Total Grid Demand:	50,509	46,191	46,823	46,823
Peak Consumption:	56,244	Peak Grid Demand:	37,820	33,502	27,644	27,644
Off-Peak Consumption:	12,844	Off-Peak Grid Demand:	12,689	12,689	19,179	19,179
Cost on Fixed Tariff:	£21,438	PV Generation:	28,338	28,338	28,338	28,338
Cost on Tou Tariff:	£23,626	Cost on Fixed Tariff:	£15,673	£14,333	£14,529	£14,270
		Cost on Tou Tariff:	£16,887	£15,316	£14,787	£14,528
		Export:	9,759	5,441	6,073	6,073
		Export Earnings:	£1,171	£653	£729	£729
		Annual Saving:	£6,936	£7,758	£7,638	£7,897

- The saving from PV remains much the same as in the base case (~£6.9k p.a.). As the cooking load is in the evening, it gains little benefit from the PV array.
- Add a 30kWh battery increases the saving to about £7.9k p.a. Again, this is pretty much the same as in the base case. For 6 months of the year, all of the PV generation is consumed by the site's base load, so there is little left to shift into the evening to service the added cooking load. And for the other 6 months of the year, there is sufficient base load to consume whatever PV generation the battery can timeshift – adding additional load does not improve the return that the battery can make.
- This suggests there may be value in adding additional capacity to both PV & battery to serve the cooking load. The next 2 slides suggest there is truth in this, but the added value isn't really enough to create a case for the battery.

Site A – Added Evening Load – System Sizing

These tables show the annual saving and payback (in years) that the site might now achieve from a PV plus battery system for a range of array and battery sizes.

The pattern of returns is very similar to the base case – the difference is probably well within the error bars given the variability of system & energy pricing, etc.

Note again that this scenario does not include the cost and emission savings created by shifting from gas to electric cooking. If the Site A were to shift to electric cooking for environmental reasons, than a PV array would be highly attractive.

Full System Saving p.a.		Size of Battery							
	£7,896.83	0.000	5.000	10.000	20.000	30.000	40.000	60.000	80.000
Size of PV Array	10.000	£2,878.60	£2,961.30	£3,020.03	£3,108.35	£3,166.91	£3,159.39	£3,751.94	£4,452.14
	20.000	£5,113.87	£5,284.35	£5,429.01	£5,629.11	£5,742.47	£5,843.22	£6,565.87	£7,069.43
	30.000	£6,936.13	£7,155.36	£7,339.98	£7,662.98	£7,896.83	£8,125.10	£8,886.79	£9,318.93
	40.000	£8,534.36	£8,782.79	£9,014.29	£9,404.77	£9,719.95	£10,048.16	£10,853.62	£11,352.87
	50.000	£10,017.68	£10,288.97	£10,535.53	£10,975.76	£11,338.56	£11,735.83	£12,553.73	£13,103.55
	60.000	£11,417.72	£11,712.62	£11,982.89	£12,464.59	£12,863.98	£13,328.19	£14,171.20	£14,705.91
	70.000	£12,757.95	£13,061.37	£13,350.17	£13,865.99	£14,310.40	£14,829.15	£15,691.46	£16,244.27
	80.000	£14,068.06	£14,377.15	£14,676.92	£15,220.59	£15,667.82	£16,224.74	£17,094.57	£17,675.49

Full System Payback		Size of Battery							
(years - excludes financing)		0.000	5.000	10.000	20.000	30.000	40.000	60.000	80.000
Size of PV Array	10.000	5.9	6.4	7.0	8.0	9.2	10.4	10.9	11.0
	20.000	5.3	5.5	5.7	6.2	6.8	7.4	7.8	8.3
	30.000	5.3	5.5	5.6	5.9	6.2	6.5	6.9	7.4
	40.000	5.5	5.6	5.7	5.8	6.1	6.3	6.5	7.0
	50.000	5.7	5.7	5.8	5.9	6.1	6.2	6.5	6.8
	60.000	5.9	5.9	5.9	6.0	6.1	6.2	6.4	6.7
	70.000	6.0	6.0	6.1	6.1	6.2	6.3	6.4	6.7
	80.000	6.2	6.2	6.2	6.2	6.3	6.3	6.5	6.7

Site A – Added Evening Load – Battery Sizing

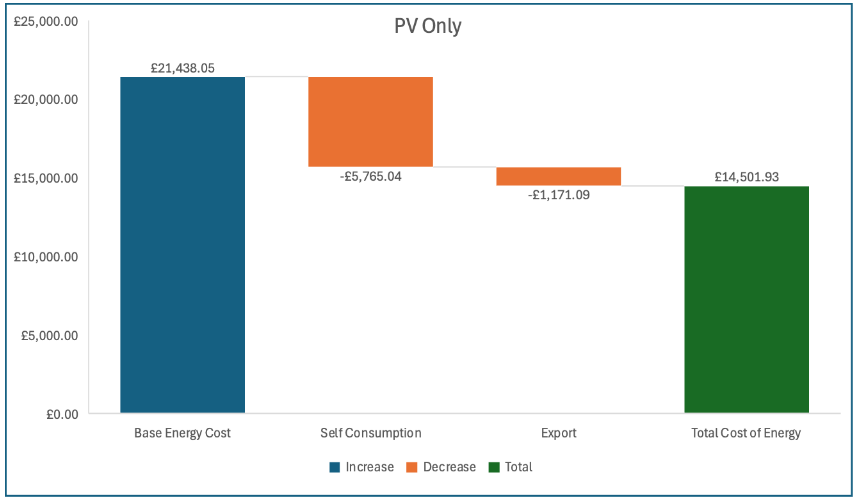
These tables show the proportion of the annual saving that can be attributed to the battery, and the payback (in years) that this would yield for investing in the battery under this scenario.

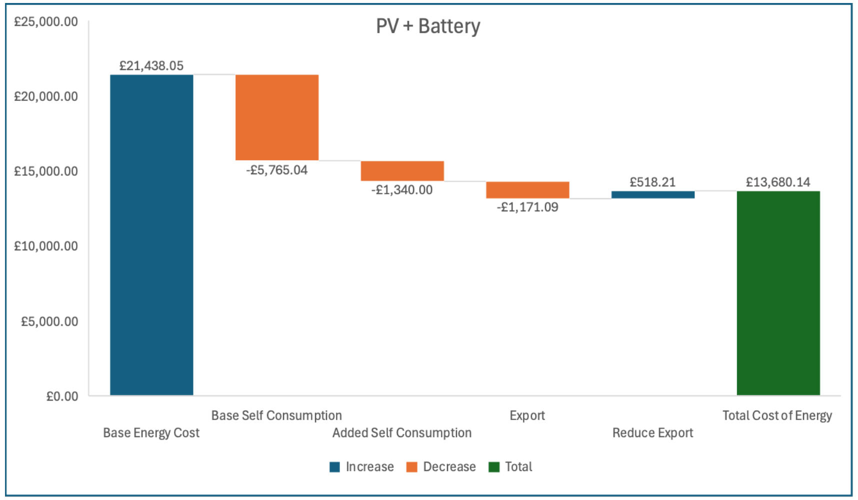
Again, the pattern is very similar to the base case – any difference is pretty much within the error bars of the calculations.

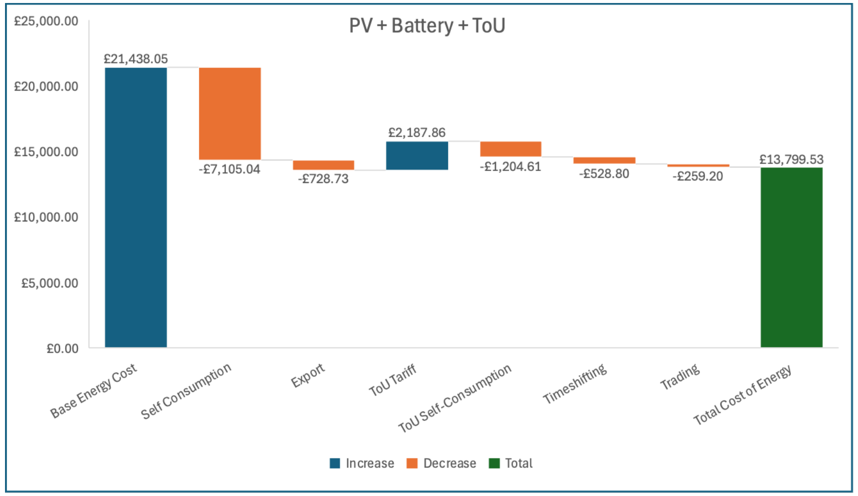
Battery Savings		Size of Battery							
	£960.70	0.000	5.000	10.000	20.000	30.000	40.000	60.000	80.000
Size of PV Array	10.000	£0.00	£82.69	£141.43	£229.75	£288.31	£280.78	£873.33	£1,573.54
	20.000	£0.00	£170.48	£315.14	£515.24	£628.60	£729.35	£1,452.00	£1,955.56
	30.000	£0.00	£219.23	£403.85	£726.86	£960.70	£1,188.97	£1,950.67	£2,382.80
	40.000	£0.00	£248.43	£479.94	£870.41	£1,185.59	£1,513.81	£2,319.26	£2,818.52
	50.000	£0.00	£271.29	£517.84	£958.07	£1,320.88	£1,718.15	£2,536.05	£3,085.87
	60.000	£0.00	£294.91	£565.17	£1,046.87	£1,446.26	£1,910.48	£2,753.48	£3,288.19
	70.000	£0.00	£303.42	£592.21	£1,108.03	£1,552.45	£2,071.19	£2,933.51	£3,486.31
	80.000	£0.00	£309.09	£608.86	£1,152.53	£1,599.77	£2,156.69	£3,026.51	£3,607.43

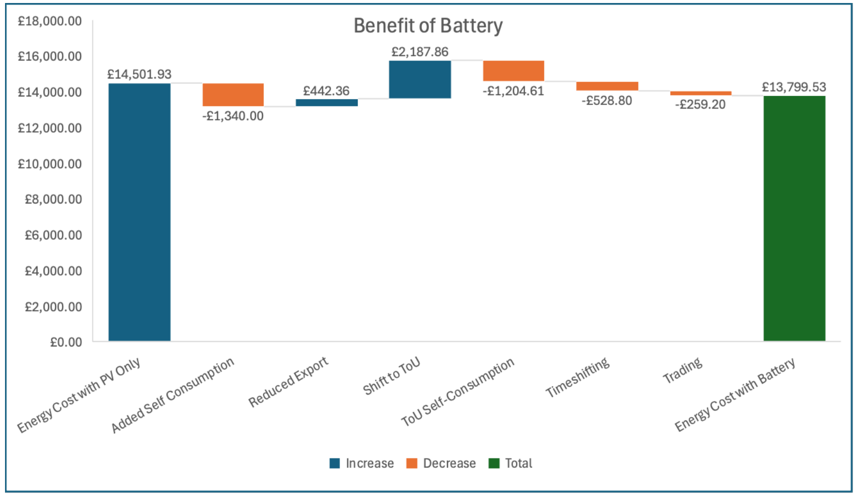
Battery Payback		Size of Battery							
		0.000	5.000	10.000	20.000	30.000	40.000	60.000	80.000
Size of PV Array	10.000	5000.0	84.7	63.6	56.6	59.0	74.8	33.2	23.5
	20.000	5000.0	41.1	28.6	25.2	27.0	28.8	20.0	18.9
	30.000	5000.0	31.9	22.3	17.9	17.7	17.7	14.9	15.5
	40.000	5000.0	28.2	18.8	14.9	14.3	13.9	12.5	13.1
	50.000	5000.0	25.8	17.4	13.6	12.9	12.2	11.4	12.0
	60.000	5000.0	23.7	15.9	12.4	11.8	11.0	10.5	11.3
	70.000	5000.0	23.1	15.2	11.7	11.0	10.1	9.9	10.6
	80.000	5000.0	22.6	14.8	11.3	10.6	9.7	9.6	10.3

Site A – Added Evening Load – Benefits Breakdown









Again, the bulk of the benefit comes from self-consuming energy generated by the PV array, yielding a cost saving of about £5.8k p.a. Adding a battery increases this by about £1.3k p.a.

There is a small additional benefit from exporting excess energy to the grid.

Shifting to a Time-of-Use tariff and using the battery to timeshift energy from off-peak times has little or no value – the increased peak time costs of the tariff outweigh the benefits of timeshifting from the off-peak tariff. (This balance might shift if a larger differential between peak and off-peak rates could be negotiated.)

Site A – Added Evening Load – Carbon Savings

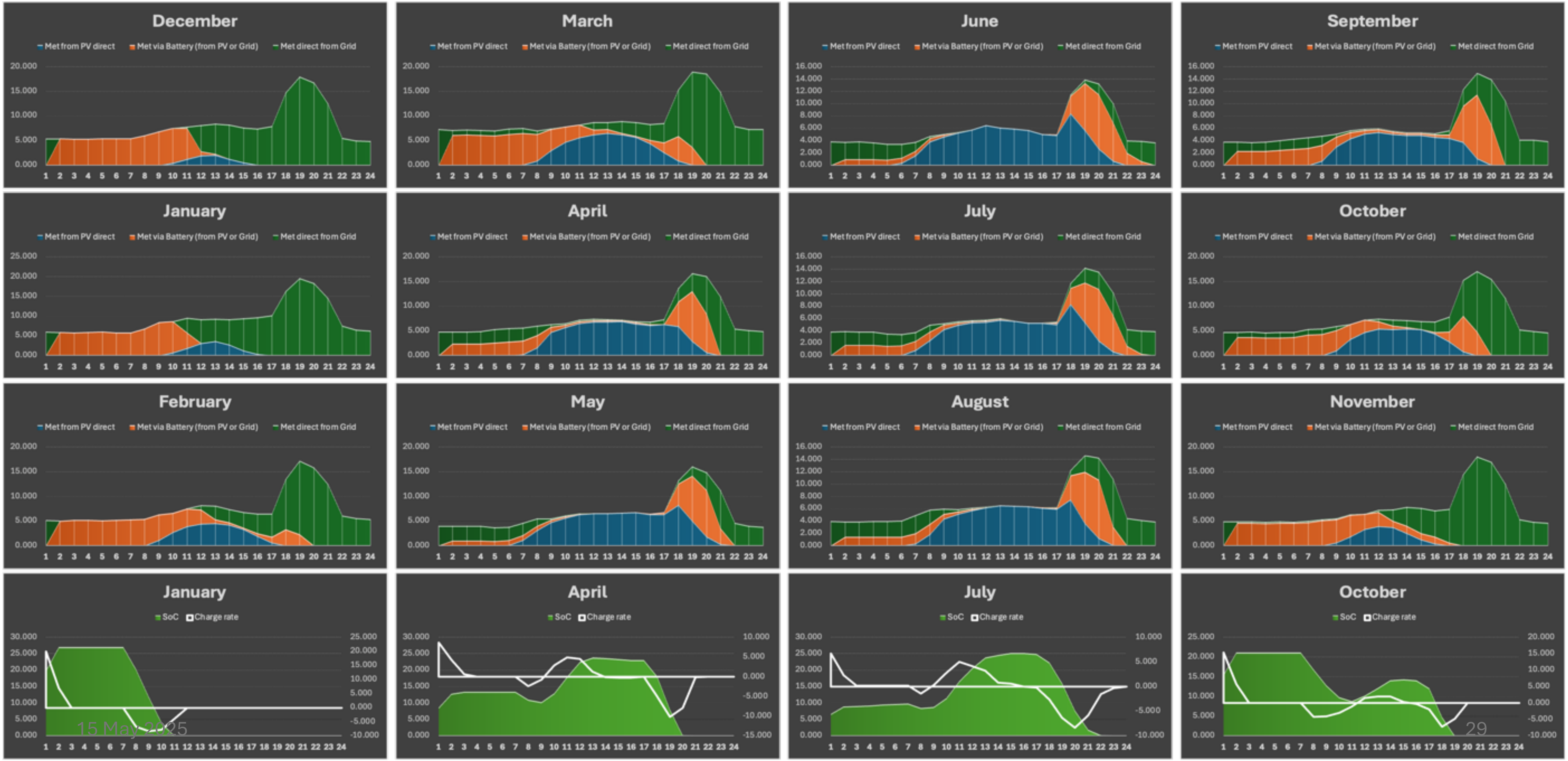
Carbon Benefits	kWh	Baseline	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading		Carbon Intensity
	Peak Grid Demand:	56,244	37,820	33,502	27,644	27,644		148
	Off-Peak Grid Demand:	12,844	12,689	12,689	19,179	19,179		57
	PV Generation:	0	28,338	28,338	28,338	28,338		0
	Export:	0	9,759	5,441	6,073	6,073		-133
	kgCO2							
	Peak Grid Demand:	8,324	5,597	4,958	4,091	4,091		
	Off-Peak Grid Demand:	732	723	723	1,093	1,093		
	PV Generation:	-	-	-	-	-		
	Export:	-	(1,298)	(724)	(808)	(808)		
	Total	**9,056**	**5,023**	**4,958**	**4,377**	**4,377**		
	Reduction		**4,034**	**4,098**	**4,679**	**4,679**		
	Benefit of Battery			**65**	**646**	**646**		

- Again, the PV array yields marginal additional environmental benefit c.f. the base case.
- But again note that this does not include the benefit of shifting from gas cooking – that would yield a substantial reduction to the carbon footprint.

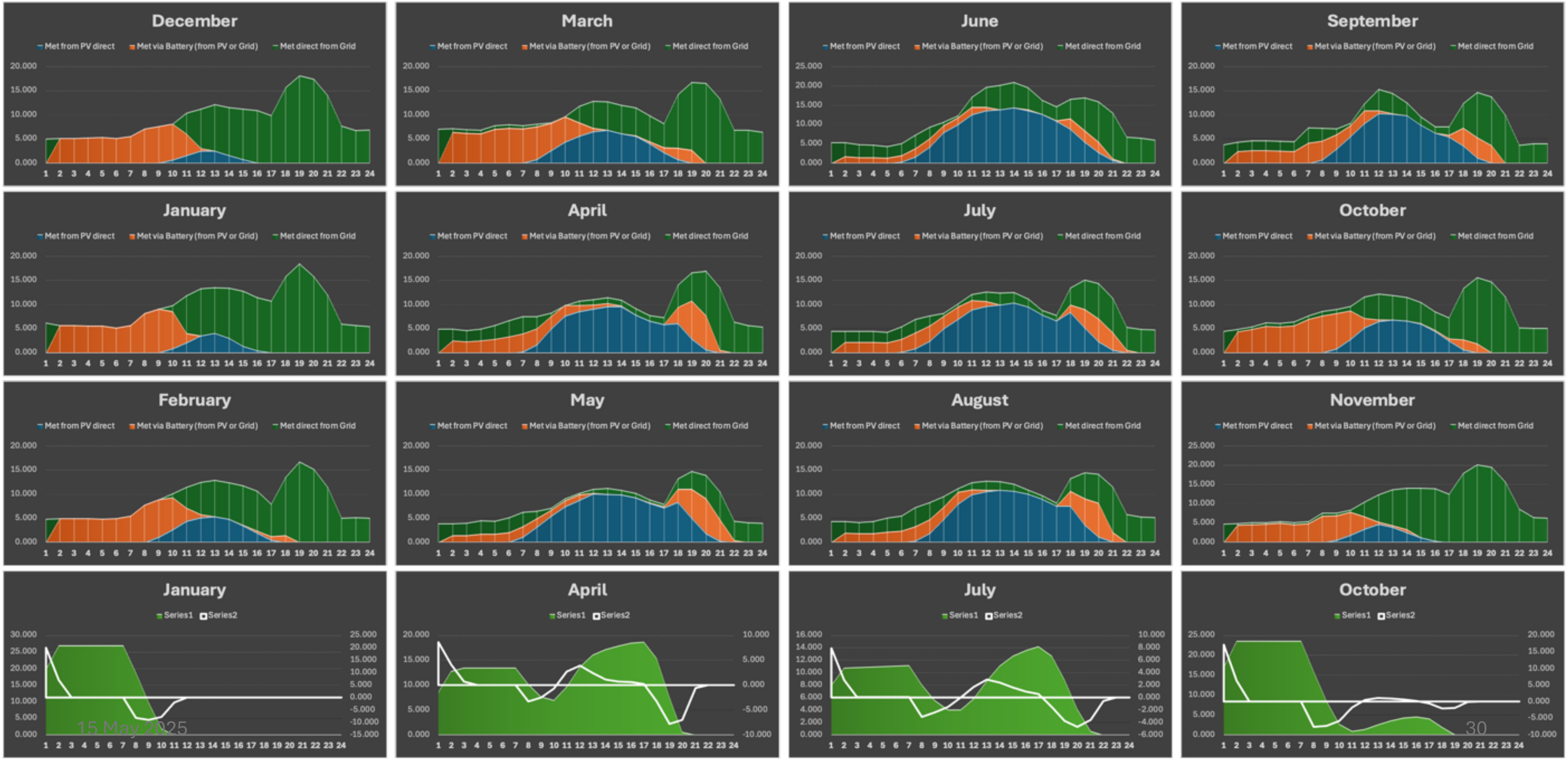
Site A – Added Evening Load – Energy usage patterns

The next 2 slides show the average daily energy usage pattern for each month of the year, for weekdays and weekends respectively. The evening load peak is pronounced, but the PV & battery patterns are broadly similar to those for the base case, with some variations in the details due to that added evening load.

Site A – Added Evening Load – Weekday energy usage



Site A – Added Evening Load – Weekend energy usage



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 based the modelling on the site's hourly energy consumption as measured by a CT-clamp monitor during Nov 2024. We then used 3.5 years of monthly meter readings (Jan 2021 – Jul 2024) to calculate average monthly consumption and hence normalise the Nov data to give hourly data for other months. This can only be an approximation – it captures trends in overall consumption, but not seasonal changes to daily patterns.
b) We have used tariffs (both fixed & Time-of-Use) from Site C, as we did not have them for this site. Again, this is an approximation. It should also be noted that tariffs can change significantly with market conditions, so there will always be uncertainty to these numbers. And future trends are open to conjecture – there is much discussion about the effect that the government's Clean Power mission (CP2030) will have on prices, for example. (There is a lot to suggest that prices will decline over the next decade, but there will probably be significant variation across that time. And a rise can't be ruled out.) We have assumed that the off-peak period is from midnight to 7am.
c) We have used the PV generation profile from a similar site in Greater Manchester. We've used an export tariff based on web research plus experience at other sites, as we did not have an export tariff for the site.
d) Energy costs are likely to be volatile over the life of the systems being modelled. It is also possible that the site's energy consumption patterns will change over time. So our results should be seen as estimates. We cannot guarantee that specific levels of return will be obtained over the life of the systems.

Site B – Summary

Base		Interventions	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading
Total Consumption:	5,876	Total Grid Demand:	3,330	2,571	2,641	2,641
Peak Consumption:	4,916	Peak Grid Demand:	2,399	1,923	1,361	1,361
Off-Peak Consumption:	960	Off-Peak Grid Demand:	931	648	1,280	1,280
Cost on Fixed Tariff:	£2,165	PV Generation:	5,668	5,668	5,668	5,668
Cost on Tou Tariff:	£2,388	Cost on Fixed Tariff:	£1,227	£947	£973	£937
		Cost on Tou Tariff:	£1,303	£1,015	£962	£926
		Export:	3,122	2,363	2,432	2,432
		Export Earnings:	£375	£284	£292	£292
		Annual Saving:	£1,313	£1,501	£1,495	£1,530

- We estimate a PV array could reduce the site's energy costs by approx. £1,300 (60%) p.a., from £2,200 to £900 (after accounting for export earnings). This is for an array sized at about 6kW. A larger array would give further benefit (e.g. doubling the array size might increase the savings by about 50%), but the best return on investment (ROI) is at 6-8kW. This array would pay back its costs in about 7 years.
- Adding a 4kWh battery would increase the saving to approx. £1,500 (70%) p.a. This would give a marginal return on investment, paying back after about 12 years. The bulk of this benefit comes from increasing self-consumption of energy generated by the PV array. The benefits of timeshifting are marginal, only just exceeding the cost of moving to a Time-of-Use tariff (which would increase the cost of energy consumed during the day c.f. a fixed tariff). Note however that the battery also gives some insulation against future tariff increases. The battery would represent a small additional investment c.f. the cost of the PV array, so on balance it is probably a worthwhile investment.

Site B – System Sizing

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.

It can be seen that the optimal return is achieved from a 6-8kW PV array with a small battery (2-4 kWh). Adding a battery also tends to increase the optimal size of the array sightly. However, the optimum is broad and shallow, so there is a fairly wide range of battery and PV sizes that work reasonably well.

Although the optimum system has a very small battery, adding a battery does not increase the payback time dramatically and the overall return is still decent for many configurations. Thus it may be worth investing in a larger battery as this could yield reasonable returns, even if not as high as for PV alone. (Noting also that, by increasing self-consumption, the battery will help mitigate the risk of future energy price increases.)

Full System Saving p.a.		Size of Battery (kWh)							
	£1,530.19	0.000	2.000	4.000	6.000	8.000	10.000	15.000	20.000
Size of PV Array (kW)	2.000	£617.27	£671.21	£707.07	£777.43	£831.75	£882.64	£962.27	£993.18
	4.000	£1,003.82	£1,104.10	£1,175.21	£1,240.86	£1,278.71	£1,313.63	£1,368.42	£1,392.12
	6.000	£1,312.58	£1,434.27	£1,530.19	£1,588.24	£1,626.45	£1,656.11	£1,702.14	£1,718.24
	8.000	£1,592.39	£1,727.12	£1,834.07	£1,893.68	£1,931.43	£1,950.70	£1,993.12	£2,009.77
	10.000	£1,855.49	£1,998.73	£2,113.92	£2,173.39	£2,205.02	£2,230.82	£2,274.00	£2,276.60
	12.000	£2,110.36	£2,259.42	£2,381.17	£2,444.93	£2,473.64	£2,498.96	£2,531.58	£2,546.12
	14.000	£2,359.19	£2,514.56	£2,640.38	£2,702.99	£2,737.93	£2,750.15	£2,787.11	£2,798.42
	16.000	£2,604.25	£2,763.72	£2,894.64	£2,956.22	£2,987.23	£3,011.77	£3,033.58	£3,046.33

Full System Payback		Size of Battery							
(years - excludes financing)		0.000	2.000	4.000	6.000	8.000	10.000	15.000	20.000
Size of PV Array	2.000	8.1	8.6	9.3	9.5	9.9	10.2	11.4	13.1
	4.000	7.0	7.1	7.3	7.6	8.0	8.4	9.5	10.8
	6.000	6.9	6.8	6.9	7.2	7.5	7.8	8.8	9.9
	8.000	6.9	6.8	6.9	7.1	7.4	7.7	8.5	9.5
	10.000	7.0	6.9	6.9	7.1	7.3	7.6	8.4	9.2
	12.000	7.1	7.0	7.0	7.1	7.4	7.6	8.3	9.0
	14.000	7.2	7.1	7.0	7.2	7.4	7.6	8.3	8.9
	16.000	7.3	7.2	7.1	7.2	7.4	7.6	8.2	8.9

Site B – Battery Sizing

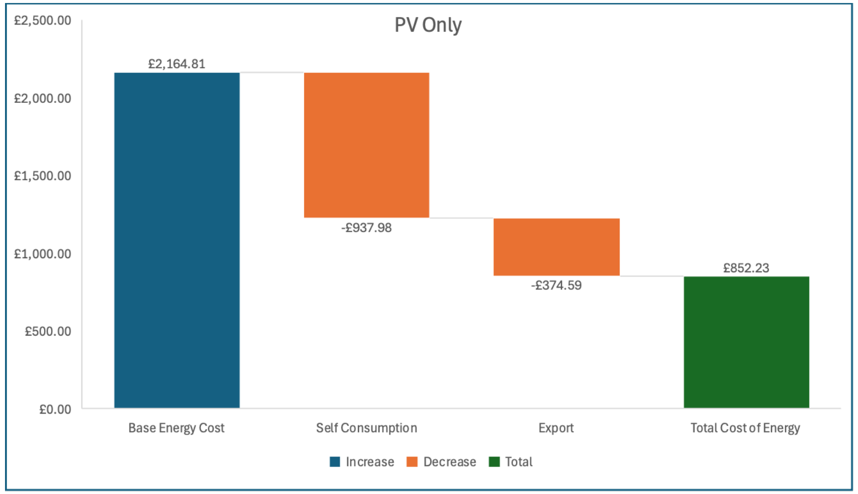
These tables show the proportion of the annual saving that can be attributed to the battery, and the payback (in years) that this would yield for investing in the battery.

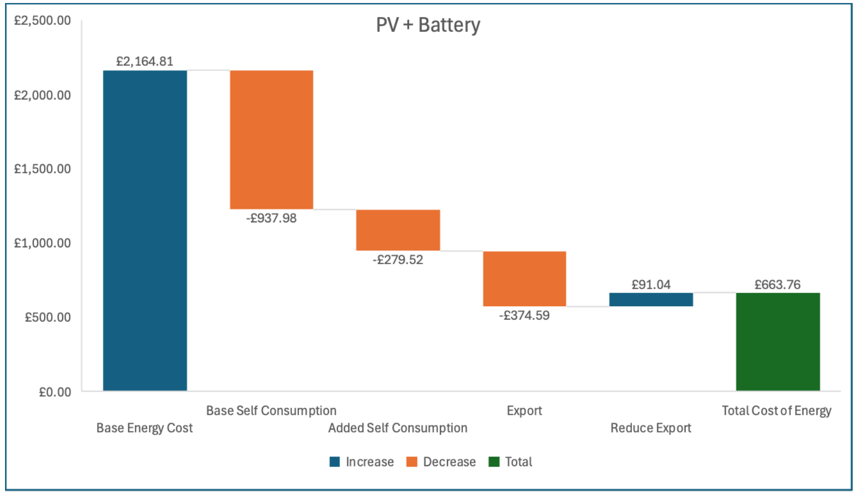
It can be seen that the optimum return is achieved for a 4kWh battery for most PV array sizes, and that the return improves as the size of the array grows. For the recommended PV size on this site (6kW), the payback on the battery would be about 12 years. This is not particularly attractive, as it aligns to the expected life of the battery. Nonetheless, the cost of such a small battery would be small c.f. the cost of the PV array, so it might be worth installing such a battery for the risk mitigation benefits mentioned earlier. This could support future growth in the site's electricity demand if, for example, it were to install heat pumps.

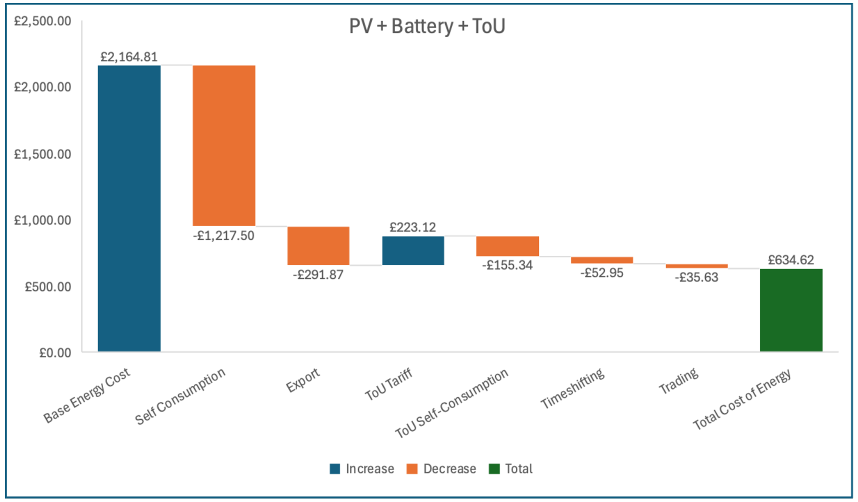
Battery Savings		Size of Battery (kWh)							
	£217.61	0.000	2.000	4.000	6.000	8.000	10.000	15.000	20.000
Size of PV Array (kW)	2.000	£0.00	£53.95	£89.80	£160.16	£214.49	£265.37	£345.00	£375.91
	4.000	£0.00	£100.27	£171.39	£237.03	£274.88	£309.81	£364.59	£388.30
	6.000	£0.00	£121.70	£217.61	£275.67	£313.88	£343.53	£389.56	£405.66
	8.000	£0.00	£134.73	£241.69	£301.29	£339.04	£358.32	£400.74	£417.39
	10.000	£0.00	£143.24	£258.43	£317.90	£349.53	£375.33	£418.51	£421.11
	12.000	£0.00	£149.07	£270.81	£334.57	£363.28	£388.60	£421.22	£435.76
	14.000	£0.00	£155.37	£281.19	£343.81	£378.75	£390.97	£427.93	£439.24
	16.000	£0.00	£159.46	£290.39	£351.96	£382.98	£407.51	£429.33	£442.08

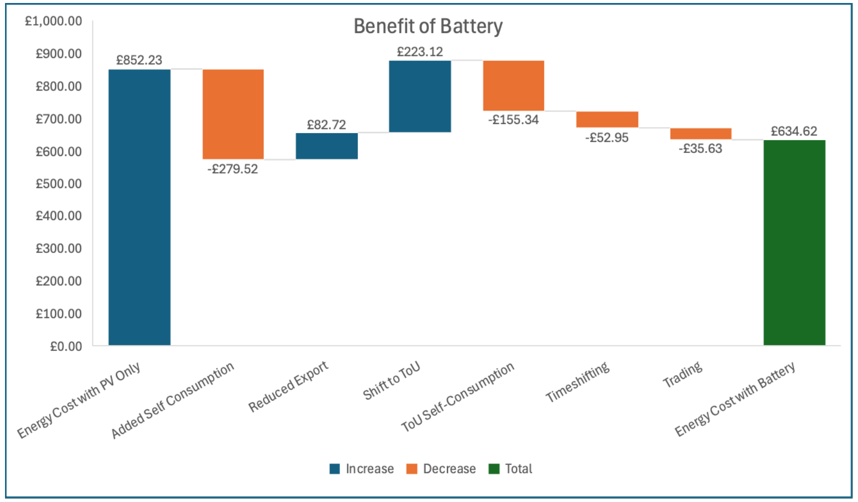
Battery Payback		Size of Battery (kWh)							
		0.000	2.000	4.000	6.000	8.000	10.000	15.000	20.000
Size of PV Array (kW)	2.000	1000.0	33.4	29.0	21.2	19.6	18.8	20.3	23.9
	4.000	1000.0	18.0	15.2	14.3	15.3	16.1	19.2	23.2
	6.000	1000.0	14.8	11.9	12.3	13.4	14.6	18.0	22.2
	8.000	1000.0	13.4	10.8	11.3	12.4	14.0	17.5	21.6
	10.000	1000.0	12.6	10.1	10.7	12.0	13.3	16.7	21.4
	12.000	1000.0	12.1	9.6	10.2	11.6	12.9	16.6	20.7
	14.000	1000.0	11.6	9.2	9.9	11.1	12.8	16.4	20.5
	16.000	1000.0	11.3	9.0	9.7	11.0	12.3	16.3	20.4

Site B – Benefits Breakdown









The bulk of the benefit from the PV array comes from allowing the site to use free solar energy rather than buying electricity from the grid ("self-consumption"). This yields a saving of about £900 p.a. from the PV array alone. Adding a battery increases this by a further £300.

There is also a reasonable benefit from exporting excess PV generation to the grid (typically during the summer). Adding a battery reduces this benefit, as it enables some of the excess generation to be self-consumed, which is generally more valuable.

The battery could also be used to shift some of the site's consumption from peak to off-peak times. This is only worthwhile if the site switches to a Time-of-Use tariff, which would entail some cost (as it increases the cost of energy consumed at peak times). The time-shifting benefit only just compensates for this cost.

Finally, spare capacity in the battery could be used to trade on wholesale & flexibility markets. The returns on such trading can be volatile, but we have estimated that they could generate revenue of the order of £40p.a. for the site.

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:	4,916	2,399	1,923	1,361	1,361		148
	Off-Peak Grid Demand:	960	931	648	1,280	1,280		57
	PV Generation:	0	5,668	5,668	5,668	5,668		0
	Export:	0	3,122	2,363	2,432	2,432		-133
	kgCO2							
	Peak Grid Demand:	728	355	285	201	201		
	Off-Peak Grid Demand:	55	53	37	73	73		
	PV Generation:	-	-	-	-	-		
	Export:	-	(415)	(314)	(323)	(323)		
	Total	**782**	**(7)**	**7**	**(49)**	**(49)**		
	Reduction		**789**	**775**	**831**	**831**		
	Benefit of Battery			**(14)**	**42**	**42**		

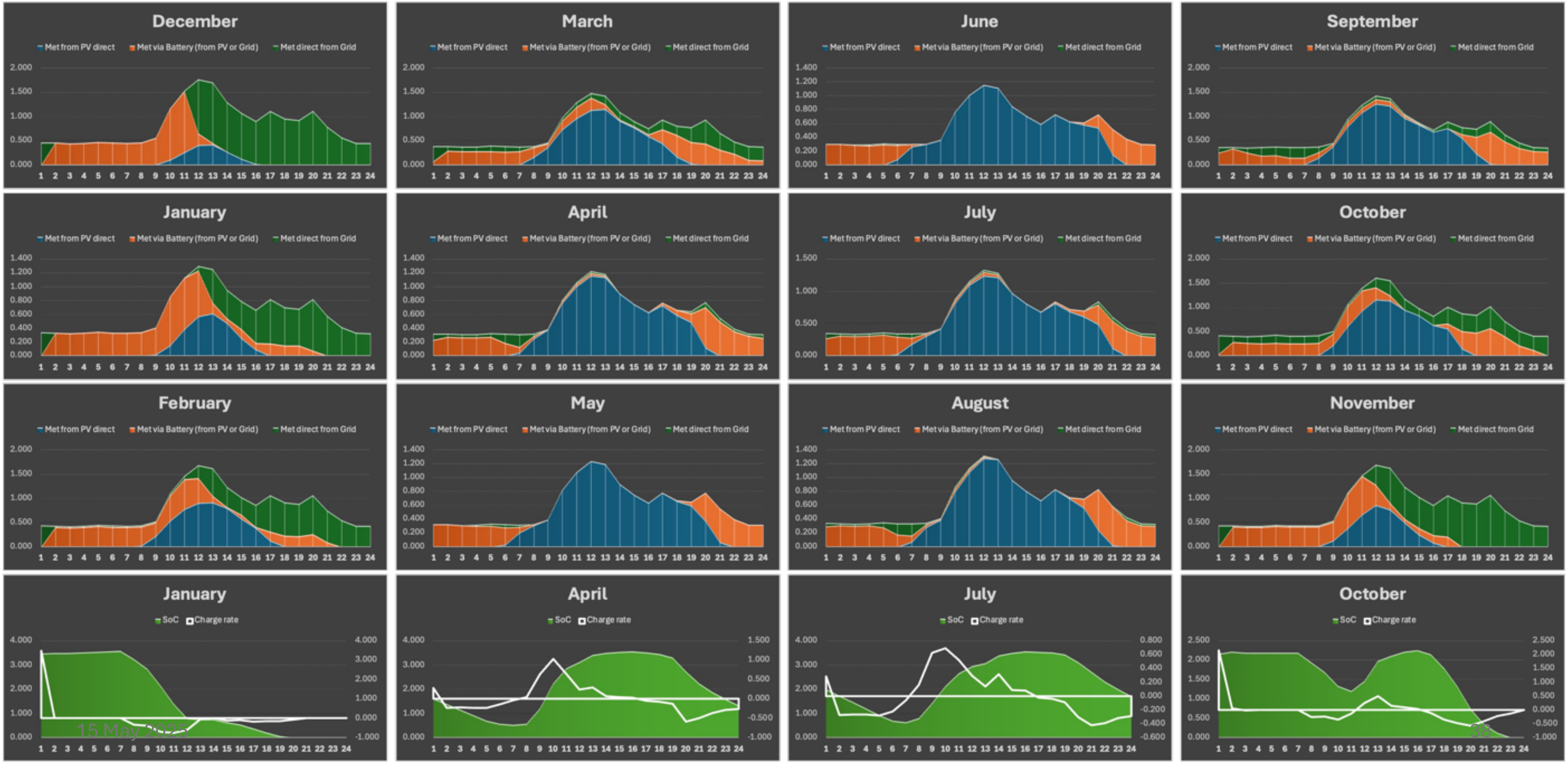
- We estimate that adding a PV array would enable the site to reduce its carbon footprint by about 0.8 tCO2e p.a., essentially becoming carbon neutral. Adding a battery would yield an additional carbon saving of approx. 0.05 tCO2e p.a., primarily by time-shifting the site's consumption to times when 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. We tend to use fairly conservative assumptions, as the grid's carbon intensity is declining rapidly and so the future benefit of avoiding importing from the grid will decline.

Site B – Energy usage patterns

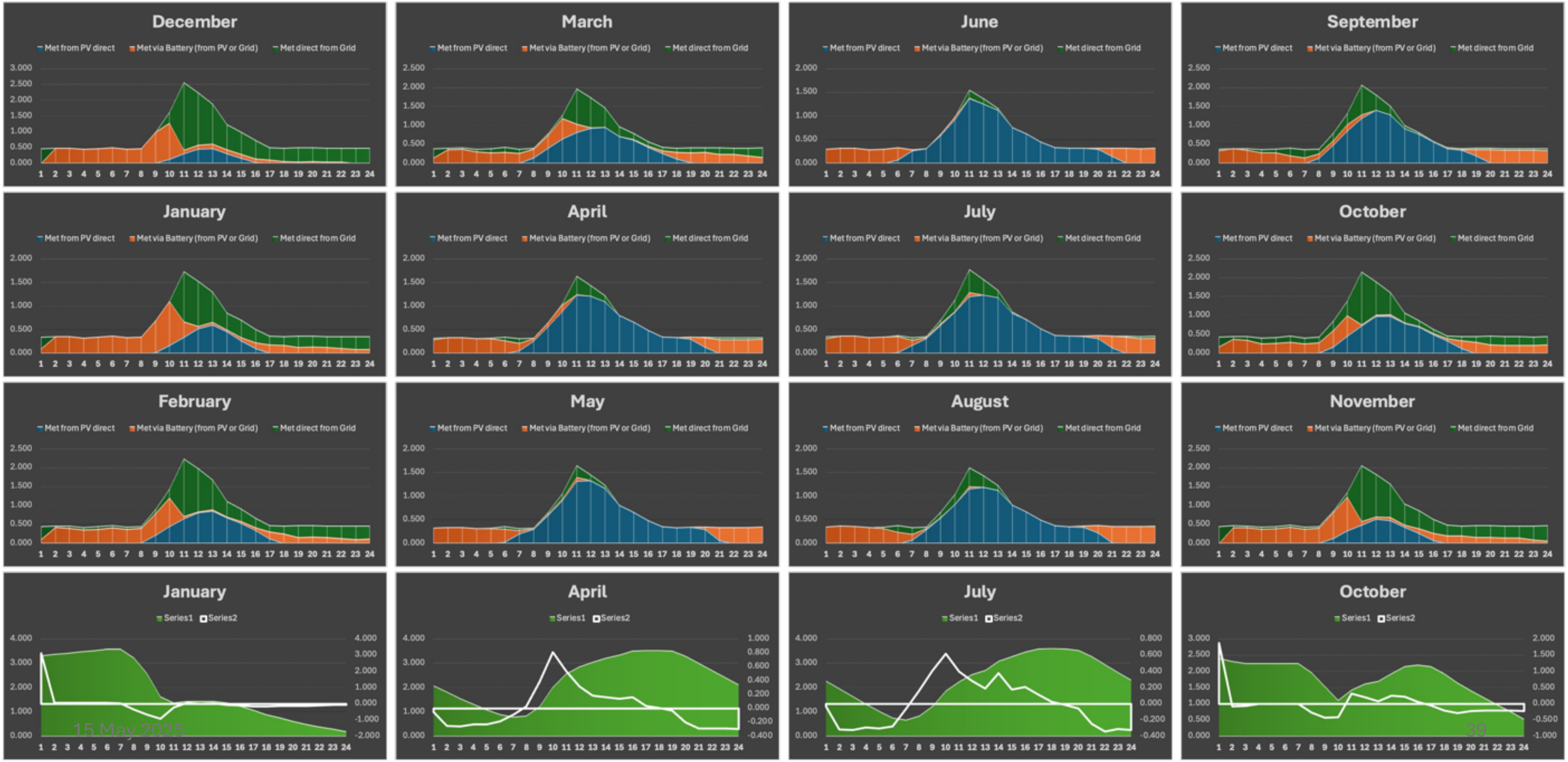
The next 2 slides show the average daily energy usage pattern for each month of the year, for weekdays and weekends respectively. These give a more detailed feel for how the PV energy and battery might be used. Features of the usage patterns include:

- During winter, the PV array does not generate enough energy to meet daily 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 April, the PV is beginning to meet consumption on some (sunny) days. 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 June, the PV is meeting demand during the day most days, and the excess is sufficient to meet evening demand on those days and some of the morning demand the next day. The battery may also capture some energy overnight and use it to meet some of the morning demand, but this may be less necessary than in the Spring months.
- In Autumn, the pattern goes back to that of the Spring months, with the battery cycling twice per day, once from the solar PV and once from cheap overnight electricity from the grid.

Site B – Weekday energy usage



Site B – Weekend energy usage



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 based the modelling on the site's hourly energy consumption as measured by a CT-clamp monitor during Nov 2024. We then used 1 year's monthly billed meter readings (March 2023 – Feb 2024) to calculate typical monthly consumption and hence normalise the Nov data to give hourly data for other months. This can only be an approximation – it captures trends in overall consumption, but not seasonal changes to daily patterns.

b) Several of the monthly bills were based on estimated meter readings. Then the first subsequent reading was anomalously high. So we spread some of that month's reading over the previous, estimated months. That adds even more uncertainty to the approximation but yields a reasonable annual profile overall.

c) The site has a combination of fixed and Time-of-Use tariffs (for presbytery and   respectively), but we have modelled it as a single unit as (a) the CT-clamp data applied to the whole site, and (b) it would need to be treated as a single site if a common PV array and battery is to be installed.

d) The site's tariffs changed twice across the year. We've used the most recent (Feb 2024) tariffs. As noted earlier, tariffs can change significantly over time, and future pricing trends are uncertain. It is also possible that the site's energy consumption patterns will change over time. So our results should be seen as estimates. We cannot guarantee that specific levels of return will be obtained over the life of the systems.

e) We have used the PV generation profile from a similar site in Greater Manchester. We've used an export tariff based on web research plus experience at other sites, as we did not have an export tariff for the site.

Site C – Summary

Base		Interventions	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading
Total Consumption:	13,371	Total Grid Demand:	7,743	7,209	7,250	7,250
Peak Consumption:	12,600	Peak Grid Demand:	7,012	6,523	5,704	5,704
Off-Peak Consumption:	771	Off-Peak Grid Demand:	732	686	1,546	1,546
Cost on Fixed Tariff:	100%	PV Generation:	7,557	7,557	7,557	7,557
Cost on Tou Tariff:	114%	Cost on Fixed Tariff:	58%	54%	54%	53%
		Cost on Tou Tariff:	65%	61%	59%	58%
		Export:	1,929	1,394	1,436	1,436
		Export Earnings:	5%	3%	3%	3%
		Annual Saving:	47%	49%	49%	50%

- We estimate a PV array could reduce the site's energy costs by approx. 47% p.a. (after accounting for export earnings). This is for an array sized at about 8kW. A larger array would give further benefit (e.g. doubling the array size might increase the savings by about 50%), but the best return on investment (ROI) is at about 8kW. This array would pay back its costs in about 5 years.
- Adding a 4kWh battery would increase the saving to approx. 50% p.a. This would give a very marginal return on investment, paying back after about 16 years. The bulk of this benefit comes from increasing self-consumption of energy generated by the PV array. The benefits of timeshifting are marginal, less than the cost of moving to a Time-of-Use tariff (which would increase the cost of energy consumed during the day c.f. a fixed tariff). Note however that the battery also gives some insulation against future tariff increases. The battery would represent a small additional investment c.f. the cost of the PV array, so on balance it may still be a worthwhile investment.

Site C – System Sizing

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.

It can be seen that the optimal return is achieved from an 8kW PV array. Adding a small battery extends the payback very slightly. It also tends to increase the optimal size of the array sightly. However, the optimum is broad and shallow, so there is a fairly wide range of battery and PV sizes that work reasonably well.

Although the optimum system has no battery, adding a battery does not increase the payback time by very much and the overall return is still decent for many configurations. Thus it may be worth investing in a battery as this could yield reasonable returns, even if not as high as for PV alone. (Noting also that, by increasing self-consumption, the battery will help mitigate the risk of future energy price increases.)

Full System Saving p.a.		Size of Battery (kWh)							
	£2,466.12	0.000	2.000	4.000	6.000	8.000	10.000	15.000	20.000
Size of PV Array (kW)	2.000	£694.17	£715.72	£736.07	£748.62	£747.88	£750.05	£798.29	£990.42
	4.000	£1,347.09	£1,389.08	£1,414.97	£1,428.89	£1,424.25	£1,427.48	£1,531.60	£1,691.00
	6.000	£1,878.68	£1,952.87	£2,002.62	£2,026.30	£2,028.44	£2,012.71	£2,124.37	£2,255.51
	8.000	£2,304.82	£2,397.10	£2,466.12	£2,505.13	£2,513.01	£2,511.61	£2,599.71	£2,721.00
	10.000	£2,674.64	£2,782.25	£2,862.78	£2,911.95	£2,937.46	£2,940.16	£3,015.23	£3,113.13
	12.000	£3,007.93	£3,125.20	£3,212.14	£3,274.17	£3,298.38	£3,317.48	£3,380.69	£3,475.40
	14.000	£3,319.89	£3,442.86	£3,539.44	£3,602.06	£3,627.83	£3,647.53	£3,713.19	£3,809.24
	16.000	£3,617.65	£3,747.85	£3,850.20	£3,920.35	£3,954.50	£3,961.98	£4,032.06	£4,111.75

Full System Payback		Size of Battery (kWh)							
(years - excludes financing)		0.000	2.000	4.000	6.000	8.000	10.000	15.000	20.000
Size of PV Array (kW)	2.000	7.2	8.1	9.0	9.9	11.0	12.0	13.8	13.1
	4.000	5.2	5.6	6.1	6.6	7.2	7.7	8.5	8.9
	6.000	4.8	5.0	5.3	5.6	6.0	6.5	7.1	7.5
	8.000	4.8	4.9	5.1	5.3	5.7	6.0	6.5	7.0
	10.000	4.9	5.0	5.1	5.3	5.5	5.8	6.3	6.7
	12.000	5.0	5.1	5.2	5.3	5.5	5.7	6.2	6.6
	14.000	5.1	5.2	5.3	5.4	5.6	5.8	6.2	6.6
	16.000	5.3	5.3	5.4	5.5	5.6	5.8	6.2	6.6

Site C – Battery Sizing

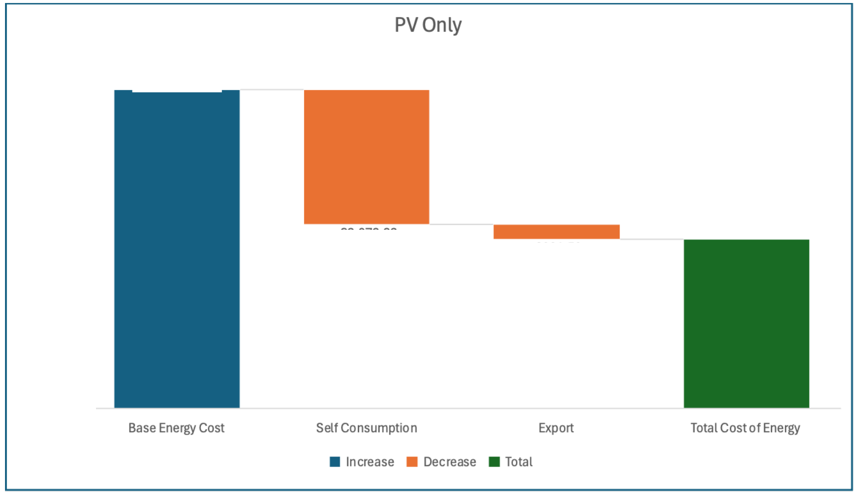
These tables show the proportion of the annual saving that can be attributed to the battery, and the payback (in years) that this would yield for investing in the battery.

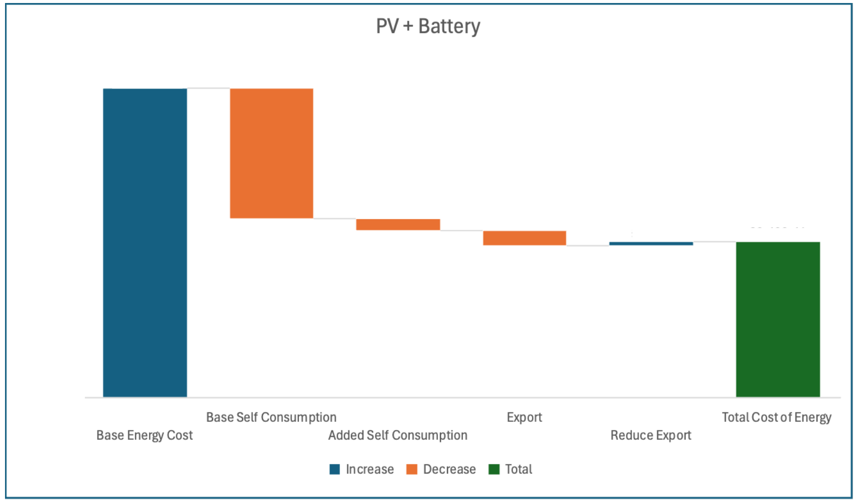
It can be seen that the optimum return is achieved for a 4kWh battery for most PV array sizes, and that the return improves as the size of the array grows. For the recommended PV size on this site (8kW), the payback on the battery would be about 16 years. This is not particularly attractive, especially given the expected life of the battery. Nonetheless, the cost of such a small battery would be small c.f. the cost of the PV array, so it might be worth installing such a battery for the risk mitigation benefits mentioned earlier. This could support future growth in the site's electricity demand if, for example, it were to install heat pumps.

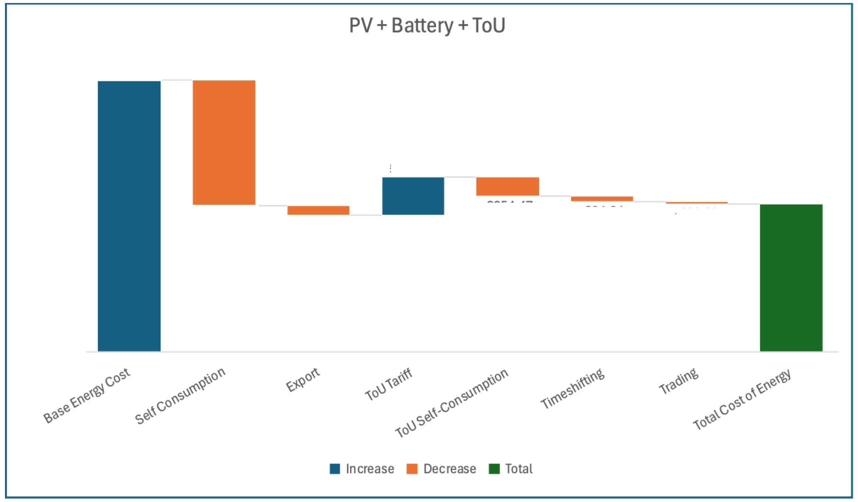
Battery Savings		Size of Battery (kWh)							
	£161.30	0.000	2.000	4.000	6.000	8.000	10.000	15.000	20.000
Size of PV Array (kW)	2.000	£0.00	£21.55	£41.90	£54.45	£53.71	£55.88	£104.12	£296.26
	4.000	£0.00	£41.99	£67.88	£81.79	£77.16	£80.39	£184.51	£343.90
	6.000	£0.00	£74.19	£123.94	£147.62	£149.76	£134.04	£245.69	£376.84
	8.000	£0.00	£92.29	£161.30	£200.31	£208.20	£206.79	£294.89	£416.19
	10.000	£0.00	£107.62	£188.15	£237.31	£262.82	£265.52	£340.60	£438.50
	12.000	£0.00	£117.26	£204.20	£266.23	£290.45	£309.55	£372.75	£467.47
	14.000	£0.00	£122.97	£219.55	£282.17	£307.94	£327.64	£393.30	£489.35
	16.000	£0.00	£130.19	£232.55	£302.70	£336.85	£344.33	£414.41	£494.09

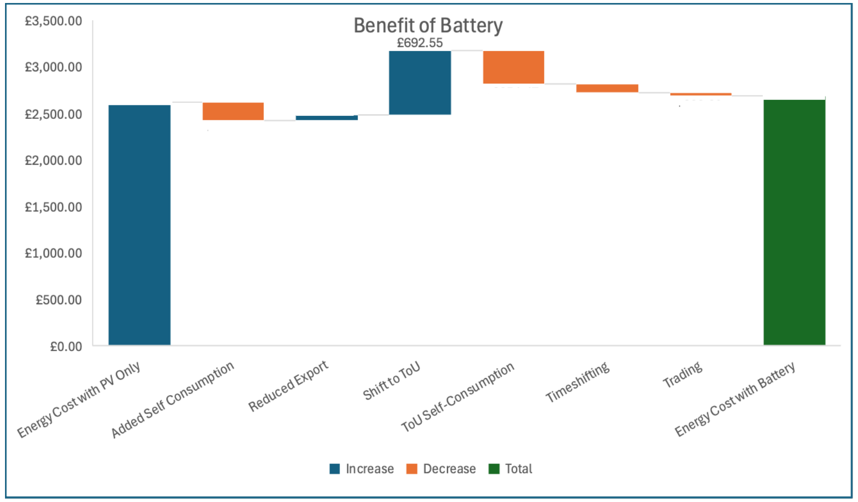
Battery Payback		Size of Battery (kWh)							
		0.000	2.000	4.000	6.000	8.000	10.000	15.000	20.000
Size of PV Array (kW)	2.000	1000.0	83.5	62.1	62.4	78.2	89.5	67.2	30.4
	4.000	1000.0	42.9	38.3	41.6	54.4	62.2	37.9	26.2
	6.000	1000.0	24.3	21.0	23.0	28.0	37.3	28.5	23.9
	8.000	1000.0	19.5	16.1	17.0	20.2	24.2	23.7	21.6
	10.000	1000.0	16.7	13.8	14.3	16.0	18.8	20.6	20.5
	12.000	1000.0	15.3	12.7	12.8	14.5	16.2	18.8	19.3
	14.000	1000.0	14.6	11.8	12.0	13.6	15.3	17.8	18.4
	16.000	1000.0	13.8	11.2	11.2	12.5	14.5	16.9	18.2

Site C – Benefits Breakdown









The bulk of the benefit from the PV array comes from allowing the site to use free solar energy rather than buying electricity from the grid ("self-consumption"). This yields a saving of about 43% p.a. from the PV array alone. Adding a battery increases this by a further 4%.

There is also a small benefit from exporting excess PV generation to the grid (typically during the summer). Adding a battery reduces this benefit, as it enables some of the excess generation to be self-consumed, which is generally more valuable.

The battery could also be used to shift some of the site's consumption from peak to off-peak times. This is only useful if the site switches to a Time-of-Use tariff, which would entail some cost (as it increases the cost of energy consumed at peak times). For this site, this is not worthwhile – the timeshifting benefit is not large enough.

Finally, spare capacity in the battery could be used to trade on wholesale & flexibility markets. The returns on such trading can be volatile, but we have estimated that they could generate revenue of the order of £40p.a. for the site.

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:	12,600	7,012	6,523	5,704	5,704		148
	Off-Peak Grid Demand:	771	732	686	1,546	1,546		57
	PV Generation:	0	7,557	7,557	7,557	7,557		0
	Export:	0	1,929	1,394	1,436	1,436		-133
	kgCO2							
	Peak Grid Demand:	1,865	1,038	965	844	844		
	Off-Peak Grid Demand:	44	42	39	88	88		
	PV Generation:	-	-	-	-	-		
	Export:	-	(257)	(185)	(191)	(191)		
	Total	**1,909**	**823**	**819**	**741**	**741**		
	Reduction		**1,086**	**1,090**	**1,167**	**1,167**		
	Benefit of Battery			**4**	**81**	**81**		

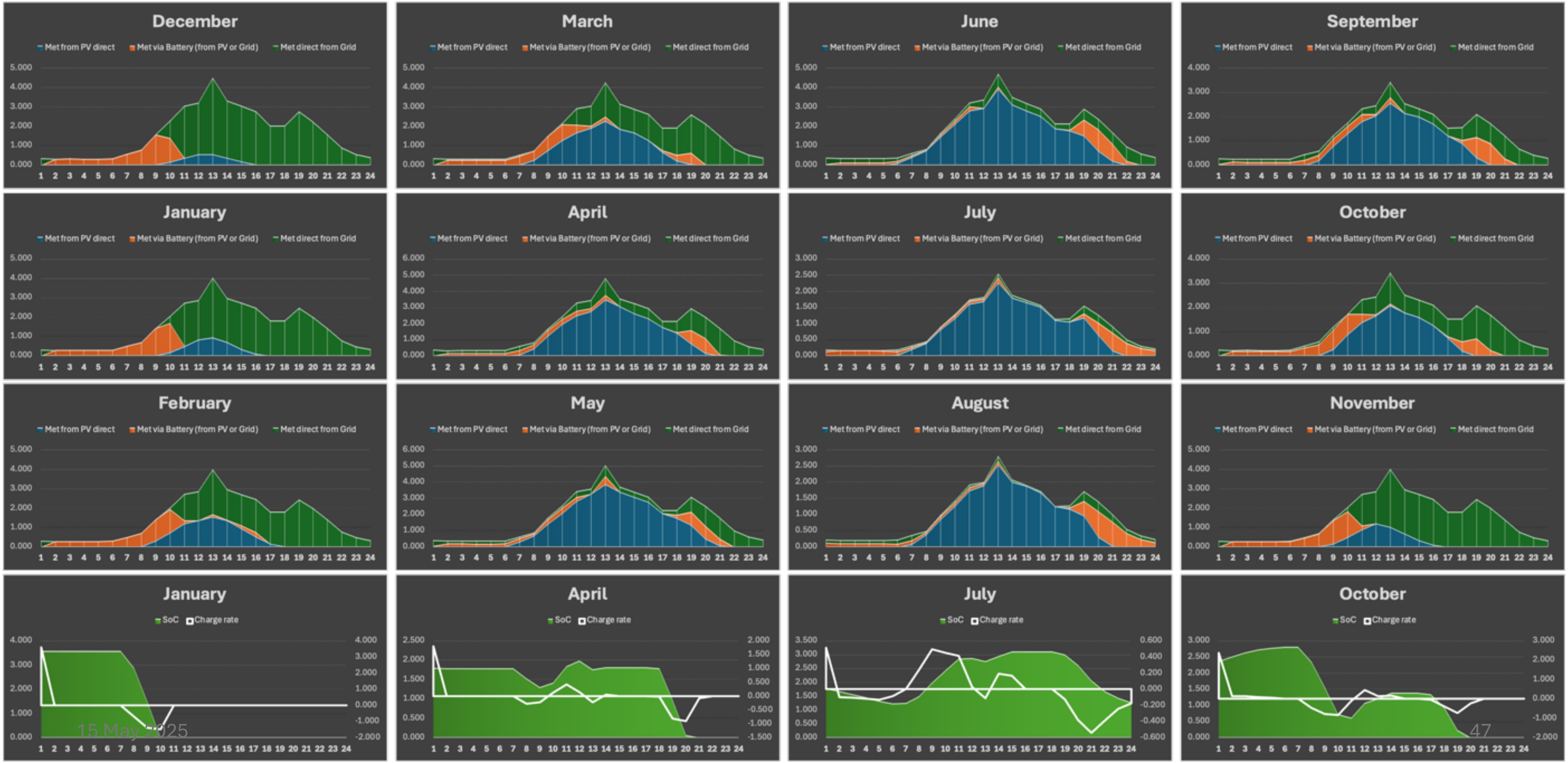
- We estimate that adding a PV array would enable the site to reduce its carbon footprint by about 1.1 tCO2e p.a. Adding a battery would yield an additional carbon saving of approx. 0.1 tCO2e p.a., primarily by time-shifting the site's consumption to times when grid carbon intensity is lower.
- Note that these calculations are highly dependent on assumptions about grid carbon intensity and how the benefits of the PV array are accounted for. We tend to use fairly conservative assumptions, as the grid's carbon intensity is declining rapidly and so the future benefit of avoiding importing from the grid will decline.

Site C – Energy usage patterns

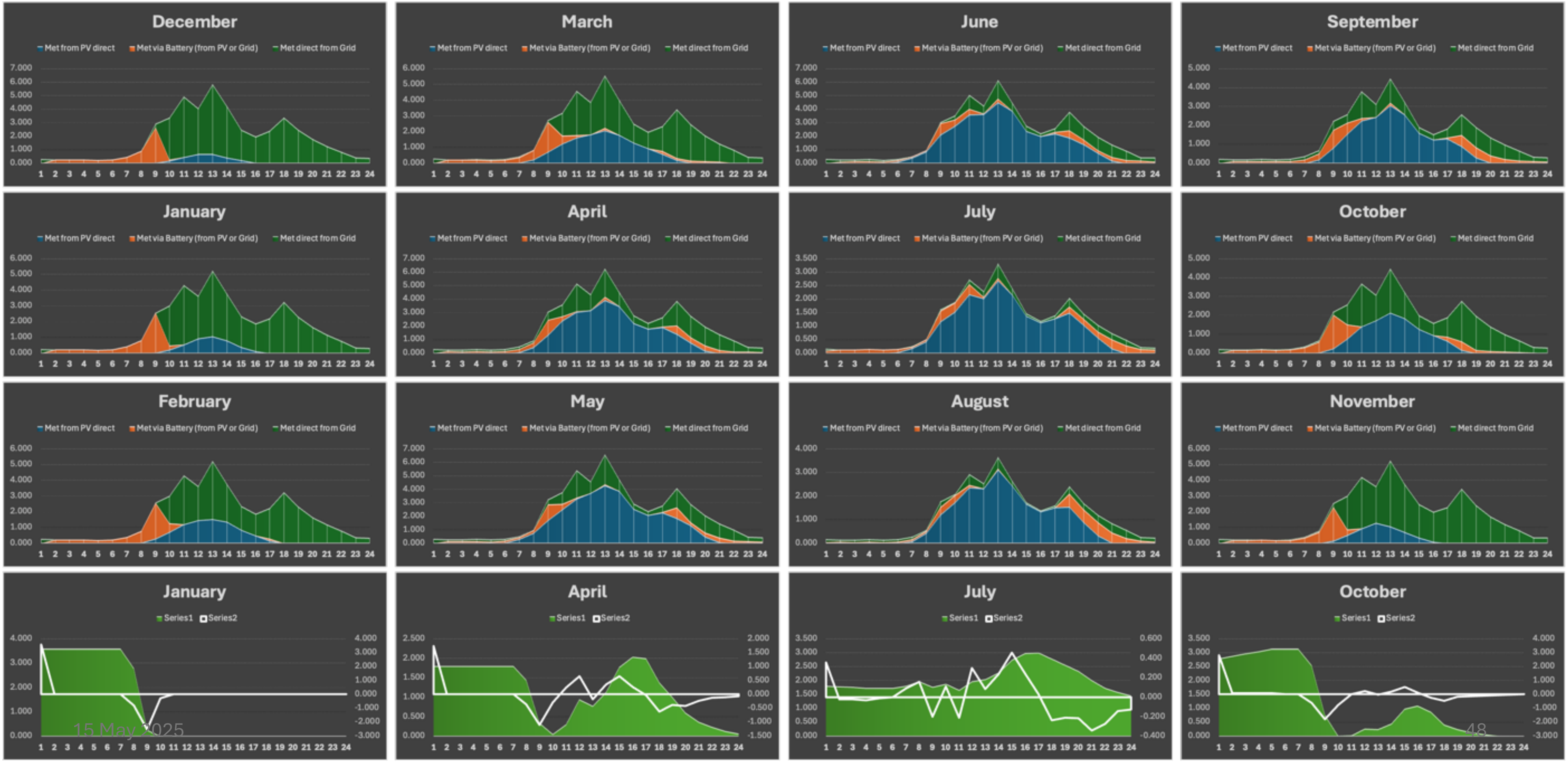
The next 2 slides show the average daily energy usage pattern for each month of the year, for weekdays and weekends respectively. These give a more detailed feel for how the PV energy and battery might be used. Features of the usage patterns include:

- During winter, the PV array does not generate enough energy to meet daily 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 April, the PV is beginning to meet consumption on some (sunny) days. 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 June, the PV is meeting demand during the day most days, and the excess is sufficient to meet most evening demand on those days and possibly some of the morning demand the next day. The battery also captures some energy overnights and uses it to meet demand the next morning. However, it also reserves capacity to ensure it can capture excess solar generation the next day.
- In Autumn, the pattern goes back to that of the Spring months, with the battery cycling twice per day, once from the solar PV and once from cheap overnight electricity from the grid.

Site C – Weekday energy usage



Site C – Weekend energy usage



Site D

The following slides show key results for Site D. Full results are given in the accompanying spreadsheets, which contains the full models, input data, etc.

Note that:

a) We did not have half hourly data for the site, so we used the consumption patterns from Site C, which appears to be the most comparable site (e.g. having church plus presbytery). We scaled the Site C data to match the total consumption at Site D. However, this means that all the caveats for Site C apply to this modelling too, plus the caveat that Site D's consumption patterns may differ.
b) We also used the Site C tariffs for this modelling, as we did not have tariff information for Site D.
c) We have used the PV generation profile from a similar site in Greater Manchester. We've used an export tariff based on web research plus experience at other sites, as we did not have an export tariff for the site.
d) As we developed the model for Site D, we noticed that a second optimum point seemed to be emerging around a significantly larger battery. So we developed a second model to explore this point a little more closely. It is not economically attractive, but it does have interesting aspects w.r.t. carbon emissions, so we have included it here also.

Site D – Summary – 4kWh battery

Base		Interventions	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading
Total Consumption:	18,739	Total Grid Demand:	11,288	10,758	10,798	10,798
Peak Consumption:	17,659	Peak Grid Demand:	10,258	9,751	8,899	8,899
Off-Peak Consumption:	1,081	Off-Peak Grid Demand:	1,030	1,007	1,899	1,899
Cost on Fixed Tariff:	100%	PV Generation:	9,446	9,446	9,446	9,446
Cost on Tou Tariff:	114%	Cost on Fixed Tariff:	60%	57%	58%	57%
		Cost on Tou Tariff:	68%	65%	63%	63%
		Export:	1,995	1,464	1,504	1,504
		Export Earnings:	3%	3%	3%	3%
		Annual Saving:	43%	45%	45%	46%

- We estimate a PV array could reduce the site's energy costs by approx. 43% p.a. (after accounting for export earnings). This is for an array sized at about 10kW. A larger array would give further benefit, but the best return on investment (ROI) is at about 10kW. This array would pay back its costs in about 4-5 years.
- Adding a 4kWh battery would increase the saving to approx. 45% p.a. This would give a very marginal return on investment, paying back after about 16 years. The bulk of this benefit comes from increasing self-consumption of energy generated by the PV array. The benefits of timeshifting are marginal, less than the cost of moving to a Time-of-Use tariff (which would increase the cost of energy consumed during the day c.f. a fixed tariff). Note however that the battery also gives some insulation against future tariff increases. The battery would represent a small additional investment c.f. the cost of the PV array, so on balance it may still be a worthwhile investment.

Site D – System Sizing

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.

It can be seen that the optimal return is achieved from an 10kW PV array. Adding a small battery extends the payback very slightly. It also tends to increase the optimal size of the array sightly. However, the optimum is broad and shallow, so there is a fairly wide range of battery and PV sizes that work reasonably well.

Although the optimum system has no battery, adding a battery does not increase the payback time by very much and the overall return is still decent for many configurations. Thus it may be worth investing in a battery as this could yield reasonable returns, even if not as high as for PV alone. (Noting also that, by increasing self-consumption, the battery will help mitigate the risk of future energy price increases.)

Full System Saving p.a.		Size of Battery (kWh)							
	£3,146.06	0.000	4.000	8.000	12.000	16.000	20.000	30.000	40.000
Size of PV Array (kW)	2.000	£695.51	£735.53	£748.87	£748.07	£747.54	£745.65	£1,063.97	£1,071.00
	4.000	£1,377.88	£1,427.86	£1,441.40	£1,440.95	£1,440.68	£1,514.76	£1,807.41	£1,813.44
	6.000	£2,005.36	£2,088.06	£2,106.20	£2,105.17	£2,102.03	£2,223.37	£2,474.21	£2,491.04
	8.000	£2,534.65	£2,664.89	£2,705.47	£2,689.63	£2,696.74	£2,815.16	£3,037.01	£3,058.46
	10.000	£2,984.51	£3,146.06	£3,206.79	£3,218.74	£3,219.90	£3,335.42	£3,524.80	£3,542.71
	12.000	£3,382.31	£3,566.30	£3,655.21	£3,678.15	£3,677.76	£3,777.03	£3,952.71	£3,977.47
	14.000	£3,745.90	£3,947.88	£4,051.74	£4,098.39	£4,094.94	£4,184.44	£4,341.42	£4,357.07
	16.000	£4,083.14	£4,300.74	£4,413.96	£4,480.06	£4,474.77	£4,550.36	£4,709.66	£4,715.79

Full System Payback		Size of Battery (kWh)							
(years - excludes financing)		0.000	4.000	8.000	12.000	16.000	20.000	30.000	40.000
Size of PV Array (kW)	2.000	7.2	9.0	10.9	13.1	15.3	17.4	16.0	19.6
	4.000	5.1	6.0	7.1	8.2	9.3	9.9	10.5	12.7
	6.000	4.5	5.1	5.8	6.6	7.3	7.6	8.5	10.0
	8.000	4.3	4.7	5.2	5.9	6.5	6.7	7.6	8.8
	10.000	4.4	4.6	5.1	5.5	6.0	6.3	7.1	8.2
	12.000	4.4	4.7	5.0	5.4	5.8	6.1	6.8	7.8
	14.000	4.5	4.7	5.0	5.3	5.7	6.0	6.7	7.6
	16.000	4.7	4.8	5.0	5.3	5.7	5.9	6.6	7.4

Site D – Battery Sizing

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 4kWh battery for most PV array sizes, and that the return improves as the size of the array grows. For the recommended PV size on this site (10kW), the payback on the battery would be about 16 years. This is not particularly attractive, especially given the expected life of the battery. Nonetheless, the cost of such a small battery would be small c.f. the cost of the PV array, so it might be worth installing such a battery for the risk mitigation benefits mentioned earlier. This could support future growth in the site's electricity demand if, for example, it were to install heat pumps.

Note that there appears to be a second optimum emerging at a battery size of about 30kWh for the level of load at this site. The payback is not attractive (20-25 years), but we decided to explore this configuration a little more closely.

Battery Savings

Size of PV Array (kW)	Size of Battery (kWh)							
£161.55	0.000	4.000	8.000	12.000	16.000	20.000	30.000	40.000
2.000	£0.00	£40.03	£53.36	£52.56	£52.03	£50.14	£368.46	£375.49
4.000	£0.00	£49.98	£63.52	£63.07	£62.80	£136.87	£429.53	£435.55
6.000	£0.00	£82.70	£100.85	£99.81	£96.68	£218.02	£468.86	£485.68
8.000	£0.00	£130.24	£170.83	£154.98	£162.09	£280.51	£502.36	£523.81
10.000	£0.00	£161.55	£222.28	£234.23	£235.39	£350.91	£540.29	£558.20
12.000	£0.00	£183.99	£272.90	£295.85	£295.46	£394.72	£570.40	£595.17
14.000	£0.00	£201.98	£305.84	£352.49	£349.04	£438.55	£595.53	£611.18
16.000	£0.00	£217.60	£330.82	£396.92	£391.63	£467.22	£626.52	£632.65

Battery Payback

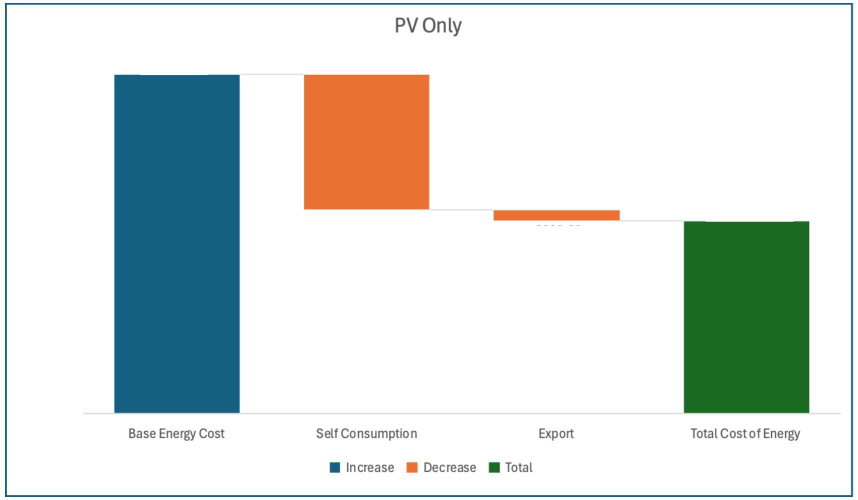
Size of PV Array (kW)	Size of Battery (kWh)							
	0.000	4.000	8.000	12.000	16.000	20.000	30.000	40.000
2.000	1000.0	65.0	78.7	110.3	142.2	179.5	35.3	45.3
4.000	1000.0	52.0	66.1	92.0	117.8	65.8	30.3	39.0
6.000	1000.0	31.4	41.6	58.1	76.5	41.3	27.7	35.0
8.000	1000.0	20.0	24.6	37.4	45.7	32.1	25.9	32.5
10.000	1000.0	16.1	18.9	24.8	31.4	25.6	24.1	30.5
12.000	1000.0	14.1	15.4	19.6	25.0	22.8	22.8	28.6
14.000	1000.0	12.9	13.7	16.5	21.2	20.5	21.8	27.8
16.000	1000.0	11.9	12.7	14.6	18.9	19.3	20.7	26.9

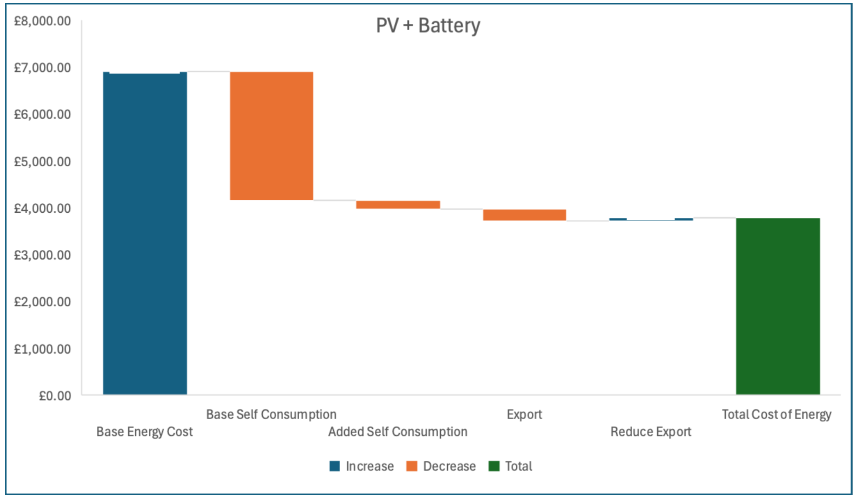
Site D – Summary – 30kWh battery

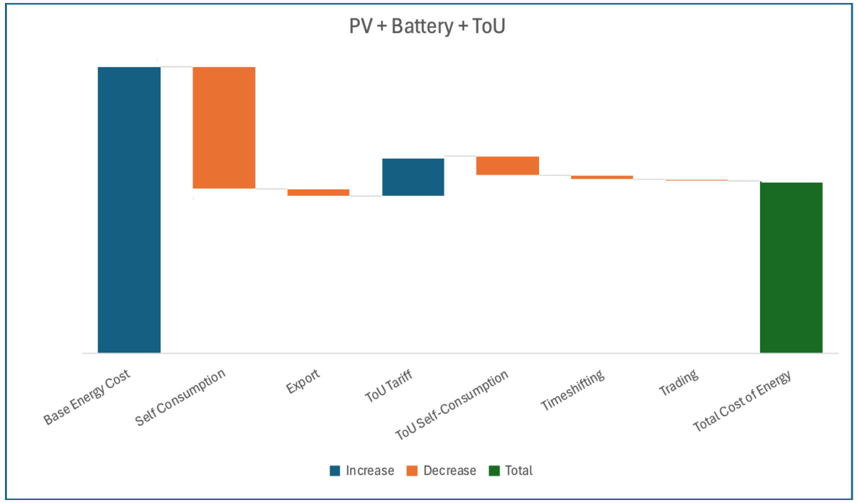
Base		Interventions	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading
Total Consumption:	18,739	Total Grid Demand:	11,288	10,128	10,624	10,624
Peak Consumption:	17,659	Peak Grid Demand:	10,258	9,294	2,963	2,963
Off-Peak Consumption:	1,081	Off-Peak Grid Demand:	1,030	833	7,661	7,661
Cost on Fixed Tariff:	100%	PV Generation:	9,446	9,446	9,446	9,446
Cost on Tou Tariff:	114%	Cost on Fixed Tariff:	60%	54%	57%	55%
		Cost on Tou Tariff:	68%	61%	51%	50%
		Export:	1,995	834	1,331	1,331
		Export Earnings:	3%	1%	2%	2%
		Annual Saving:	43%	47%	51%	53%

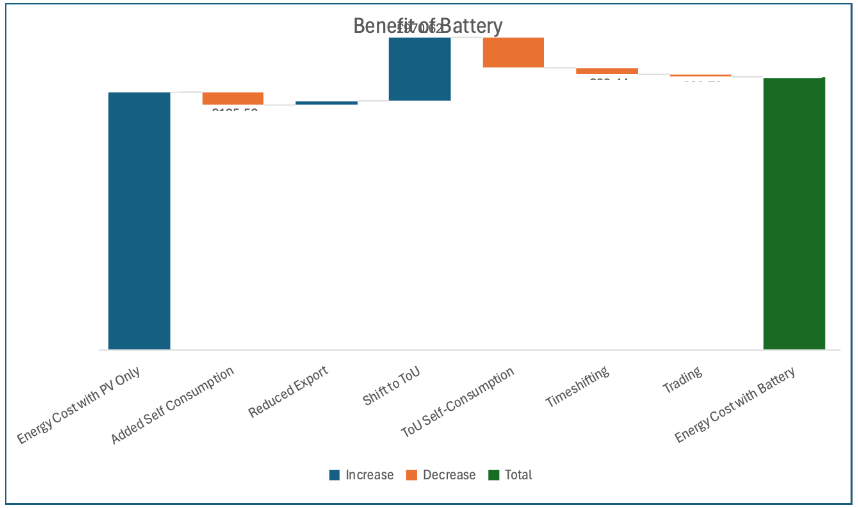
- This table shows the results for a 30kWh battery (retaining the 10kW PV array). The saving from the PV array remains the same, but the battery now delivers a further saving of about 7%. This is because the larger battery enables sufficient energy to be timeshifted from peak to off-peak times that it is worthwhile switching to a time-of-use tariff. This is still not economically attractive, due to the added cost of such a large battery, but it does enable the site to get very close to net zero carbon emissions, as we'll show in a couple of slides.

Site D – Benefits Breakdown – 4kWh battery









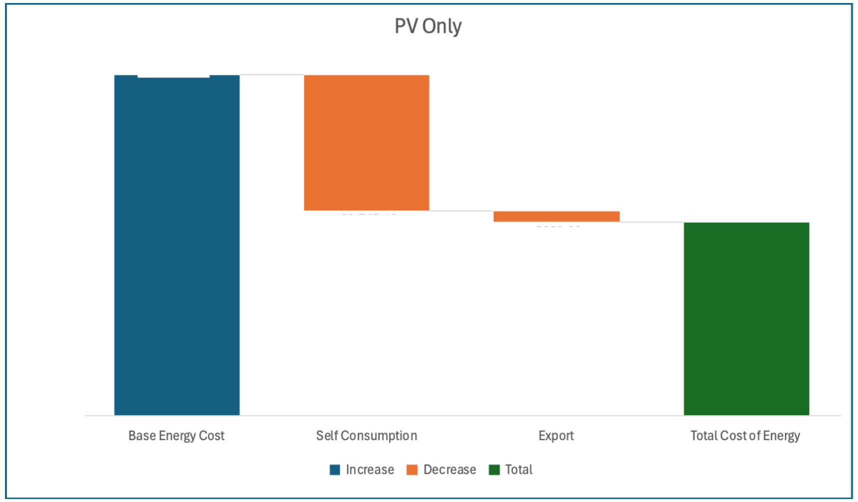
The bulk of the benefit from the PV array comes from allowing the site to use free solar energy rather than buying electricity from the grid (“self-consumption”). This yields a saving of about 39% p.a. from the PV array alone. Adding a battery increases this by a further 3%.

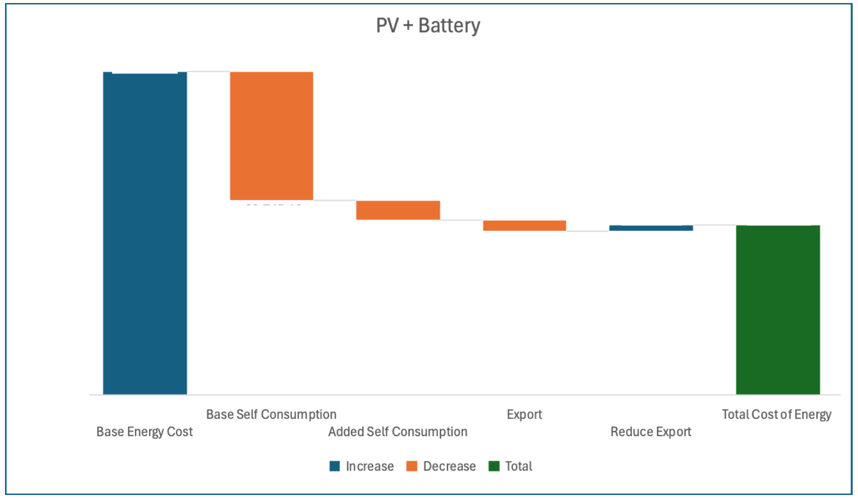
There is also a small benefit from exporting excess PV generation to the grid (typically during the summer). Adding a battery reduces this benefit, as it enables some of the excess generation to be self-consumed, which is generally more valuable.

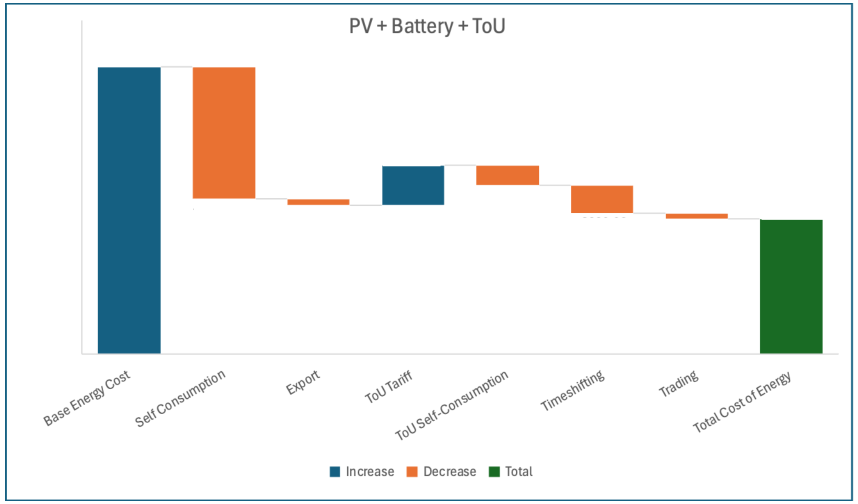
The battery could also be used to shift some of the site’s consumption from peak to off-peak times. This is only useful if the site switches to a Time-of-Use tariff, which would entail some cost (as it increases the cost of energy consumed at peak times). For this site, this is not worthwhile – the timeshifting benefit is not large enough.

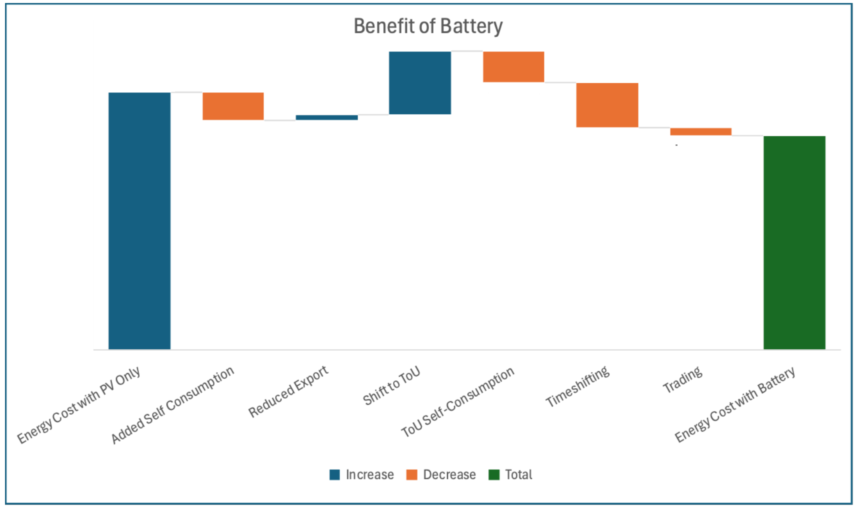
Finally, spare capacity in the battery could be used to trade on wholesale & flexibility markets. The returns on such trading can be volatile, but we have estimated that they could generate revenue of the order of £40p.a. for the site.

Site D – Benefits Breakdown – 30kWh battery









Adding a larger battery increases the self-consumption benefit by a further 3%, at the expense of reducing the export benefit by a further 1%.

More importantly, the timeshifting benefit grows from 8% to 17%, now exceeding the cost of shifting to a Time-of-Use tariff.

The larger battery also enables slightly more value to be obtained from trading on flex markets.

The end result does not make the battery viable, but it shows that optimum battery sizing can be highly sensitive to load patterns and to the differential between peak and off-peak tariff rates. Site D has about 30% higher consumption than Site C, for which this second optimum was not apparent.

And again, the effect on carbon emissions is very interesting.

Site D – Carbon Savings – 4kWh battery

Carbon Benefits	kWh	Baseline	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading		Carbon Intensity
	Peak Grid Demand:	17,659	10,258	9,751	8,899	8,899		148
	Off-Peak Grid Demand:	1,081	1,030	1,007	1,899	1,899		57
	PV Generation:	0	9,446	9,446	9,446	9,446		0
	Export:	0	1,995	1,464	1,504	1,504		-133
	kgCO2							
	Peak Grid Demand:	2,613	1,518	1,443	1,317	1,317		
	Off-Peak Grid Demand:	62	59	57	108	108		
	PV Generation:	-	-	-	-	-		
	Export:	-	(265)	(195)	(200)	(200)		
	Total	**2,675**	**1,312**	**1,306**	**1,225**	**1,225**		
	Reduction		**1,364**	**1,369**	**1,450**	**1,450**		
	Benefit of Battery			**6**	**86**	**86**		

- We estimate that adding a PV array would enable the site to reduce its carbon footprint by about 1.4 tCO2e p.a. Adding a battery would yield an additional carbon saving of approx. 0.1 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. We tend to use fairly conservative assumptions, as the grid's carbon intensity is declining rapidly and so the future benefit of avoiding importing from the grid will decline.

Site D – Carbon Savings – 30kWh battery

Carbon Benefits	kWh	Baseline	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading		Carbon Intensity
	Peak Grid Demand:	17,659	10,258	9,294	2,963	2,963		148
	Off-Peak Grid Demand:	1,081	1,030	833	7,661	7,661		57
	PV Generation:	0	9,446	9,446	9,446	9,446		0
	Export:	0	1,995	834	1,331	1,331		-133
	kgCO2							
	Peak Grid Demand:	2,613	1,518	1,376	438	438		
	Off-Peak Grid Demand:	62	59	47	437	437		
	PV Generation:	-	-	-	-	-		
	Export:	-	(265)	(111)	(177)	(177)		
	Total	**2,675**	**1,312**	**1,312**	**698**	**698**		
	Reduction		**1,364**	**1,363**	**1,977**	**1,977**		
	Benefit of Battery			**(1)**	**613**	**613**		

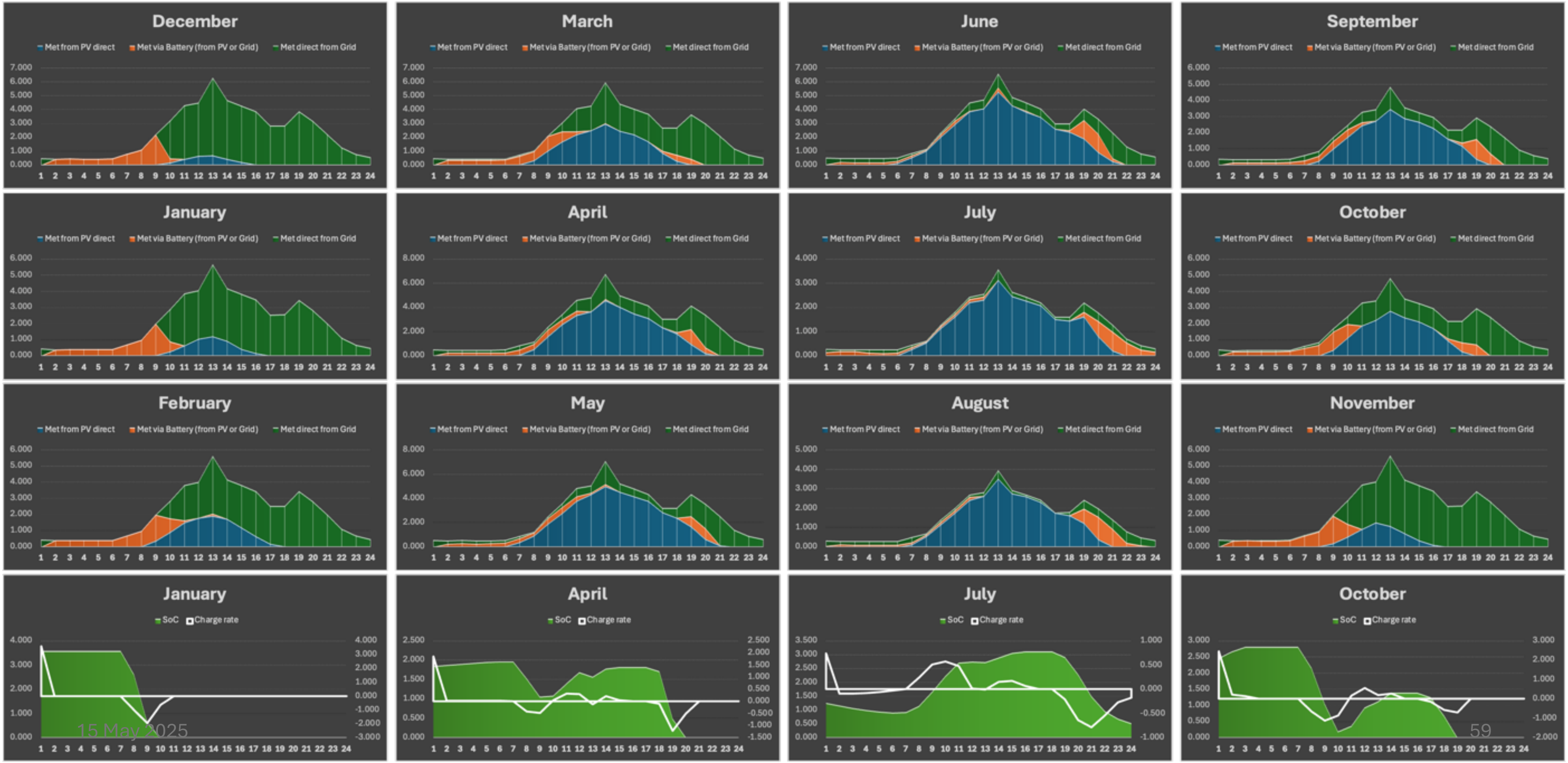
- Expanding the battery to 30kWh significantly increases the carbon savings, by a further 0.5 tCO2e p.a. This brings the site's carbon emissions due to electricity consumption to well less than 1 tCO2e p.a.
- **With this battery, expanding the PV array to about 16-17kW would enable the site to have zero net carbon emissions from its electricity consumption, under our assumptions regarding grid carbon intensity and accounting for exports from the PV array. This takes the payback period for the PV+battery system from 5 to 7 years. So while not optimum, it could still be a viable investment.**

Site D – Energy usage patterns

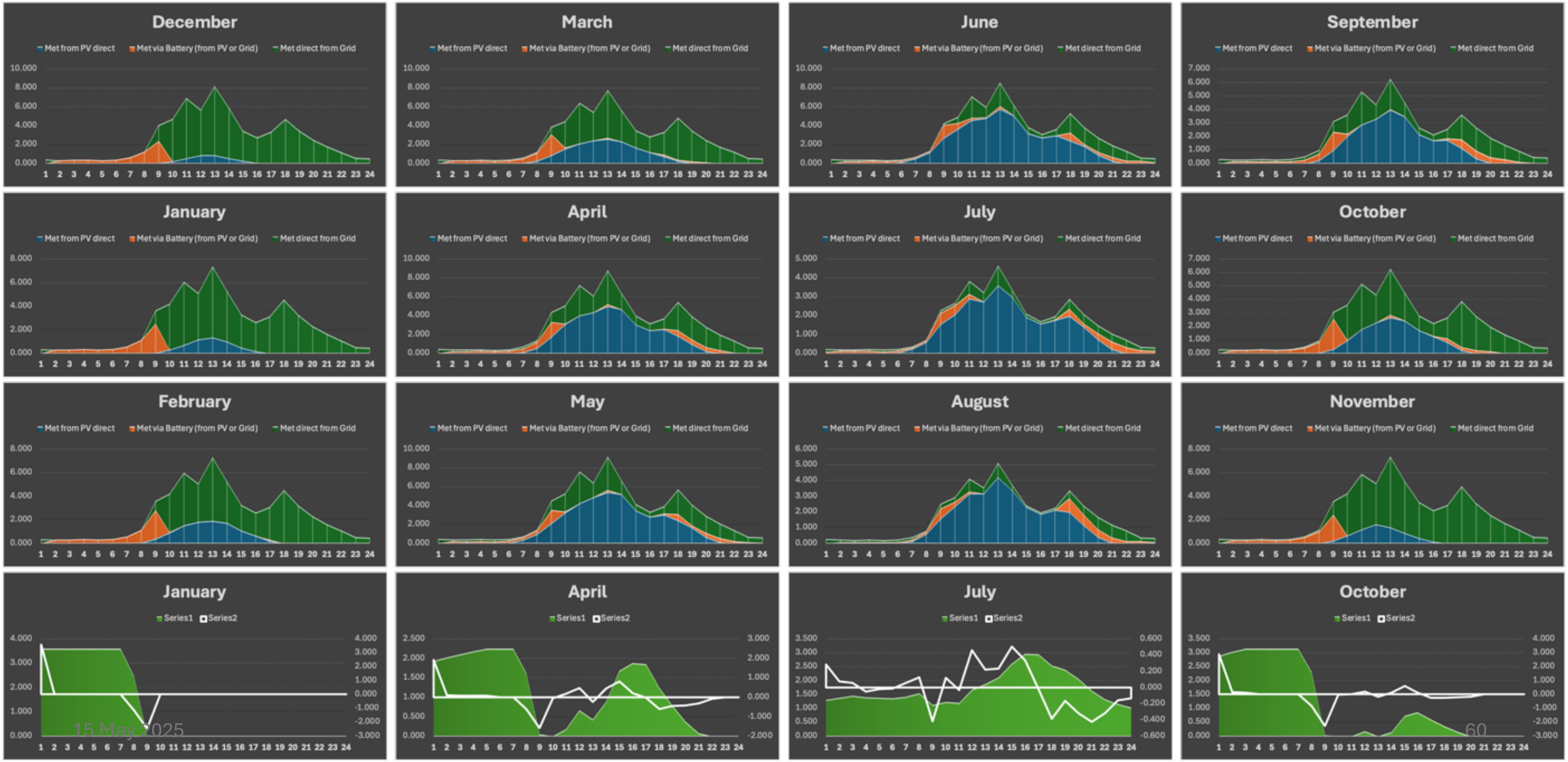
The next 4 slides show the average daily energy usage pattern for each month of the year, for weekdays and weekends respectively. These give a more detailed feel for how the PV energy and battery might be used. The first 2 slides are for a 4kWh battery, where the patterns are very similar to those for Site C (unsurprisingly, as we’ve used its consumption patterns).

The second 2 slides are for a 30kWh battery. It can be seen that this battery enables the site to meet most of its demand from solar and off-peak energy (which tends to be low carbon) for many months of the year.

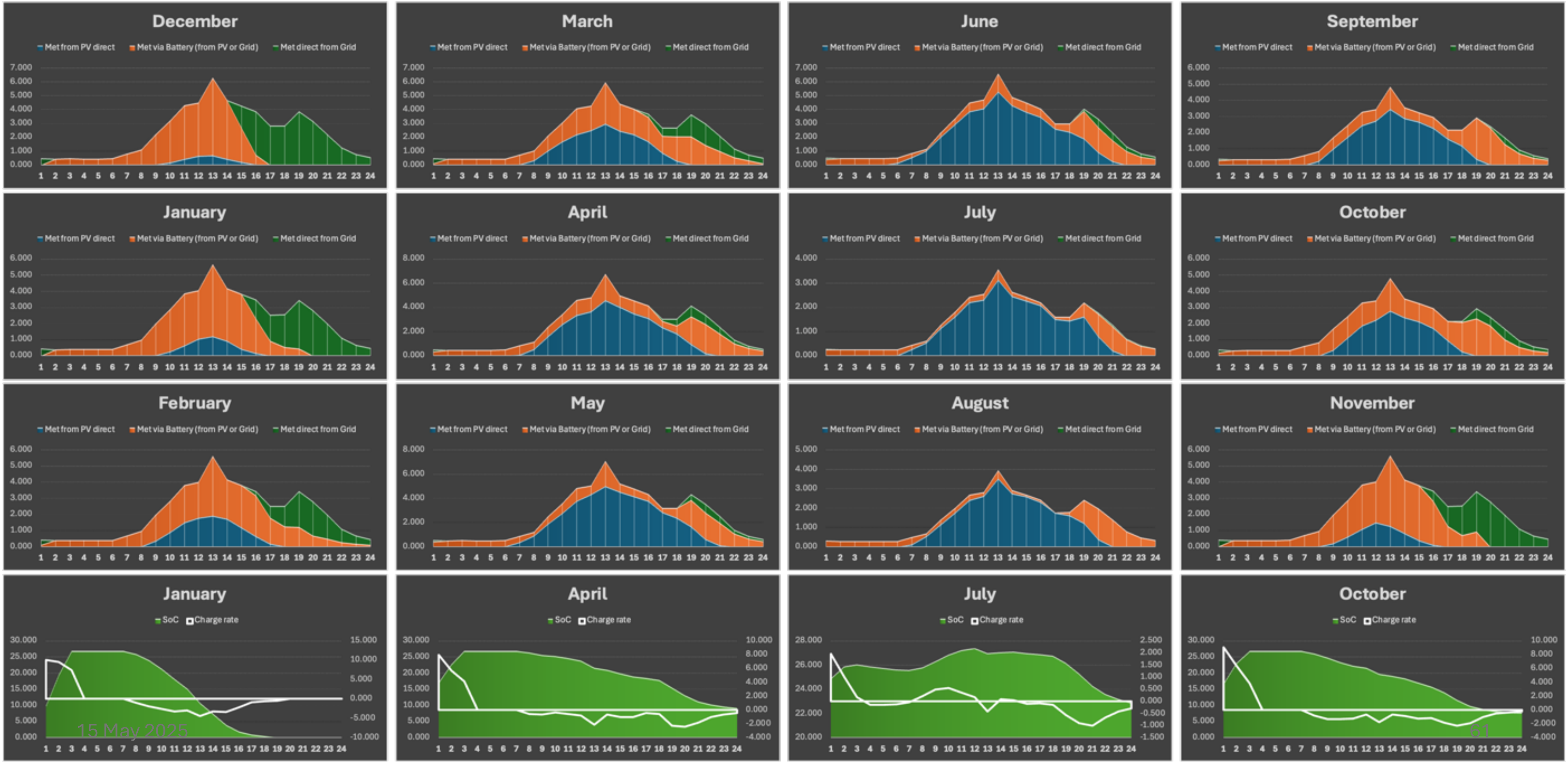
Site D – Weekday energy usage – 4kWh battery



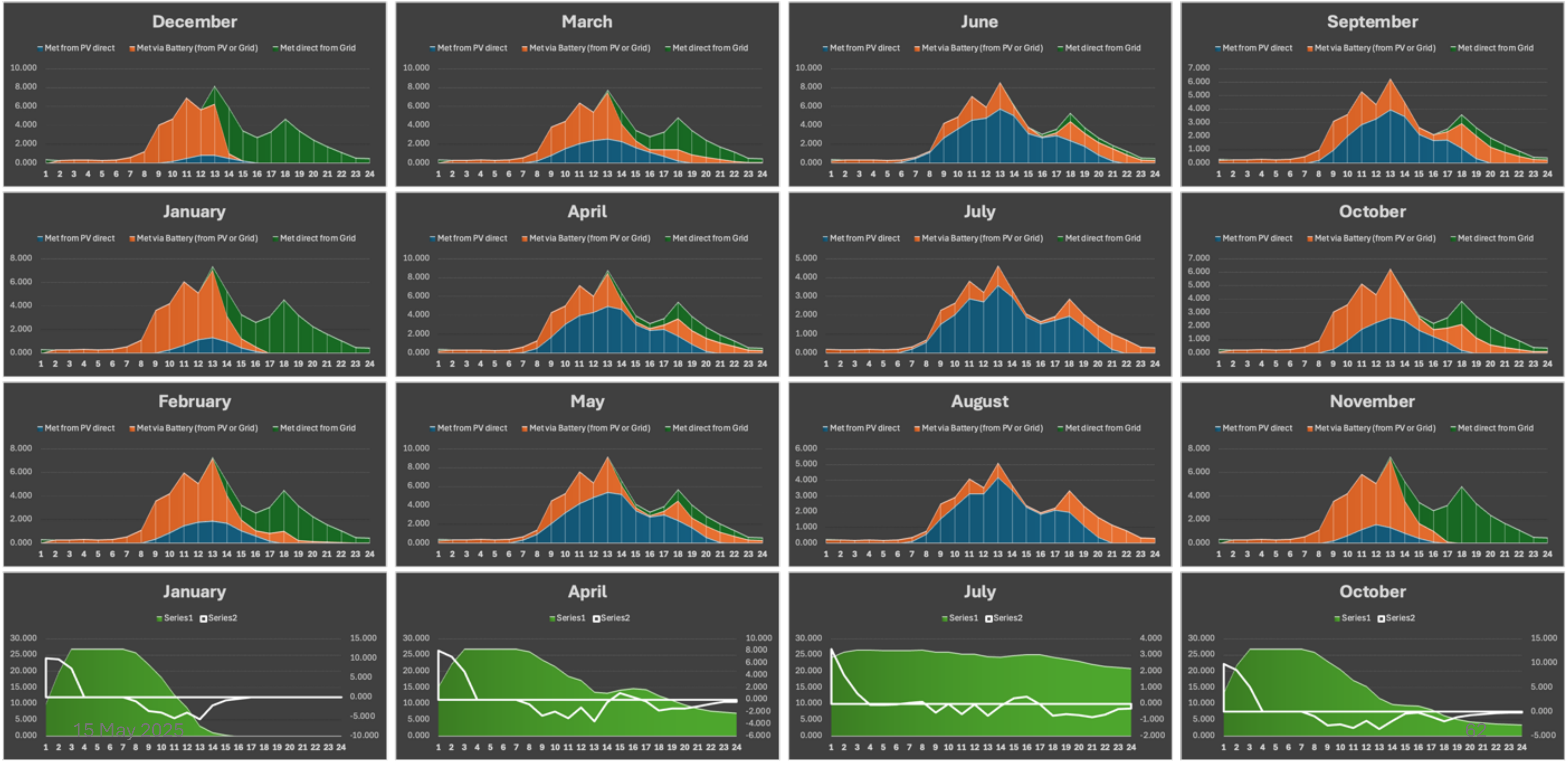
Site D – Weekend energy usage – 4kWh battery



Site D – Weekday energy usage – 30kWh battery



Site D – Weekend energy usage – 30kWh battery



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 based the modelling on the site's hourly energy consumption as measured by a CT-clamp monitor during Dec 2024. We then used a year of monthly meter readings (July 2023 – July 2024) to calculate average monthly consumption and hence normalise the Dec data to give hourly data for other months. This can only be an approximation – it captures trends in overall consumption, but not seasonal changes to daily patterns. That may be significant for this site, given that it's reported to run a lot of electrical heating on winter evenings.

b) We used the fixed tariff from the site's latest energy bill and compared it against the Time-of-Use tariff from Site C. Again, this is an approximation. As with the other sites, tariffs can change significantly with market conditions and future trends are very difficult to predict, so there will always be significant uncertainty associated with these numbers.

c) We have used the PV generation profile from a similar site in Greater Manchester. We've used an export tariff based on web research plus experience at other sites, as we did not have an export tariff for the site.

d) Energy costs are likely to be volatile over the life of the systems being modelled. It is also possible that the site's energy consumption patterns will change over time. So our results should be seen as estimates. We cannot guarantee that specific levels of return will be obtained over the life of the systems.

Site E – Summary

Base		Interventions	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading
Total Consumption:	18,158	Total Grid Demand:	14,153	13,147	13,220	13,220
Peak Consumption:	13,914	Peak Grid Demand:	9,950	9,074	8,053	8,053
Off-Peak Consumption:	4,244	Off-Peak Grid Demand:	4,203	4,073	5,168	5,168
Cost on Fixed Tariff:	£6,628	PV Generation:	7,557	7,557	7,557	7,557
Cost on Tou Tariff:	£7,212	Cost on Fixed Tariff:	£5,166	£4,799	£4,825	£4,773
		Cost on Tou Tariff:	£5,504	£5,091	£4,979	£4,927
		Export:	3,552	2,546	2,619	2,619
		Export Earnings:	£426	£306	£314	£314
		Annual Saving:	£1,888	£2,134	£2,116	£2,169

- We estimate a PV array could reduce the site's energy costs by approx. £1,900 (28%) p.a., from £6,600 to £4,700 (after accounting for export earnings). This is for an array sized at about 8kW. A larger array would give further benefit (e.g. doubling the array size might increase the savings by about 50%), but the best return on investment (ROI) is at 6-8kW. This array would pay back its costs in about 6 years.
- Adding a 6kWh battery would increase the saving to approx. £2,200 (33%) p.a. This would give a marginal return on investment, paying back after about 12 years. The bulk of this benefit comes from increasing self-consumption of energy generated by the PV array. The benefits of timeshifting are marginal, and do not exceed the cost of moving to a Time-of-Use tariff (which would increase the cost of energy consumed during the day c.f. a fixed tariff). Note however that the battery also gives some insulation against future tariff increases. The battery would represent a small additional investment c.f. the cost of the PV array, so on balance it is probably a worthwhile investment.

Site E – System Sizing

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.

It can be seen that the optimal return is achieved from a 6-8kW PV array with no battery. Adding a battery tends to increase the optimal size of the array sightly. However, the optimum is broad and shallow, so there is a fairly wide range of battery and PV sizes that work reasonably well.

Although the optimum system has no battery, adding a small battery does not increase the payback time by very much and the overall return is still decent for many configurations. Thus it may be worth investing in a battery as this could yield reasonable returns, even if not quite as high as for PV alone. (Noting also that, by increasing self-consumption, the battery will help mitigate the risk of future energy price increases.)

Full System Saving p.a.		Size of Battery (kWh)							
	£2,168.90	0.000	2.000	4.000	6.000	8.000	10.000	15.000	20.000
Size of PV Array (kW)	4.000	£1,160.32	£1,235.46	£1,288.31	£1,319.81	£1,320.87	£1,312.02	£1,348.87	£1,406.93
	6.000	£1,549.75	£1,644.56	£1,722.49	£1,782.03	£1,812.87	£1,827.59	£1,848.13	£1,884.51
	8.000	£1,888.05	£1,998.33	£2,090.15	£2,168.90	£2,212.96	£2,255.71	£2,271.37	£2,321.10
	10.000	£2,202.93	£2,319.83	£2,423.90	£2,510.53	£2,568.72	£2,622.26	£2,658.27	£2,695.17
	14.000	£2,797.64	£2,926.31	£3,042.88	£3,146.67	£3,221.39	£3,274.58	£3,337.32	£3,381.68
	18.000	£3,351.07	£3,491.34	£3,618.49	£3,731.87	£3,821.30	£3,887.35	£3,980.13	£4,013.17
	22.000	£3,885.57	£4,031.32	£4,167.64	£4,287.28	£4,378.17	£4,447.37	£4,552.06	£4,618.03
	26.000	£4,405.84	£4,555.04	£4,697.81	£4,823.04	£4,921.79	£4,982.51	£5,094.66	£5,172.87

Full System Payback		Size of Battery (kWh)							
(years - excludes financing)		0.000	2.000	4.000	6.000	8.000	10.000	15.000	20.000
Size of PV Array (kW)	4.000	6.0	6.3	6.7	7.1	7.7	8.4	9.6	10.7
	6.000	5.8	6.0	6.2	6.4	6.7	7.1	8.1	9.0
	8.000	5.8	5.9	6.0	6.2	6.4	6.6	7.5	8.2
	10.000	5.9	5.9	6.0	6.1	6.3	6.5	7.1	7.8
	14.000	6.1	6.1	6.1	6.2	6.3	6.4	6.9	7.4
	18.000	6.3	6.2	6.2	6.3	6.3	6.4	6.8	7.2
	22.000	6.4	6.4	6.4	6.4	6.4	6.5	6.8	7.1
	26.000	6.6	6.5	6.5	6.5	6.5	6.6	6.9	7.2

Site E – Battery Sizing

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 4-8kWh battery for most PV array sizes, and that the return improves as the size of the array grows. For the recommended PV size on this site (8kW), the payback on the battery would be about 12 years. This is not particularly attractive, as it aligns to the expected life of the battery. Nonetheless, the cost of such a small battery would be small c.f. the cost of the PV array, so it might be worth installing such a battery for the risk mitigation benefits mentioned earlier. This could also support future growth in the site's electricity demand if, for example, it were to install heat pumps.

Battery Savings		Size of Battery (kWh)							
	£280.85	0.000	2.000	4.000	6.000	8.000	10.000	15.000	20.000
Size of PV Array (kW)	4.000	£0.00	£75.14	£127.99	£159.48	£160.55	£151.70	£188.55	£246.61
	6.000	£0.00	£94.81	£172.73	£232.28	£263.11	£277.84	£298.38	£334.75
	8.000	£0.00	£110.28	£202.09	£280.85	£324.91	£367.66	£383.32	£433.05
	10.000	£0.00	£116.90	£220.96	£307.60	£365.79	£419.33	£455.34	£492.24
	14.000	£0.00	£128.67	£245.24	£349.03	£423.75	£476.94	£539.68	£584.04
	18.000	£0.00	£140.27	£267.42	£380.79	£470.23	£536.28	£629.06	£662.10
	22.000	£0.00	£145.75	£282.07	£401.70	£492.59	£561.79	£666.49	£732.46
	26.000	£0.00	£149.20	£291.97	£417.20	£515.95	£576.67	£688.83	£767.03

Battery Payback		Size of Battery (kWh)							
		0.000	2.000	4.000	6.000	8.000	10.000	15.000	20.000
Size of PV Array (kW)	4.000	1000.0	24.0	20.3	21.3	26.2	33.0	37.1	36.5
	6.000	1000.0	19.0	15.1	14.6	16.0	18.0	23.5	26.9
	8.000	1000.0	16.3	12.9	12.1	12.9	13.6	18.3	20.8
	10.000	1000.0	15.4	11.8	11.1	11.5	11.9	15.4	18.3
	14.000	1000.0	14.0	10.6	9.7	9.9	10.5	13.0	15.4
	18.000	1000.0	12.8	9.7	8.9	8.9	9.3	11.1	13.6
	22.000	1000.0	12.3	9.2	8.5	8.5	8.9	10.5	12.3
	26.000	1000.0	12.1	8.9	8.1	8.1	8.7	10.2	11.7

Site E – Benefits Breakdown

The bulk of the benefit from the PV array comes from allowing the site to use free solar energy rather than buying electricity from the grid ("self-consumption"). This yields a saving of about £1,500 p.a. from the PV array alone. Adding a battery increases this by a further £400.

There is also a reasonable benefit from exporting excess PV generation to the grid (typically during the summer). Adding a battery reduces this benefit, as it enables some of the excess generation to be self-consumed, which is generally more valuable.

The battery could also be used to shift some of the site's consumption from peak to off-peak times. This is only worthwhile if the site switches to a Time-of-Use tariff, which would entail some cost (as it increases the cost of energy consumed at peak times). The saving due to time-shifting is not sufficient to compensates for this cost.

Finally, spare capacity in the battery could be used to trade on wholesale & flexibility markets. The returns on such trading can be volatile, but we have estimated that they could generate revenue of the order of £50p.a. for the site.

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:	13,914	9,950	9,074	8,053	8,053		148
	Off-Peak Grid Demand:	4,244	4,203	4,073	5,168	5,168		57
	PV Generation:	0	7,557	7,557	7,557	7,557		0
	Export:	0	3,552	2,546	2,619	2,619		-133
	kgCO2							
	Peak Grid Demand:	2,059	1,473	1,343	1,192	1,192		
	Off-Peak Grid Demand:	242	240	232	295	295		
	PV Generation:	-	-	-	-	-		
	Export:	-	(472)	(339)	(348)	(348)		
	Total	**2,301**	**1,240**	**1,236**	**1,138**	**1,138**		
	Reduction		**1,061**	**1,065**	**1,163**	**1,163**		
	Benefit of Battery			**3**	**102**	**102**		

- We estimate that adding a PV array would enable the site to reduce its carbon footprint by about 1.1 tCO2e p.a. Adding a battery would yield an additional carbon saving of approx. 0.1 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. We tend to use fairly conservative assumptions, as the grid's carbon intensity is declining rapidly and so the future benefit of avoiding importing from the grid will decline.

Site E – Energy usage patterns

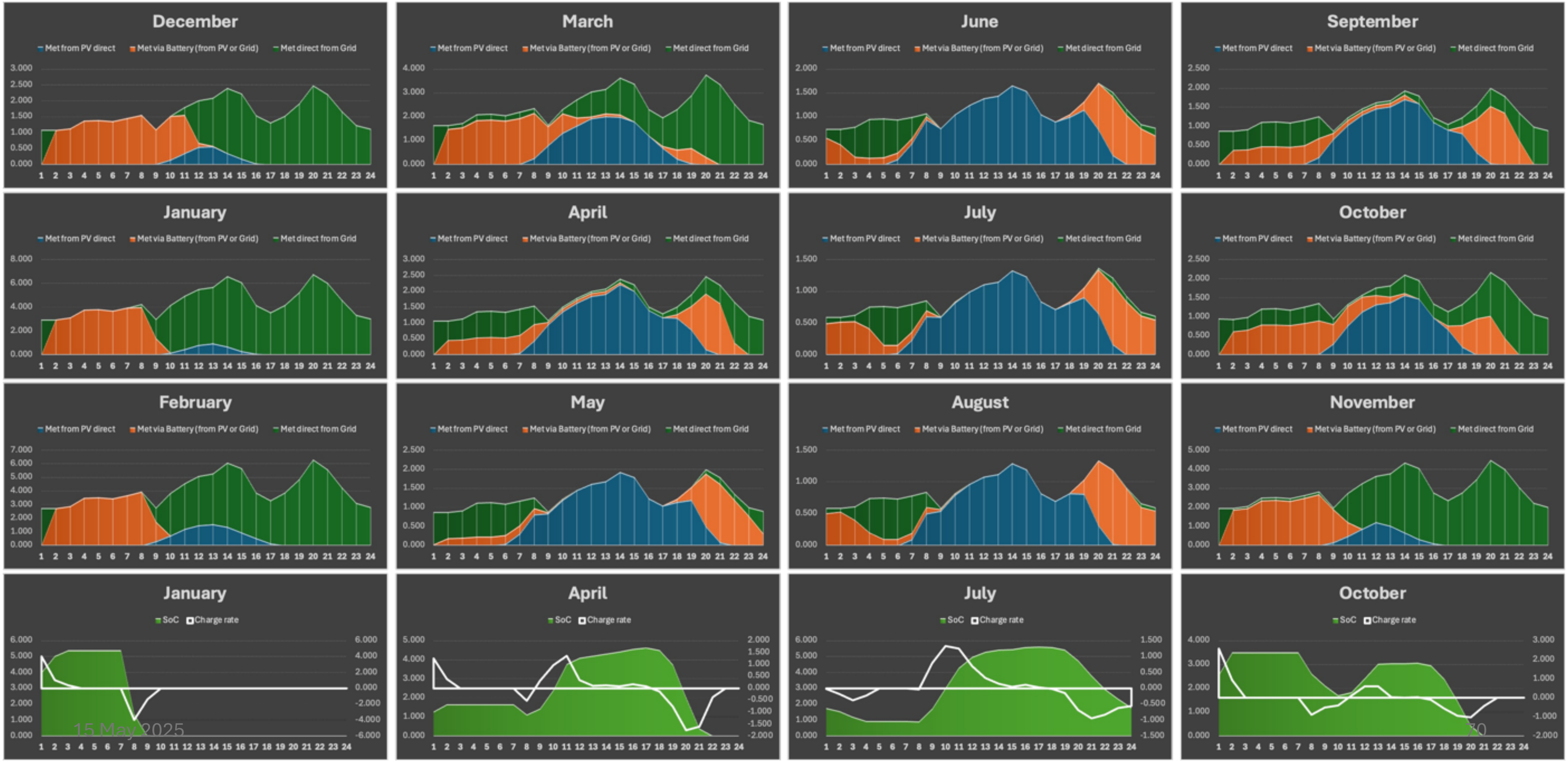
The next 2 slides show the average daily energy usage pattern for each month of the year, for weekdays and weekends respectively. These give a more detailed feel for how the PV energy and battery might be used.

The site has a distinctive demand profile c.f. the other sites in this report, with a pronounced evening peak and strong demand throughout the night. This increases the benefit of using a battery to shift energy produced by a PV array into the evening, but reduces the benefit it can create from a Time-of-Use tariff (as that overnight energy is already being used). That said, the PV & battery usage patterns are broadly similar to the other sites:

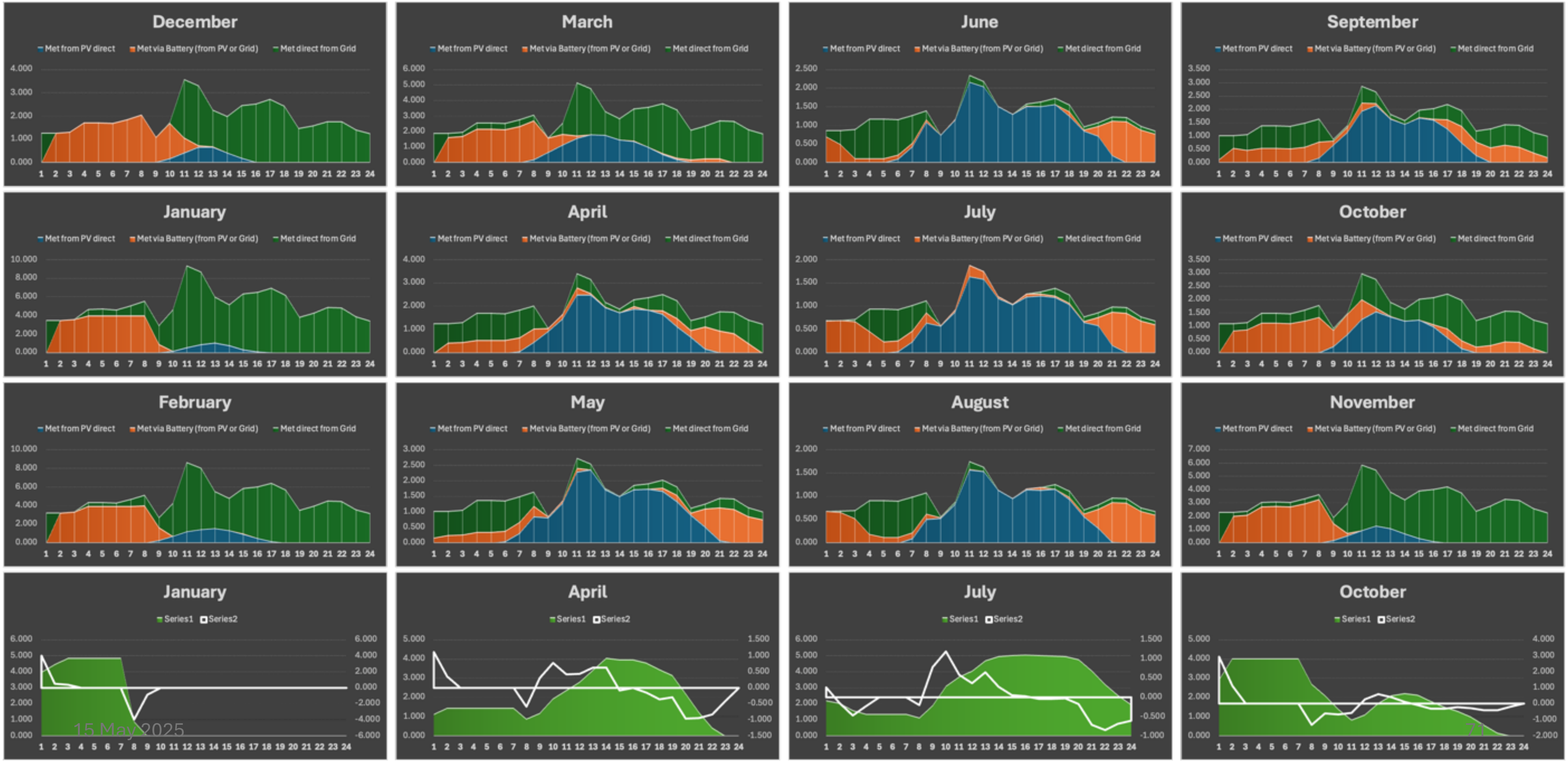
- During winter, the PV array does not generate enough energy to meet daily consumption. The battery is used primarily to import energy at off-peak times overnight and to use this to meet consumption in the morning.
- By April, the PV is beginning to meet consumption on some (sunny) days. The battery 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 June, the PV is meeting demand during the day most days, and the excess is sufficient to meet some of the evening demand on those days. The battery tends not to charge overnight as (a) the overnight demand is already significant, and (b) it needs to reserve significant capacity to capture the next day's solar output.
- In Autumn, the pattern goes back to that of the Spring months, with the battery cycling twice per day, once from the solar PV and once from cheap overnight electricity from the grid.

Note however that our analysis is biased by our only having hourly demand data for December – demand patterns in the summer months may actually be quite different.

Site E – Weekday energy usage



Site E – Weekend energy usage



Site F

The following slides show key results for Site F. Full results are given in the accompanying spreadsheet, which contains the full model, input data, etc.

Note that:

a) We based the modelling on the site's hourly energy consumption as measured by a CT-clamp monitor during late February and early March 2025. We then used a year of monthly meter readings (April 2023 – March 2024) to calculate average monthly consumption and hence normalise the February data to give hourly data for other months. This can only be an approximation – it captures trends in overall consumption, but not seasonal changes to daily patterns.

b) We used the fixed and Time-of-Use tariffs from the site's March 2024 energy bill. As with the other sites, tariffs can change significantly with market conditions and future trends are very difficult to predict, so there will always be significant uncertainty associated with these numbers.

c) We have assumed that the site's three meter points (for church, hall and presbytery) will be consolidated to a single point so that output from a PV array and associated battery can be shared across all three buildings, and hence that they will operate under a single tariff.

d) We have used the PV generation profile from a similar site in Greater Manchester. We've used an export tariff based on web research plus experience at other sites, as we did not have an export tariff for the site.

e) Energy costs are likely to be volatile over the life of the systems being modelled. It is also possible that the site's energy consumption patterns will change over time. So our results should be seen as estimates. We cannot guarantee that specific levels of return will be obtained over the life of the systems.

Site F – Summary

Base		Interventions	PV Only	PV+Battery (no grid import)	PV+Battery (with grid import)	Active Trading
Total Consumption:	17,873	Total Grid Demand:	13,270	10,568	11,007	11,007
Peak Consumption:	13,984	Peak Grid Demand:	9,433	7,040	4,140	4,140
Off-Peak Consumption:	3,889	Off-Peak Grid Demand:	3,837	3,528	6,867	6,867
Cost on Fixed Tariff:	100%	PV Generation:	9,446	9,446	9,446	9,446
Cost on Tou Tariff:	108%	Cost on Fixed Tariff:	74%	59%	62%	61%
		Cost on Tou Tariff:	79%	62%	58%	57%
		Export:	4,843	2,142	2,581	2,581
		Export Earnings:	9%	4%	5%	5%
		Annual Saving:	35%	45%	47%	48%

- We estimate a PV array could reduce the site's energy costs by approx. 35% p.a. (after accounting for export earnings). This is for an array sized at about 10kW. A larger array would give further benefit (e.g. doubling the array size might increase the savings by about 60%), but the best return on investment (ROI) is at 8-10kW. This array would pay back its costs in about 6 years.
- Adding a 15kWh battery would increase the saving to approx. 48% p.a. This would give a reasonable return on investment, paying back after about 8-9 years. The bulk of this benefit comes from increasing self-consumption of energy generated by the PV array. The benefits of timeshifting are marginal, only just exceeding the cost of moving to a Time-of-Use tariff (which would increase the cost of energy consumed during the day c.f. a fixed tariff). Note however that the battery also gives some insulation against future tariff increases. The battery would represent a small additional investment c.f. the cost of the PV array, so on balance it is probably a worthwhile investment.

Site F – System Sizing

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.

It can be seen that the optimal return is achieved from a 8-10kW PV array with no battery. Adding a battery tends to increase the optimal size of the array sightly. However, the optimum is broad and shallow, so there is a fairly wide range of battery and PV sizes that work reasonably well.

Although the optimum system has no battery, adding a small battery does not increase the payback time by very much and the overall return is still decent for many configurations. Thus it may be worth investing in a battery as this could yield reasonable returns, even if not quite as high as for PV alone. (Noting also that, by increasing self-consumption, the battery will help mitigate the risk of future energy price increases.)

Full System Saving p.a.		Size of Battery (kWh)							
	£3,143.04	0.000	4.000	8.000	12.000	15.000	18.000	21.000	24.000
Size of PV Array (kW)	2.000	£679.55	£734.71	£761.45	£836.18	£956.91	£1,081.62	£1,206.28	£1,327.95
	4.000	£1,177.18	£1,337.07	£1,403.29	£1,566.42	£1,692.29	£1,804.38	£1,905.13	£1,999.46
	6.000	£1,579.91	£1,788.26	£1,915.19	£2,135.00	£2,269.84	£2,366.60	£2,448.16	£2,503.26
	8.000	£1,942.23	£2,181.21	£2,345.56	£2,581.72	£2,726.87	£2,837.73	£2,929.97	£3,001.85
	10.000	£2,277.17	£2,543.72	£2,730.94	£2,996.99	£3,143.04	£3,276.83	£3,369.46	£3,446.89
	12.000	£2,594.46	£2,879.34	£3,095.89	£3,367.56	£3,543.10	£3,680.12	£3,761.29	£3,845.57
	14.000	£2,896.28	£3,196.75	£3,438.54	£3,724.81	£3,899.99	£4,037.18	£4,151.31	£4,231.01
	16.000	£3,186.89	£3,497.80	£3,764.06	£4,059.26	£4,240.12	£4,385.29	£4,489.36	£4,559.23

Full System Payback		Size of Battery (kWh)							
(years - excludes financing)		0.000	4.000	8.000	12.000	15.000	18.000	21.000	24.000
Size of PV Array (kW)	2.000	7.7	9.3	11.1	12.0	11.8	11.5	11.3	11.2
	4.000	6.2	6.6	7.4	7.7	7.8	8.0	8.2	8.4
	6.000	5.9	6.1	6.5	6.6	6.7	7.0	7.2	7.5
	8.000	5.8	5.9	6.2	6.2	6.3	6.5	6.7	6.9
	10.000	5.8	5.8	6.0	6.0	6.1	6.2	6.4	6.6
	12.000	5.9	5.9	6.0	6.0	6.0	6.1	6.3	6.5
	14.000	6.0	5.9	5.9	5.9	6.0	6.1	6.2	6.3
	16.000	6.0	6.0	6.0	5.9	6.0	6.0	6.2	6.3

Site F – Battery Sizing

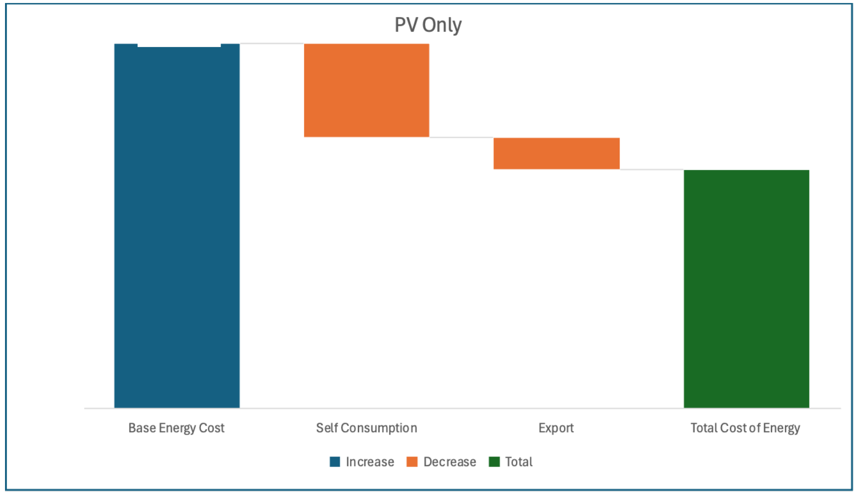
These tables show the proportion of the annual saving that can be attributed to the battery, and the payback (in years) that this would yield for investing in the battery.

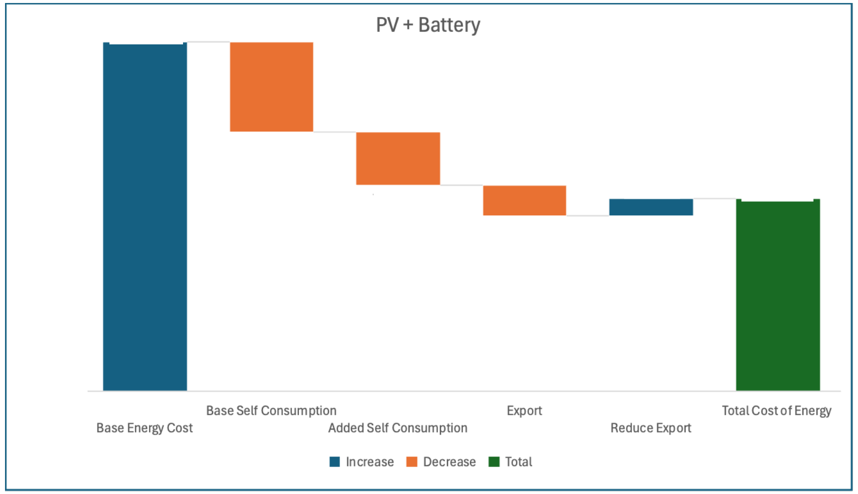
It can be seen that the optimum return is achieved for a ~15kWh battery for most PV array sizes, and that the return improves as the size of the array grows. For the recommended PV size on this site (10kW), the payback on the battery would be about 8-9 years. This is not as attractive as for the PV array alone, but it is still reasonable at current interest rates and given an expected battery life of about 15 years. And again, such a battery would help mitigate the risk of future tariff increases by maximising self-consumption of output from the PV array.

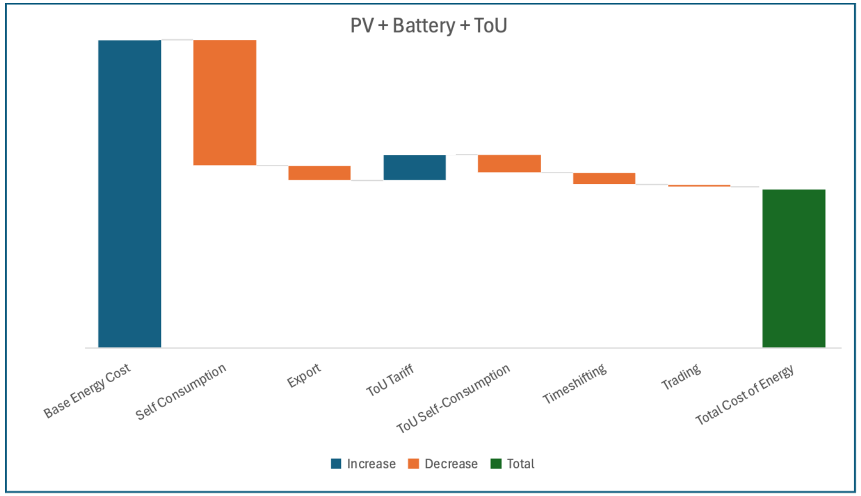
Battery Savings		Size of Battery (kWh)							
	£865.86	0.000	4.000	8.000	12.000	15.000	18.000	21.000	24.000
Size of PV Array (kW)	2.000	£0.00	£55.16	£81.90	£156.63	£277.36	£402.08	£526.73	£648.41
	4.000	£0.00	£159.89	£226.11	£389.24	£515.12	£627.20	£727.96	£822.29
	6.000	£0.00	£208.35	£335.28	£555.09	£689.92	£786.69	£868.25	£923.34
	8.000	£0.00	£238.98	£403.33	£639.49	£784.64	£895.50	£987.74	£1,059.63
	10.000	£0.00	£266.54	£453.77	£719.82	£865.86	£999.66	£1,092.28	£1,169.71
	12.000	£0.00	£284.89	£501.43	£773.10	£948.64	£1,085.66	£1,166.84	£1,251.11
	14.000	£0.00	£300.47	£542.26	£828.53	£1,003.71	£1,140.90	£1,255.03	£1,334.73
	16.000	£0.00	£310.91	£577.17	£872.37	£1,053.22	£1,198.40	£1,302.47	£1,372.34

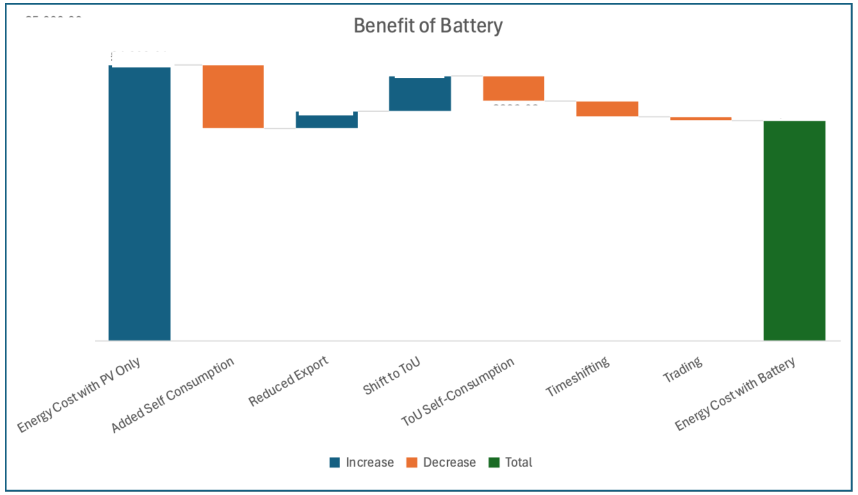
Battery Payback		Size of Battery (kWh)							
		0.000	4.000	8.000	12.000	15.000	18.000	21.000	24.000
Size of PV Array (kW)	2.000	1250.0	51.7	54.3	38.6	26.1	21.0	18.3	16.7
	4.000	1250.0	17.8	19.7	15.5	14.1	13.5	13.3	13.2
	6.000	1250.0	13.7	13.3	10.9	10.5	10.7	11.1	11.8
	8.000	1250.0	11.9	11.0	9.5	9.2	9.4	9.8	10.2
	10.000	1250.0	10.7	9.8	8.4	8.4	8.5	8.8	9.3
	12.000	1250.0	10.0	8.9	7.8	7.6	7.8	8.3	8.7
	14.000	1250.0	9.5	8.2	7.3	7.2	7.4	7.7	8.1
	16.000	1250.0	9.2	7.7	6.9	6.9	7.1	7.4	7.9

Site F – Benefits Breakdown









The bulk of the benefit from the PV array comes from allowing the site to use free solar energy rather than buying electricity from the grid ("self-consumption"). This yields a saving of about 26% p.a. from the PV array alone. Adding a battery increases this by a further 15%.

There is also a reasonable benefit from exporting excess PV generation to the grid (typically during the summer). Adding a battery reduces this benefit, as it enables some of the excess generation to be self-consumed, which is generally more valuable.

The battery could also be used to shift some of the site's consumption from peak to off-peak times. This is only worthwhile if the site switches to a Time-of-Use tariff, which would entail some cost (as it increases the cost of energy consumed at peak times). The saving due to time-shifting only just compensates for this cost.

Finally, spare capacity in the battery could be used to trade on wholesale & flexibility markets. The returns on such trading can be volatile, but we have estimated that they could generate revenue of the order of £60p.a. for the site.

Site F – 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:	13,984	9,433	7,040	4,140	4,140		148
	Off-Peak Grid Demand:	3,889	3,837	3,528	6,867	6,867		57
	PV Generation:	0	9,446	9,446	9,446	9,446		0
	Export:	0	4,843	2,142	2,581	2,581		-133
	kgCO2							
	Peak Grid Demand:	2,070	1,396	1,042	613	613		
	Off-Peak Grid Demand:	222	219	201	391	391		
	PV Generation:	-	-	-	-	-		
	Export:	-	(644)	(285)	(343)	(343)		
	Total	**2,291**	**971**	**958**	**661**	**661**		
	Reduction		**1,321**	**1,333**	**1,630**	**1,630**		
	Benefit of Battery			**12**	**310**	**310**		

- We estimate that adding a PV array would enable the site to reduce its carbon footprint by about 1.3 tCO2e p.a. Adding a battery would yield an additional carbon saving of approx. 0.3 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. We tend to use fairly conservative assumptions, as the grid's carbon intensity is declining rapidly and so the future benefit of avoiding importing from the grid will decline.

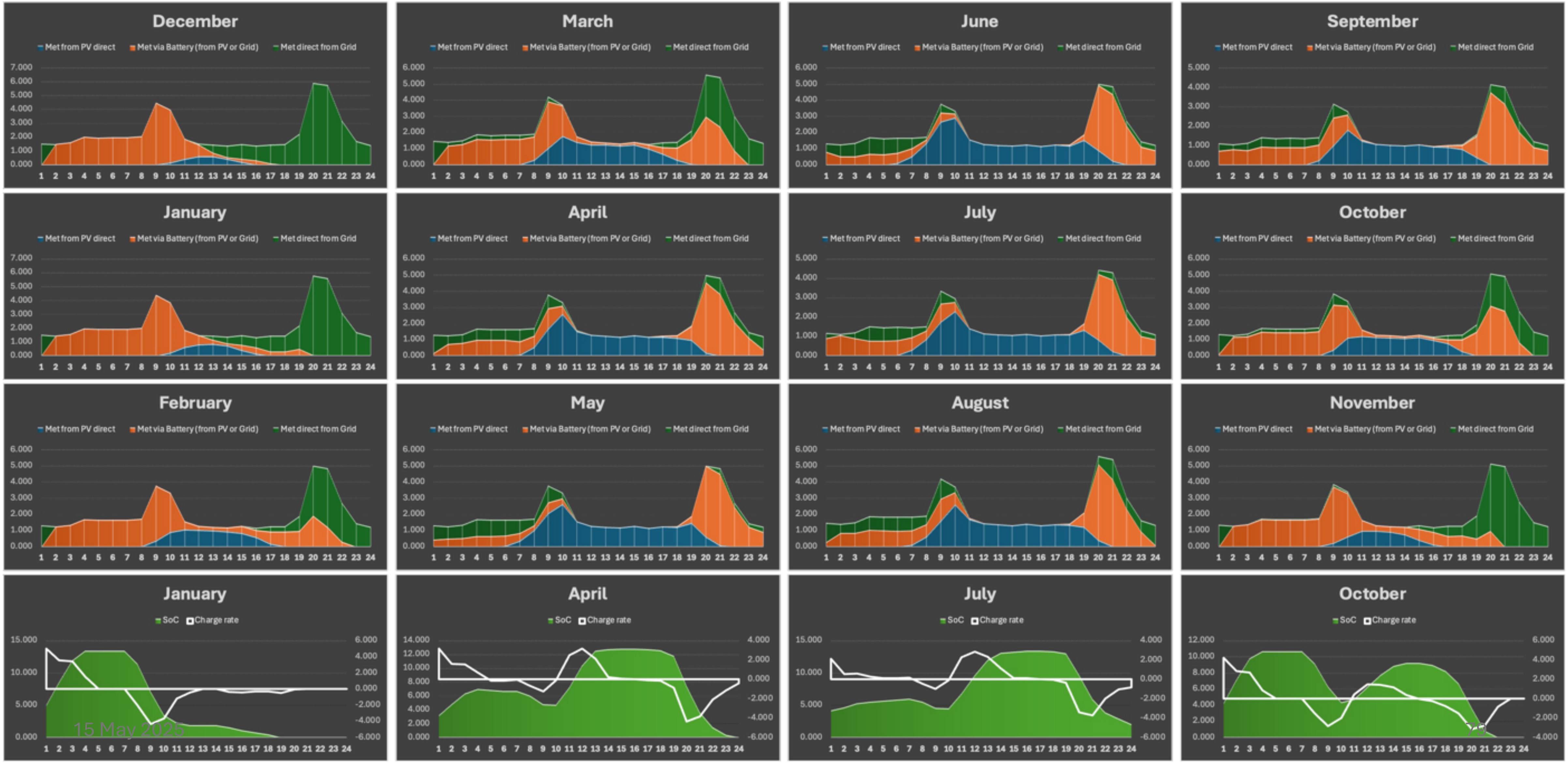
Site F – Energy usage patterns

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.

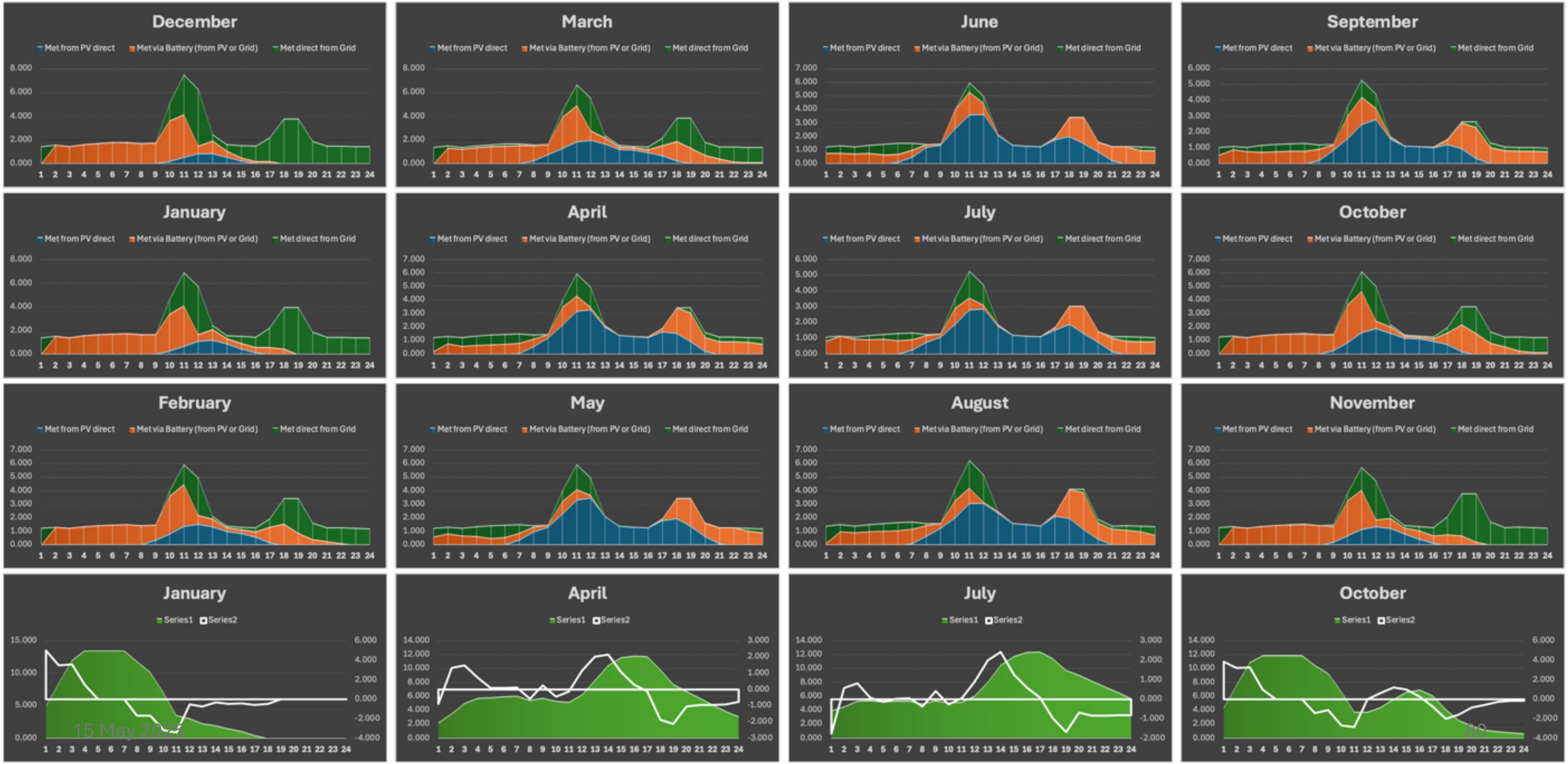
The site has pronounced morning and evening peaks in consumption that make it well suited to installing a battery, which can then shift energy generated by the solar array into the evening peak and cheap overnight energy into the morning peak. However, it should again be noted that our modelling is based on limited hourly consumption data, so we cannot be sure that this pattern is the same throughout the year.

As for the other sites, this daily pattern is overlaid with a seasonal pattern with low solar PV generation in the winter and higher generation in the summer. Thus the battery cycles once per day during winter, shifting cheaper overnight energy to meet the daytime load. It then cycles roughly twice per day for the rest of the year, when there is also sufficient PV generation to shift into the evening peak also. (This is true even in Spring and Autumn – the midday load is sufficiently low that there is some residual PV generation available for the evening even in thee shoulder periods.)

Site F – Weekday energy usage



Site F – Weekend energy usage



Solar for GM Faiths

Thank You

Appendix A

Modelling Approach

Modelling Approach – Overview

These models are based on modelling energy each site's consumption and generation pattern across a full year, then calculating 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 model

The model estimates the site's energy costs for five options:

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 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.

Modelling Approach – Input Parameters

- Key parameters input to the model for each site were:

	Site A (current)	Site A (added daytime load)	Site A (added evening load)	Site B	Site C	Site D	Site E	Site F
Flat Tariff	31.03 p/kWh	31.03 p/kWh	31.03 p/kWh	36.84 p/kWh			36.50 p/kWh	
Peak Tariff	36.37 p/kWh	36.37 p/kWh	36.37 p/kWh	42.78 p/kWh			42.78 p/kWh	
Off-Peak Tariff	24.68 p/kWh	24.68 p/kWh	24.68 p/kWh	29.69 p/kWh			29.69 p/kWh	
Export Tariff	12.00 p/kWh	12.00 p/kWh	12.00 p/kWh	12.00 p/kWh			12.00 p/kWh	
Consumption	58,000 kWh p.a.	69,000 kWh p.a.	69,000 kWh p.a.	5,800 kWh p.a.	13,200 kWh p.a.	18,500 kWh p.a.	18,300 kWh p.a.	17,600 kWh p.a.
PV Size	30kW	30kW	30kW	6kW	8kW	10kW	8kW	10kW
PV cost/kW	£1,000	£1,000	£1,000	£1,000	£1,000	£1,000	£1,000	£1,000
Battery Size[1]	30 kWh battery 20 kW inverter	30 kWh battery 20 kW inverter	30 kWh battery 20 kW inverter	4kWh battery 4kW inverter	4kWh battery 4 kW inverter	4kWh battery 4 kW inverter	6kWh battery 4 kW inverter	15kWh battery 5 kW inverter
Battery cost/kWh	£400	£400	£400	£400	£400	£400	£400	£400
Fixed Cost	£7,000	£7,000	£7,000	£3,000	£3,000	£3,000	£3,000	£3,250
Total Cost	£49,000	£49,000	£49,000	£10,600	£12,600	£14,600	£13,400	£19,250
Flex events p.a.[2]	63	63	65	59	65	66	66	58
Flex event value	£0.20/kWh	£0.20/kWh	£0.20/kWh	£0.20/kWh	£0.20/kWh	£0.20/kWh	£0.20/kWh	£0.20/kWh
Useable energy per flex event	20kWh	20kWh	20kWh	3kWh	3kWh	3kWh	4kWh	5kWh

[1] This is the central battery size against which sensitivities were calculated. The recommended battery size may be different, depending on the results of the sensitivity analysis; its cost will be driven by the same per kWh figure. (The recommended size is discussed in the main body of the report.)

[2] Number of flex events is an output, calculated by the model based on availability of battery capacity, as driven by the consumption pattern. However, it is included here for transparency.

Appendix B

Scenarios and Sensitivities

Scenarios and Sensitivities – discussion

The models in this report are all sensitive to factors such as future energy prices and market arrangements. Given the projected life of a PV array (20+ years) or battery (~15 years), it is worth considering how these might affect the benefits the system can deliver. The accompanying spreadsheet ("scenarios and sensitivities.xlsx") contains a brief analysis of how future scenarios might affect the returns that the six sites might achieve from investing in PV and batteries.

The spreadsheet contains:

- A number of scenarios for the sites, built around possible changes to export tariffs, peer-to-peer (p2p) trading, flexibility markets and wholesale energy markets.
- Analysis of the returns the sites could achieve under a slightly simplified subset of these scenarios.
- A summary of the aggregate IRR for all six sites against these scenarios.

These scenarios are brief. You could go a lot further to map them onto detailed market forecasts from various energy market analysts. They are intended to give a quick view of some of the factors that might drive value from PV and batteries. Our broad conclusions from the analysis are that:

1) Installing PV is a bit of a no-brainer. It has good IRR under all likely scenarios, and is a great hedge against future price rises.
2) Installing a battery is marginal, at least from the perspective of immediate financial returns. However, it gives an additional hedge against future price rises, and creates options to earn further value as/if flexibility markets, p2p trading and local energy markets develop. In an uncertain world, this optionality is valuable.
3) There is also clear environmental value in investing in both types of technology. Again, PV is a bit of a no-brainer and a battery is more marginal. (This is discussed in more detail in the main report. The scenarios do not attempt to include carbon analysis as that is itself subject to further assumptions about factors such as the pace of decarbonisation of the grid.

Scenarios and Sensitivities – PV scenario summaries

There are 5 scenarios for PV in the spreadsheet, ordered by the value they create for PV, from low to high:

1. **Low energy prices**. Price of energy on wholesale markets goes down, leading to 25% lower tariffs. This also tends to push down the spread between peak and off-peak tariffs, both because of the lower base price and because there is sufficient flexibility in the market (from a combination of demand side response and grid-scale assets) to contain the volatility introduced by high proportions of variable renewable generation.
2. **Low export tariffs**. Energy prices overall remain pretty much as they are now. Large volumes of renewable generation on the system (both grid scale and smaller, localised systems) mean that the export tariffs available to most people are at the low end of what is currently available, as they are naturally forced to sell at times of oversupply due to the weather-driven correlations in their output.
3. **Baseline**. The current state, as built into the detailed models for the 6 places of worship.
4. **High export tariffs**. As for scenario 2, energy prices remain much as they are now. However, widespread development of local / p2p markets combined with availability of batteries to timeshift energy generated by PV into peak periods means that PV owners can get 50% higher prices (either as export tariffs or via p2p trading) for the energy they export.
5. **High energy prices**. Price of energy on wholesale markets goes up, leading to 50% higher tariffs, e.g. due to geopolitical shocks to the system. Price volatility increases proportionately, leading to 50% wider spreads between peak and off-peak tariffs.

Scenarios and Sensitivities – battery scenario summaries

The scenarios for batteries are more complex. There are seven of them, also ordered from low to high by the value they create:

1. **Grid scale dominates**. Energy prices and volatility are low, as per PV scenario 1. This is driven by widespread deployment of grid-scale renewable generation and energy storage systems. This grid scale storage dominates flex and arbitrage markets, making it difficult for smaller systems to earn value from them.
2. **High export tariffs**. As per PV scenario 4. In contrast to PV, high export tariffs reduce the value of batteries — self-consumption and timeshifting are less valuable if you can get a good price simply by exporting your excess generation as it occurs. Note that the price obtained from p2p trading in this scenario is fairly fixed — there is little or no time-of-use element to it. That reflects that consumer pricing continues to be dominated by fixed price tariffs, so p2p markets need to keep this price structure to be attractive to consumers.
3. **Low energy prices**. As per PV scenario 1.
4. **Baseline**. Current state, as per the detailed modelling.
5. **Enhanced p2p**. As per PV scenario 4 (and battery scenario 2), wholesale energy prices and tariffs remain much as they are now. However, there is widespread development of p2p and local energy markets, so PV owners can get better prices for their exports. By comparison to battery scenario 2, there is now much more widespread development of time-of-use pricing in these local markets, so there is a premium attached to being able to shift your exports to times of peak pricing.
6. **High energy prices & volatility**. As per PV scenario 5.
7. **Open flex markets**. As per scenario 6, but now combined with far greater access to flex markets for small assets. This may arise simply because current slow-moving trends in favour of smaller assets (in DSO & NESO markets, in access to BM & wholesale markets, in revenue stacking, in operational metering, in interoperability, etc) finally get to a tipping point where the balance swings more towards equal access for smaller assets. Or it may be forced by factors such as load growth on LV networks from electrification of household heating and EVs (which requires local flex if it is to be managed cost-effectively), or by consumer/citizen concern about the fairness of a transition that is dominated by large scale assets.