Flexibility Services Pilot

Analysing baseline methods

1. Baseline Analysis

1.1 Background

The Flexibility Services Pilot (100MW Challenge) is led by Western Power and supported by partnerships with businesses in WA. It is part of our drive to transform and future-proof the south-west grid for the West Australian community by using emerging technologies and connecting an increasing mix of renewable energy.

The pilot will be delivered through a flexibility services program, where energy users and generators of solar PV, on the distribution network, voluntarily change their energy use to support the network in return for payment by Western Power.

To inform the pilot, Western Power undertook research and analysis to assess the most suitable and equitable for method for baselining calculations, to apply during the pilot.

The analysis and results informed the method that Western Power selected for the pilot, as well as the other suitable methods that may apply, should the selected method not be suitable. The analysis underwent internal peer review, as well as technical peer review by Western Power's external solution integrator (IBM).

This paper is publicly available during the pilot, to ensure that learnings are maximised during the pilot period and that partners in the pilot may consider the approach.

1.2 Objective

Objectives include:

1. Assess whether the agreed baselines can detect PV curtailment (or Load creation) for the bulk of analysed NMIs;
2. Determine which factors play a role in baseline calculation and validate the baseline methodologies;
3. Determine if there are more than one baseline that are useful for the range of NMIs that are targeted;
4. Assuming there are multiple baseline methodologies to choose from, determine which baseline is most appropriate for each NMI and when (factoring seasonality and Sat/Sun differences).

1.3 Summary results

Initially 100+ NMIs were assessed, indicating that the baseline technology detected about 85% of the PV curtailment during event days in April and October. The following baselines are required to achieve this:

Baseline methodology	% of the NMIs	Confidence factor
Standard Weekend (non-adjustable)	~43%	High
Standard Sat / Sun (non-adjustable)	~42%	High
Adjustable Weekend	~10%	Low - medium
Adjustable Sat/Sun	<5%	Low - medium

Results were verified against a further 400 randomised NMIs.

Based on the standard weekend method representing around 75% of NMIs at a high confidence factor, this method is preferable for use in the pilot.

2. Approach

2.1 General

These are the major inputs to the analysis:

1. Different baseline methodologies available
2. PV Sizes and PV output/generation simulation for event days per NMI
3. Load creation simulation for event days per NMI
4. Aggregated interval data from MBS/Data warehouse to obtain a profile for a NMI in terms of
    - Demand profile compared to the Flex Target defined for the NMI
    - Seasonal differences
    - Saturday / Sundays differences
5. Detailed interval data per day from MBS/Data warehouse to verify outcomes from #2

Using the above information, we examined the following aspects for each NMI:

1. PV vs Load ratio – measure for how the PV size compares to average load (between 10am-2pm) on a Sat/Sun during a season. Typically, if the PV size is very small compared to the average load, it could be difficult for a baseline to pick up PV curtailment. On the other hand, If the PV size is large compared to the average load, we expect it to be easy to pick up the PV curtailment change from the revenue meter data. However, other factors like noise (variations in load) also play a factor.
2. PV vs Noise between days ratio – measure for how the PV size compares to typical variations between Saturdays in a season (or between Sundays in a season) – useful information for baseline adjustment.
3. PV vs Noise on a typical Sat/Sun – measure for how the PV size compares to typical variations in demand on a Sat/Sun.
4. Early hour differences (5-7am) compared to event hours (10am-2pm) – this is useful for baseline adjustment: and the early hours can be used as an indication for what happens during the event hours later in the day.
5. Comparison between Sat and Sun within a season – which NMIs show significant differences in demand profile for Sat and Sun between 10am-2pm. If this is the case a different baseline should be applied for the Saturday compared to the Sunday. If behaviour between Sat and Sun is similar, then the same baseline can be used for events on a Saturday or Sunday.

2.2 Baseline methodologies

The following baseline methodologies were considered:

1. Standard weekend
2. Standard Saturday
3. Standard Sunday
4. Adjusted weekend
5. Adjusted Saturday
6. Adjusted Sunday

2.2.1 Standard weekend

The "Standard Weekend" baseline is the basis for all baselines and is calculated as follows:
The weekend baseline will look back a maximum of 90 days to identify similar days (similar: Sat, Sun or public holiday + a complete set of readings). Once 5 similar days are identified, the 4 with the lowest average kW during the event hours are selected for the baseline. The 4 selected days are then averaged together interval-by-interval to create a baseline for the event day.

2.2.2 Standard Saturday / Sunday

The Saturday / Sunday baselines are the same as the weekend baseline, instead it is specifically looking for Sat or Sun, depending on when the event is. Public holidays are treated the same as Sundays. Instead of 5 similar days, it is looking for 3 and it will pick the 2 lowest average days instead of 4. This is to avoid having to go back in history too far to make up the baseline. However, these are parameters and can be adjusted if needed.

2.2.3 Adjusted baseline

Once the standard baseline is calculated, and after actual load data is uploaded to the Flexibility Services Platform, the entire "Standard Weekend" baseline will be adjusted by constant kWh value.
The "Adjusted Saturday" and "Adjusted Sunday" baseline follow the same principle.

2.2.4 Example of a using a baseline

The following graph shows the actuals for a NMI for a couple of weekends in March, leading up to the event day on the Saturday 4th of April.

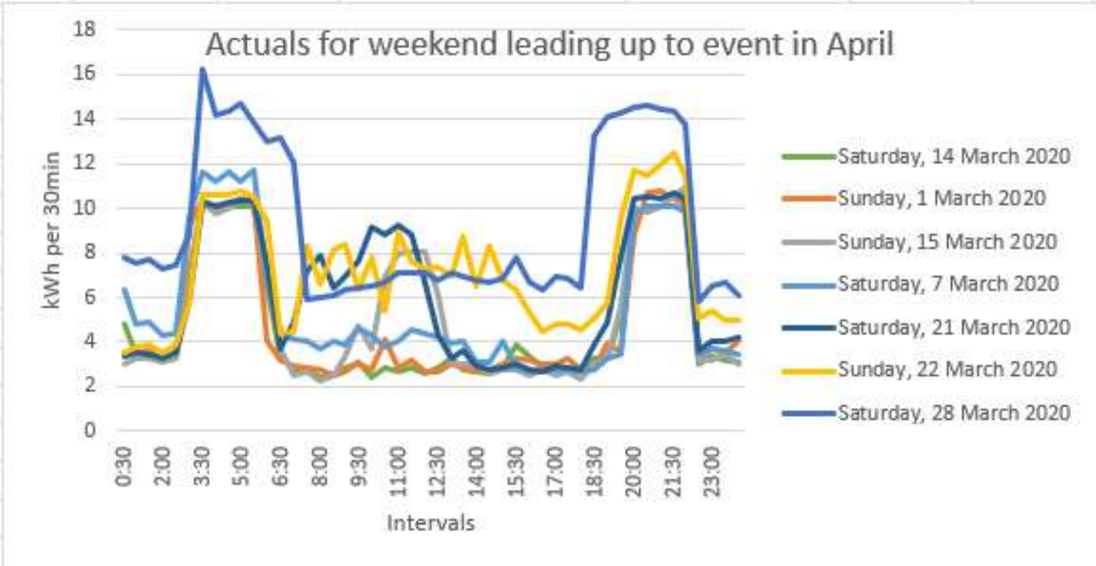


Figure 1 - actuals leading up to an event day

Using these actuals, the "weekend baseline" can be calculated by ranking the previous days and taking the 4 lowest average days (average between 10am-2pm). For those lowest 4 days out of the 5 similar days, take the average for each 30min interval and this becomes the actual for the baseline for that interval (bottom row):

rank	NMI	day	9:00	9:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:0
1		Sunday, 15 March 2020	3.328	4.736	3.728	6.896	7.968	8.08	8.08	6.096	3.008	2.976	2.976	2.608	2.75
2		Saturday, 21 March 2020	6.976	7.584	9.152	8.848001	9.2	8.8	6.688	4.256	3.296	3.632	2.96	2.784	2.84
3		Sunday, 22 March 2020	8.368	6.352	7.824	5.376	8.88	7.616	7.28	7.392	6.912	8.688	6.48	8.272	6.78
4		Saturday, 28 March 2020	6.304	6.432	6.48	6.72	7.088	7.104	7.104	6.736	7.072	6.976	6.752	6.672	6.81
5		Sunday, 29 March 2020	6.4	12.528	9.872	12.416	11.824	14.32	13.008	8.672	8.288	7.552	7.536	7.92	10.46
		weekend baseline	6.244	6.276	6.796	6.96	8.284	7.9	7.288	6.12	5.072	5.568	4.792	5.084	4.

Figure 2 - actuals used for baseline calculation

The following figure shows this baseline plotted in a graph. The graph also has the actual event day meter readings plotted (with the PV system shutdown simulated). The red lines indicate the lower (50%) and upper threshold (100%) that are being used to determine whether an interval is conforming or not.

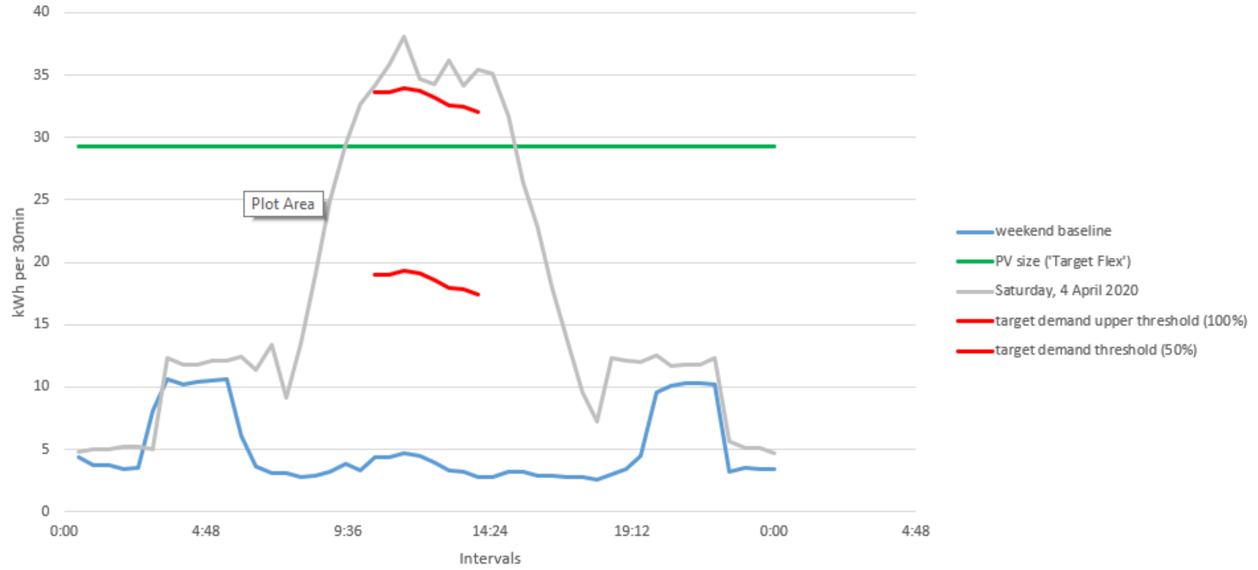


Figure 3 - Event day actuals & baseline

2.3 Aggregated information from Data Warehouse

An initial 100+ NMIs were used to extract the following data from the Metering Datawarehouse:

1. 48 x 30min Interval meter readings for each day
2. For the months of September, October (Spring) 2019 and March, April (Autumn) 2020
3. The 30min interval data was aggregated so we have:
   - Average per interval for Saturdays as well as Sundays in Spring and Autumn
   - Standard deviation per interval for Saturdays as well as Sundays in Spring and Autumn (basically tells us how much difference there is between Saturdays in a season or between Sundays in a season)
   - Average standard deviation for the whole of Saturdays as well as Sundays in Spring and Autumn (basically tells us how "noisy" a typical Sat or Sun is in either Spring or Autumn)

So, we basically get 4 rows per NMI:

NMI	Season	Sat/Sun	Avg std deviation	Average per interval			Standard deviation per interval		
				Intv 1	**…**	**Intv 48**	**Intv 1**	**…**	**Intv 48**
80010XXXXX	Autumn	Sat	5.51	28.48200013		24.14399975	5.935499125		3.783541111
80010XXXXX	Autumn	Sun	5.16	25.90133333		26.91199967	4.121572992		7.233194052
80010XXXXX	Spring	Sat	7.08	21.00300013		22.17299988	6.588114047		8.541466887
80010XXXXX	Spring	Sun	3.21	20.55466678		19.13333344	5.32677596		1.622985922
… for all NMIs the same information …									

Figure 4 - SQL result from data warehouse

2.4 PV sizes and event day simulation

The second important data input for the analysis is the PV sizes used per NMI, conducted using an addition 400 NMIs and their PV sizes. Its noted that the data is not perfect (sometimes we see 30min interval readings where there is import (generation) far larger than the size of the PV system.

For the event days in April and October we simulated PV curtailment by simply adding the following kWh values to each actual interval value:

PV size * 0.78 * 0.5

Where 0.78 is the 78% efficiency adjustment factor for seasonal variation of PV yield and 0.5 is to bring back the PV kW size to 30min kWh interval values. This value is then added to the actual interval value for the event days using the following ratios to simulate PV output as the sun rises and sets during the day (for the intervals in between the midpoint between the two adjacent factors is used, i.e. 0.78 for 9:30am):

7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
0.04	0.33	0.65	0.9	1	1	1	1	0.92	0.64	0.33	0.04

2.5 Assessing PV vs load

If the size of the PV compared to the average load of the NMI between 10am – 2pm is large, then there is very likely the PV shutdown can easily be detected by a baseline comparison on an event day. This measurement is calculated as follows:

$$PV\ Load\ ratio = \frac{\text{Target Flex per Interval}}{\text{Average Demand per interval between 10am} - \text{2pm}}$$

Where

- Target Flex per Interval = PVSize / 2
- PVsize = PV nameplate size = minimum of [PV panels size* 78%] and Inverter size

This is what these values look like for an example NMI:

NMI	Season	Day	Target Flex	avg 10-2pm	PV/Load
800100XXXX	autumn	SAT	29.25	22.03912501	133%
800100XXXX	autumn	SUN	29.25	6.207666683	471%
800100XXXX	spring	SAT	29.25	37.63875033	78%
800100XXXX	spring	SUN	29.25	25.21633339	116%

The following scale is used to rate the PV/Load ratio:

BAD: < 30%	GOOD: > 30%

In other words: If the PV size is more than 30% of the average load in between 10am and 2pm, we should be able to determine whether the PV system has been shut down by just looking at the revenue net-meter readings.

Here are two extreme examples of NMIs with PV/Load ratios: on the left a 30kW system, on the right a 75kW system. Remember that the graphs show kWh (so roughly divide 30 and 75 by 2 to plot the green line for the PV size).

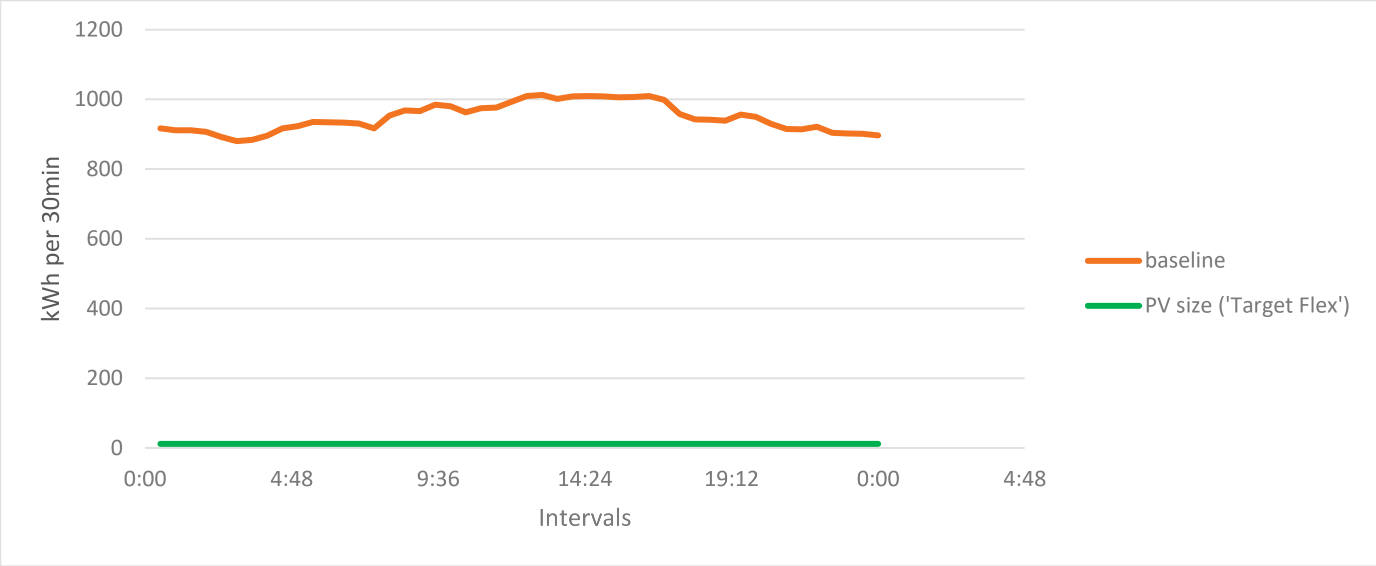


Figure 5 - PV/Load ratio for example NMI

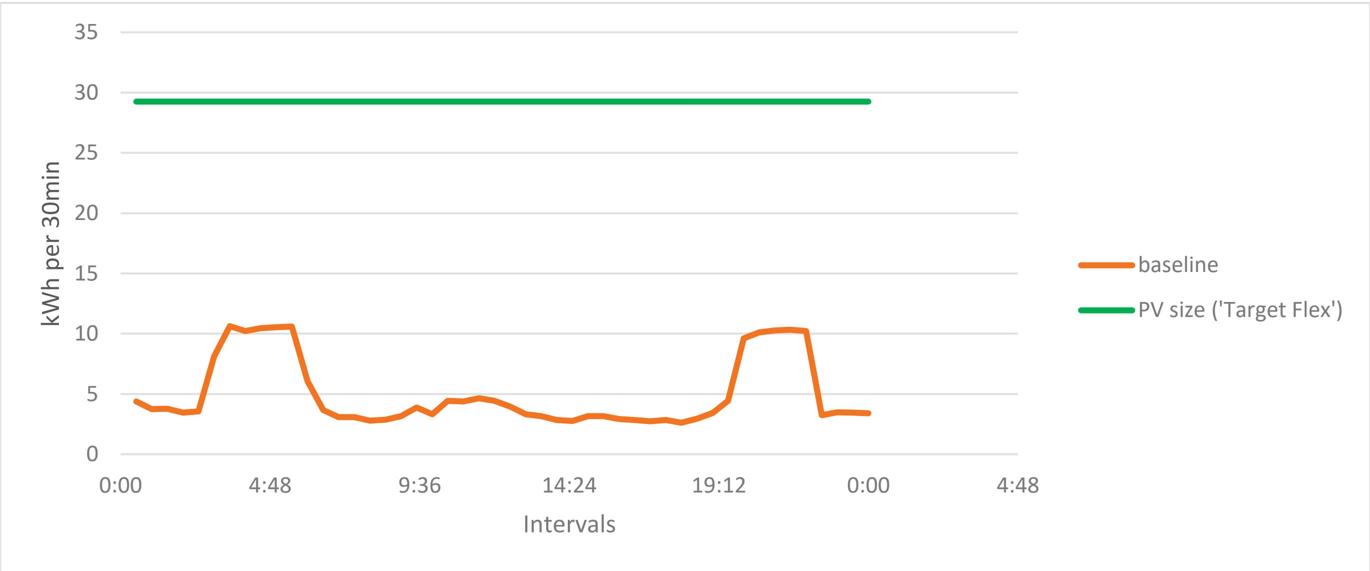


Figure 6 - PV/Load ratio for example NMI

2.6 Assessing PV vs noise between days

In some cases where the PV/Load ratio seems to be great, it might still be difficult to determine whether a PV system was shut down or not. This is mainly due to the amount of "noise" that is natural and can be expected for a NMI on the event days as well as the days leading up to the event that are used for baseline calculation.

What we mean by "noise" is really the "amount of variation" between intervals and can be measured in two different ways:

1. The variation between the days – how different are days compared to each other?
2. The variation on a day – how stable is a particular day from one interval to the next?

The first variation is calculated as follows:

$$PV\ noise\ between\ days\ ratio = \frac{\text{Target Flex per Interval}}{\text{Average (StdDev between 10am} - \text{2pm per interval)}}$$

For the example NMI this looks like:

NMI	Season	Day	Target Flex	Noise between days	PV/noise
8001XXXXXXX	autumn	SAT	29.25	11.65373065	251%
8001XXXXXXX	autumn	SUN	29.25	9.280682537	315%
8001XXXXXXX	spring	SAT	29.25	10.43865837	280%
8001XXXXXXX	spring	SUN	29.25	11.62977359	252%
8001XXXXXXX	autumn	SUN	29.25	43.05320182	68%

The following scale is used to rate the PV/noise-between-days ratio:

BAD: < 200%	GOOD: > 200%

2.6.1 What does this mean?

If the PV size is relatively small (<200%) compared to the noise between days, it means that there is a natural variation between days that is bigger than the size of the PV system. So, when the event day comes along and the actuals are compared to the baseline, the question now is: is the difference between baseline because of the PV being shut down, or because the natural higher demand than usual?

This measurement in combination with the next noise measurement can be used to adjust to better predict the demand during the 10-2pm interval.

2.7 PV vs noise on a given day

The second noise measurement is the PV size compared to the variation on a single day and is calculated as:

$$PV\ noise\ on\ a\ day\ ratio = \frac{\text{Target Flex per Interval}}{\text{Average (StdDev between 10am} - \text{2pm per day)}}$$

For the example NMI this looks like:

NMI	Season	Day	Target Flex	Noise on a day	PV/noise
8001XXXXXXX	autumn	SAT	29.25	5.514648959	530%
8001XXXXXXX	autumn	SUN	29.25	5.160247413	567%
8001XXXXXXX	spring	SAT	29.25	7.079775666	413%
8001XXXXXXX	spring	SUN	29.25	3.205481397	912%
8001XXXXXXX	autumn	SAT	21.45	30.21730828	71%

The following scale is used to rate the PV/noise-on-a-day ratio:

BAD: < 200%	GOOD: > 200%

2.7.1 What does this mean?

If the PV size is relatively small (<200%) compared to the noise on a particular day, it means that there is a natural variation on that day that is bigger than the size of the PV system. So, when the event day comes along and the actuals are compared to the baseline, the question now is: is the difference between baseline because of the PV being shut down, or because the natural higher demand than usual?

This measurement in combination with the previous noise measurement can be used to adjust the baseline to better predict the demand during the 10-2pm interval.

2.8 Use of early hours on the event day

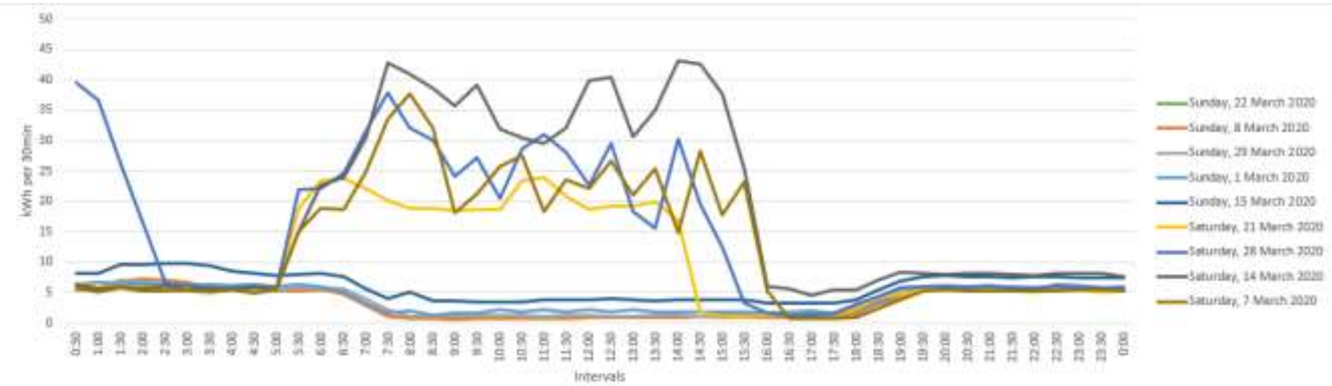
When there is a lot of variation between days in a season (first noise), but the variation on a single day is small (second noise) there is a real opportunity to adjust the baseline (potentially quite heavily) to better predict the demand during the event hours.

We have some NMIs where the PV/Load ratio is not great (e.g. ratio is less than 30%) so the standard baseline (picking the average) might not be good enough (event day could turn out to be quite a bit lower than the average). But if the days are typically stable (PV/noise-on-a-day is great: > 200%) then we could use the early hours of the event day to check if we should adjust the baseline. We can only use the hours before 7am (otherwise the PV System interferes with the readings – and we don't know for sure if PV has been shut down or not). So looking at the hours between 5am and 7am on the event day, and knowing that this NMI is typically very stable (not noisy during the day), we can compare the avg load between 5am and 7am with the baseline and adjust the baseline to bring it closer to the event day actuals.

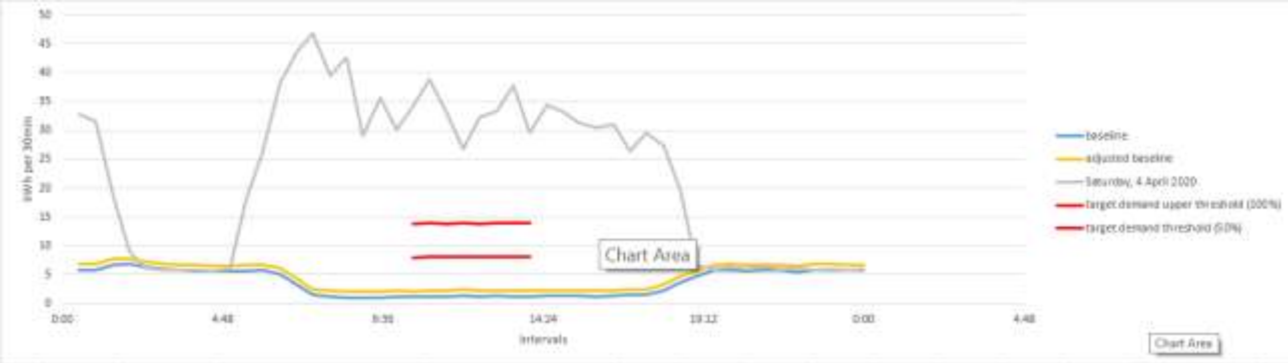
Adjusted baselines (either adjWeekend or adjSat/Sun baselines) are not allocated as a default. Instead, where an account/NMI is defined as "noisy" a manual review is done after the event has settled and the appropriate baseline is selected. This could be any of the baselines including the adjusted ones.

2.9 Saturday vs Sunday

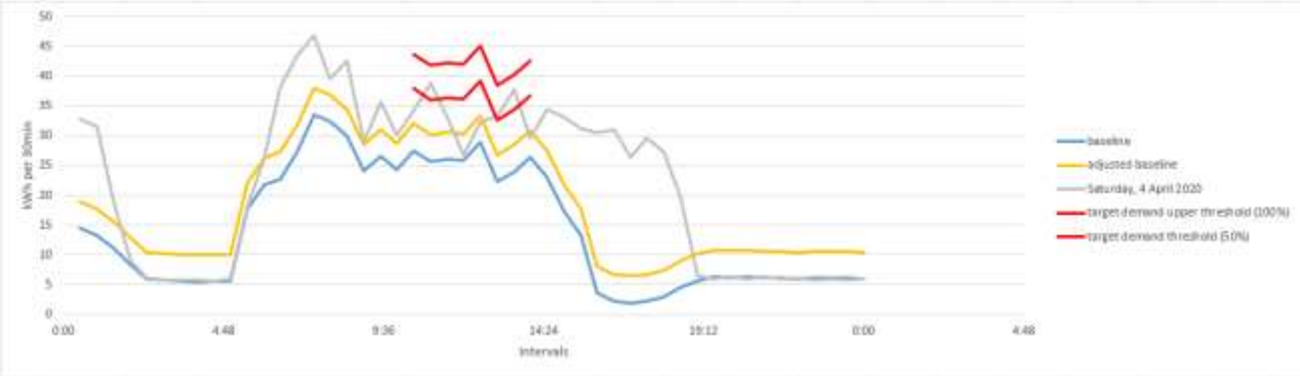
About 16% of the NMIs showed significant differences between Saturday and Sunday demand patterns. For those NMIs it is important to distinguish between Saturdays and Sundays when it comes to baseline calculations. Here is an example of a NMI and what the demand curves look like for Sat and Sun during March 2020 (NMI: 80010XXXXX). Saturdays show a lot of activity, Sundays don't.



This is what would happen if we simply applied the standard weekend baseline for a Saturday event (grey line has PV shutdown values simulated):



The baseline will be based on the 4 lowest avg out of 5 similar days. So will always pick the Sundays. Therefore, any activity on a Saturday will be conforming. Instead a baseline specifically looking at the previous Saturdays will do a much better job:



Note: in the above example the adjustable Saturday baseline was pushed up because the hours between 5 and 7am for the actual event day were higher than the baseline values (blue line).

2.9 How to determine if there is a difference between Saturdays and Sundays

There are two factors that are used to determine whether there is a difference between Saturday and Sunday demand (within a season):

- Average Difference between Sat & Sun as a percentage of the Flexibility Target
- Average Difference between Sat & Sun as a percentage of the System size

The Appendix shows an example of how these percentages are calculated.

These ratios can be put on a band to give us the indication whether a specific Saturday or Sunday baseline is required for a NMI in a season. If either of these ratios is a yes, then a Saturday/Sunday baseline will be allocated. In case both ratios are "no" then a weekend baseline is allocated:

Difference as % of Target Flex	**no: < 40%**	**yes: > 40%**
Difference as % of System Size	**no: < 60%**	**yes: > 60%**

3. Baseline selection criteria

Available baselines: 1) standard weekend, 2) Standard Sat/Sun, 3) manual review.

In case of a manual review (after the event has settled) we can change to adjustable weekend, adjustable Sat/Sun baseline.

3.1 Baseline menu

This list is based on data separated per season and Saturday/Sunday, so each NMI has four representations.

Baseline menu

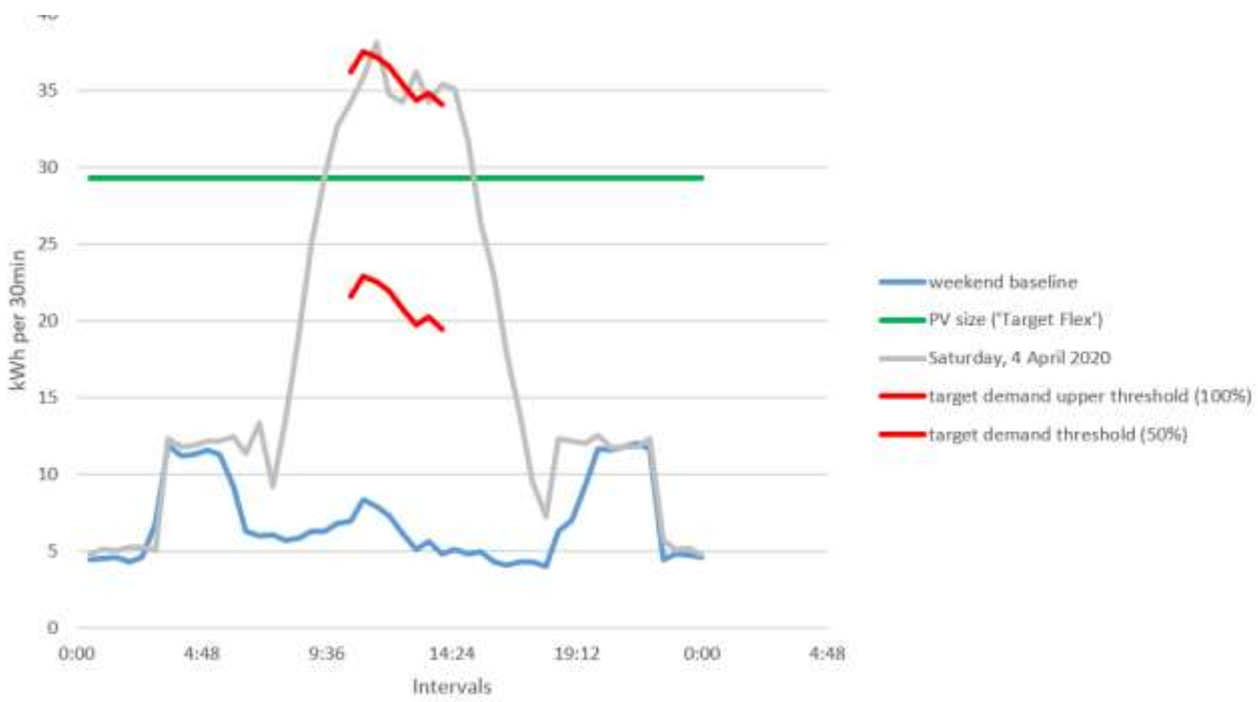
This list is based on data separated per season and SAT/SUN. So each NMI has four representations.

%	PV compared to avg Load 10am-2pm	PV compared to noise *between* days	PV compared to noise *in a single* day	Sat/Sun difference in behaviour	Recommended Baseline
31.7%	GOOD	GOOD	GOOD	yes	Standard Sat/Sun
51.1%	GOOD	GOOD	GOOD	no	Standard weekend
3.9%	GOOD	BAD	GOOD	yes	Manual review
1.6%	BAD	BAD	GOOD	no	Manual review
2.9%	GOOD	BAD	GOOD	no	Manual review
0.4%	BAD	GOOD	GOOD	no	Manual review
0.9%	BAD	BAD	BAD	no	Manual review
1.8%	BAD	BAD	BAD	yes	Manual review
1.1%	GOOD	BAD	BAD	yes	Manual review
3.3%	BAD	BAD	GOOD	yes	Manual review
0.1%	GOOD	BAD	BAD	no	Manual review
1.2%	BAD	GOOD	GOOD	yes	Manual review
0.0%	BAD	GOOD	BAD	no	Manual review
0.1%	BAD	GOOD	BAD	yes	Manual review
0.0%	GOOD	GOOD	BAD	no	Standard weekend
0.0%	GOOD	DOUBTFUL	GOOD	no	Manual review
0.0%	GOOD	DOUBTFUL	GOOD	yes	Manual review
0.0%	DOUBTFUL	DOUBTFUL	GOOD	no	Manual review
0.0%	DOUBTFUL	DOUBTFUL	GOOD	yes	Manual review
0.0%	DOUBTFUL	BAD	GOOD	no	Manual review

Appendices

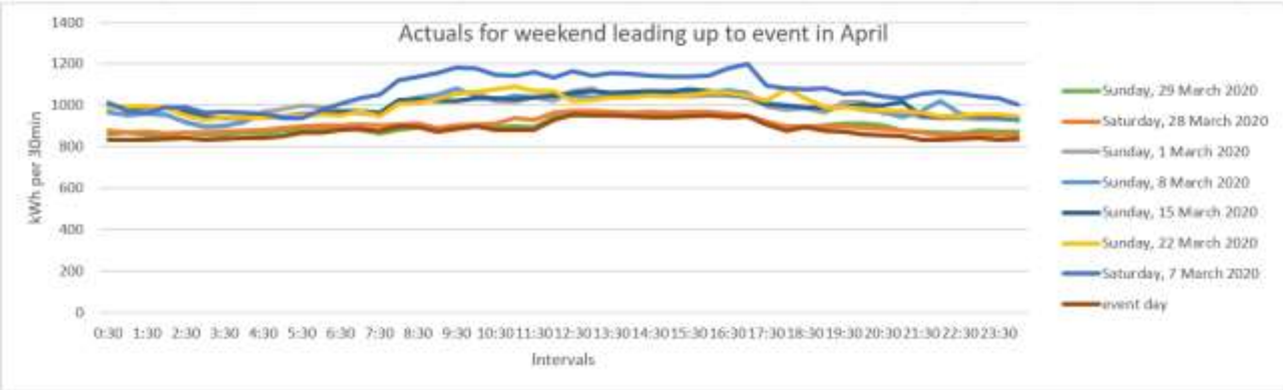
NMI A. Example

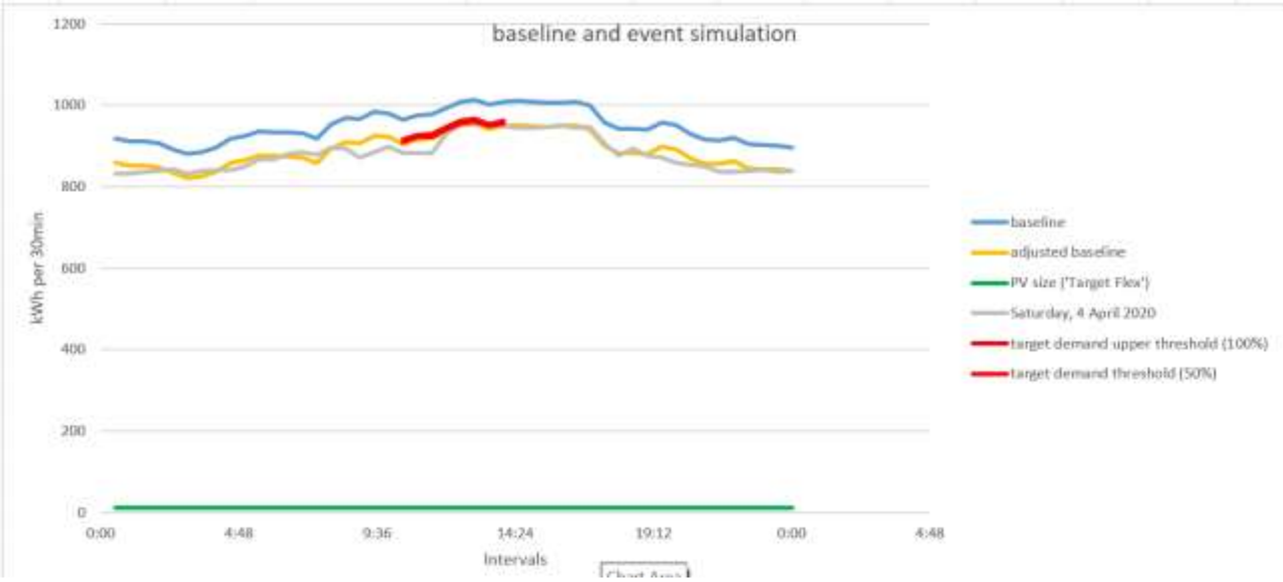
PV Size	75kW
Baseline	Basic weekend baseline, no adjustment
Classification	Good
Explanation	Good example of how the basic baseline works well. Size of the PV is much bigger than any of the fluctuation (noise) that can be expected during an event.



NMI B

PV Size	30kW
Baseline	Basic weekend baseline, with adjustment
Classification	Problematic
Explanation	Size of the PV is not big enough when added to the baseline to jump out of the noise band. Actual event day (with simulated PV shutdown) was much lower than the baseline. Even after baseline adjustment the baseline still sits much higher than the actual during the event.

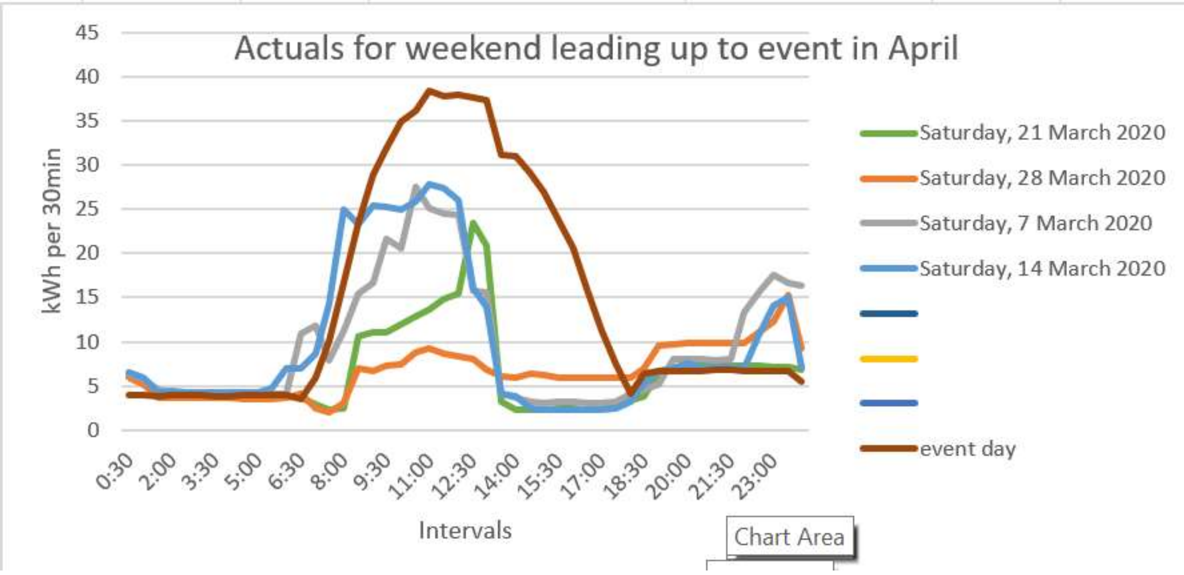


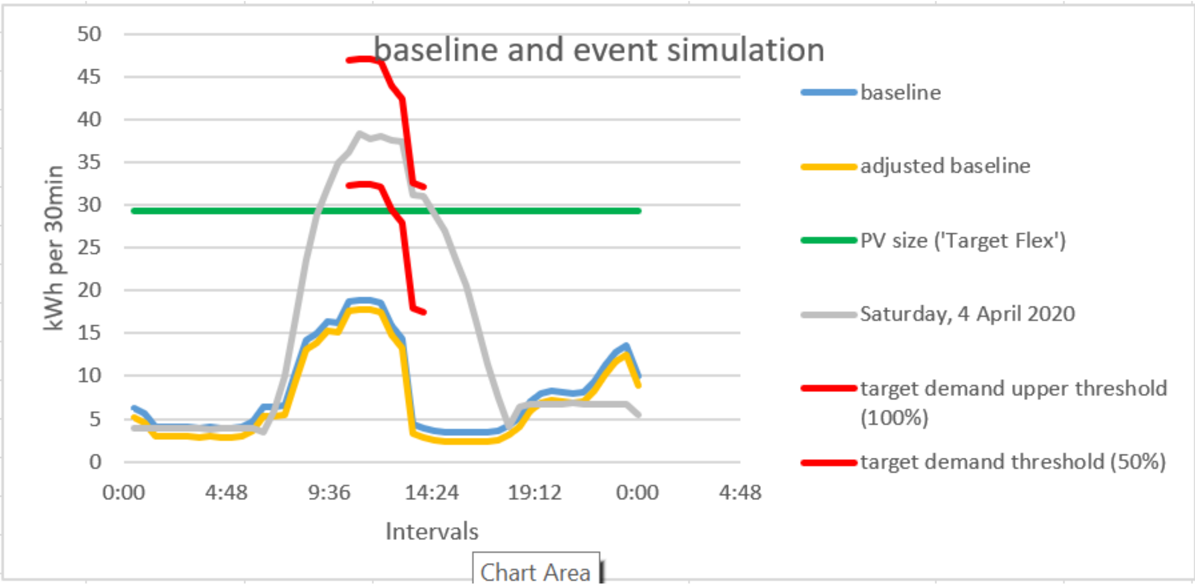


NMI C

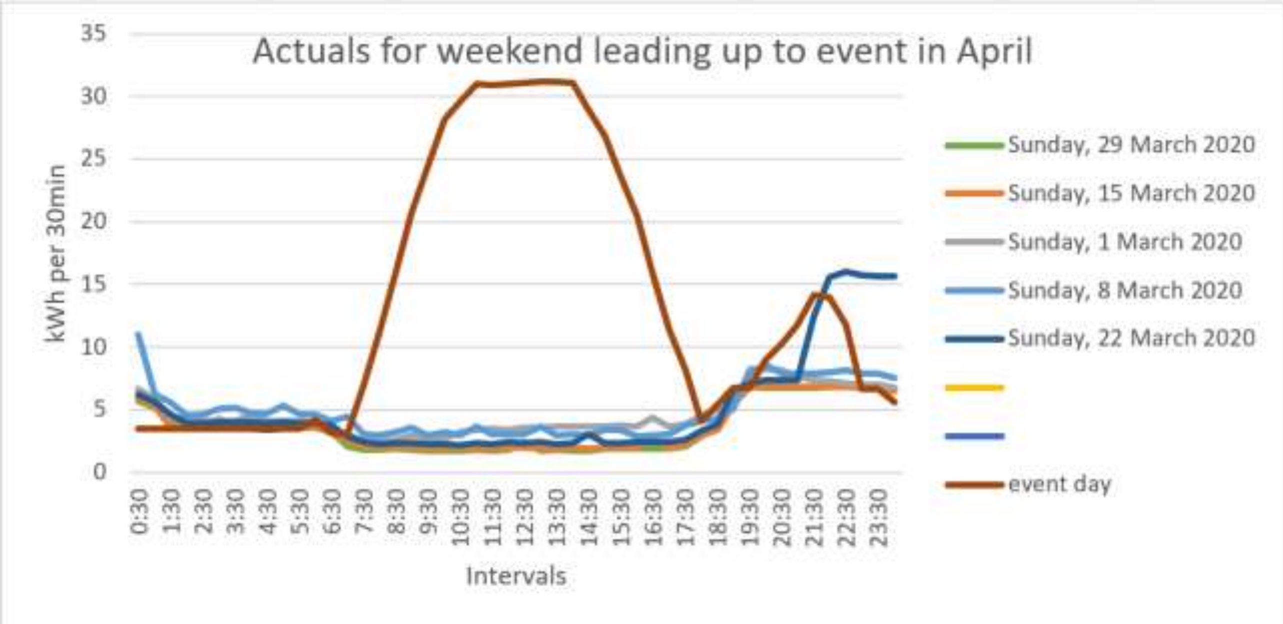
PV Size	75kW
Baseline	Basic Sat/Sun baseline, no adjustment needed
Classification	Good
Explanation	Significant difference between Saturday and Sunday behaviour.

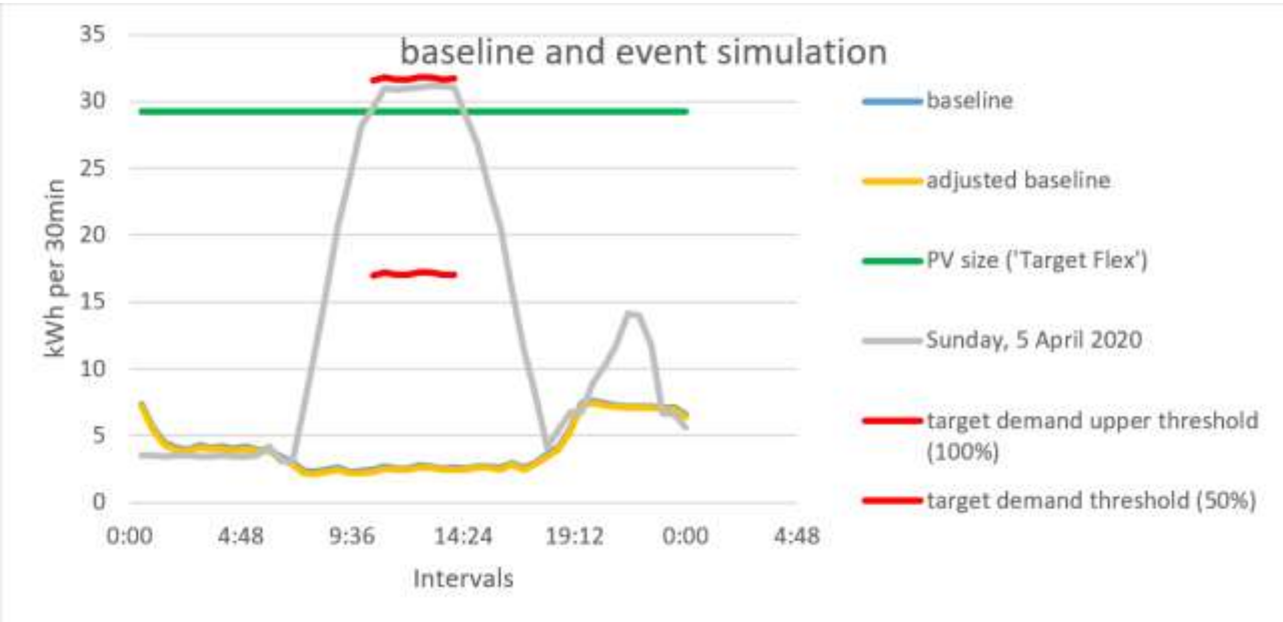
Saturday behaviour





Sunday behaviour

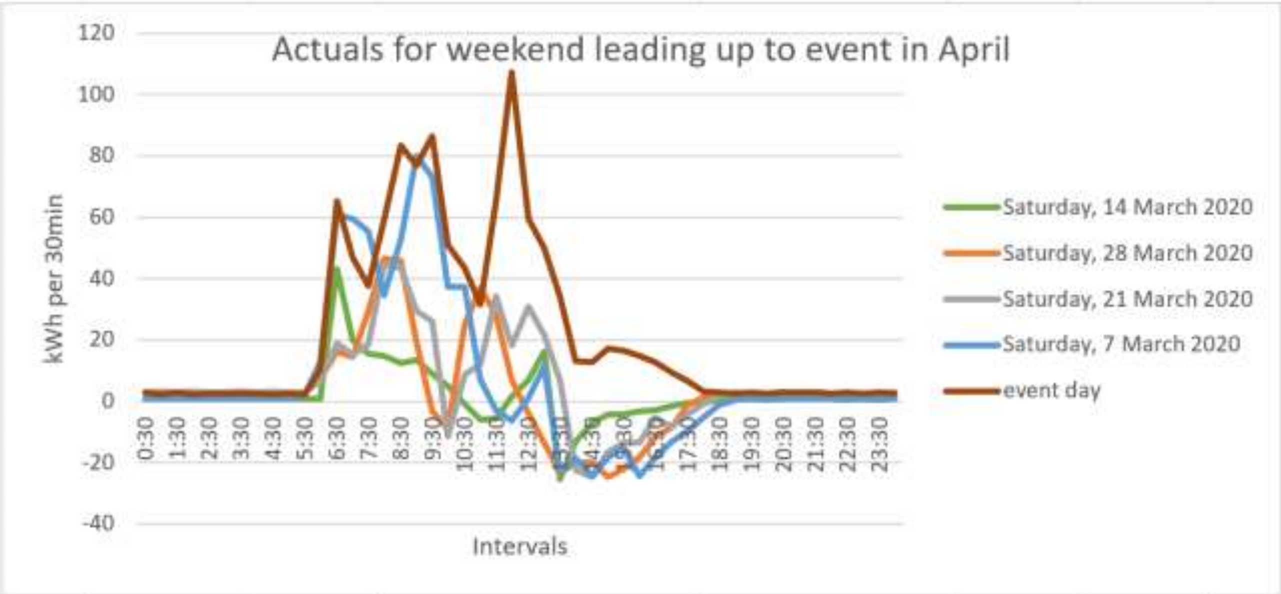


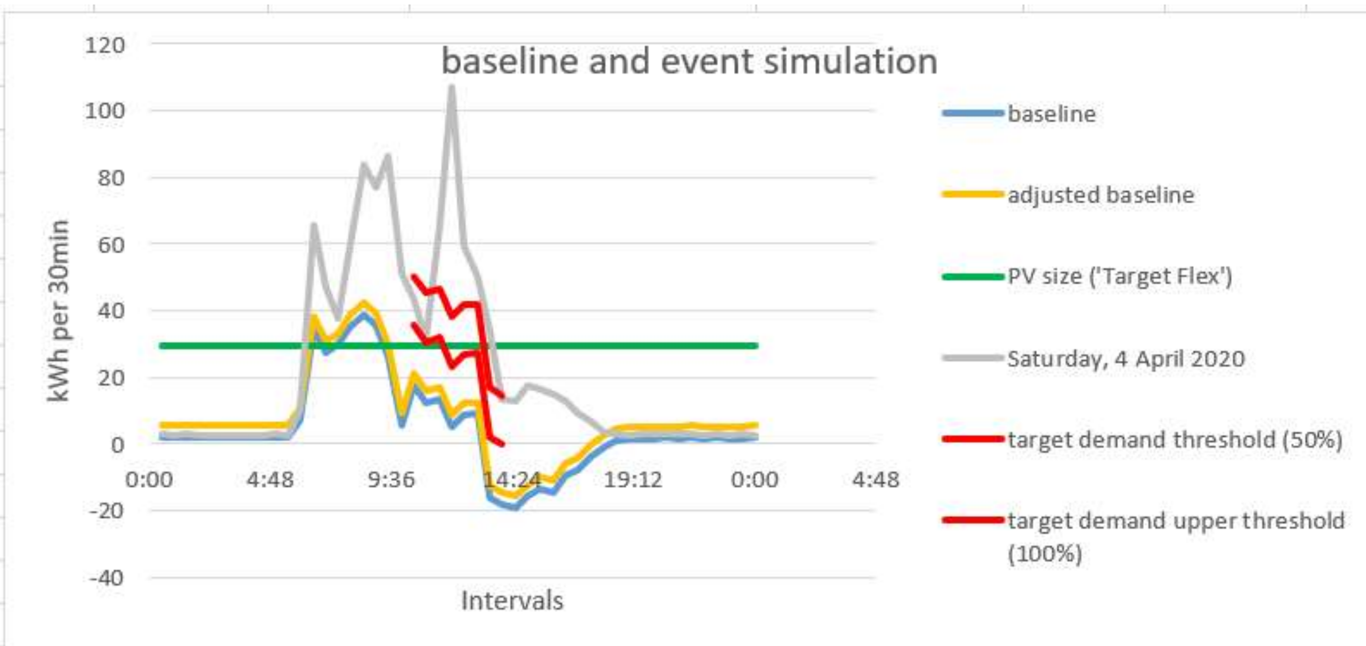


NMI D

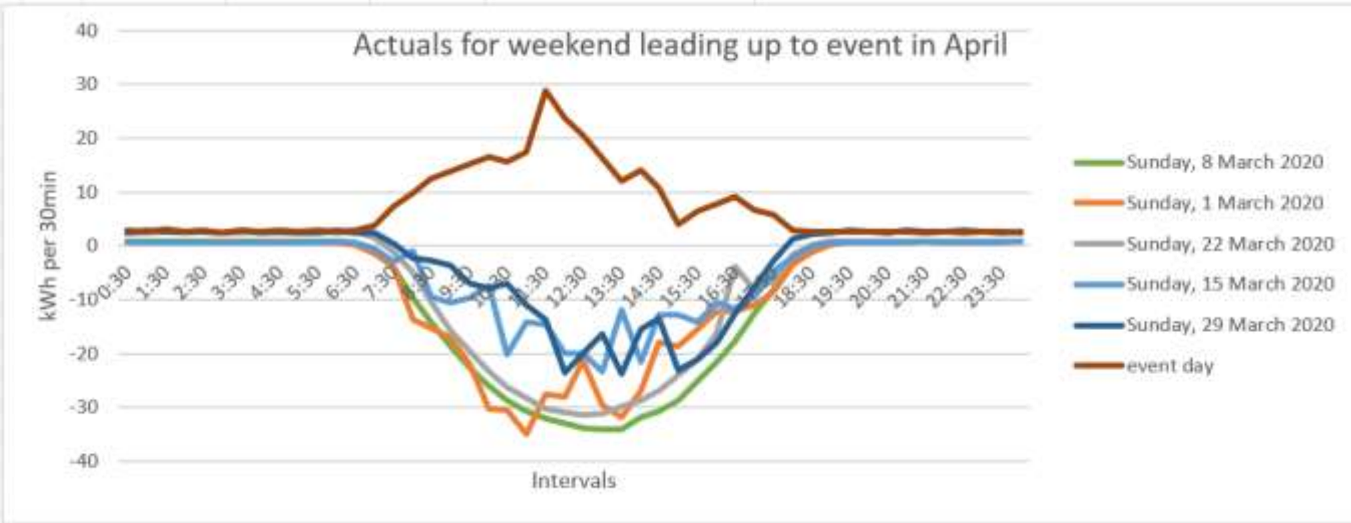
PV Size	75kW
Baseline	Basic Sat/Sun baseline, no adjustment needed
Classification	Good
Explanation	Significant difference between Saturday and Sunday behaviour.

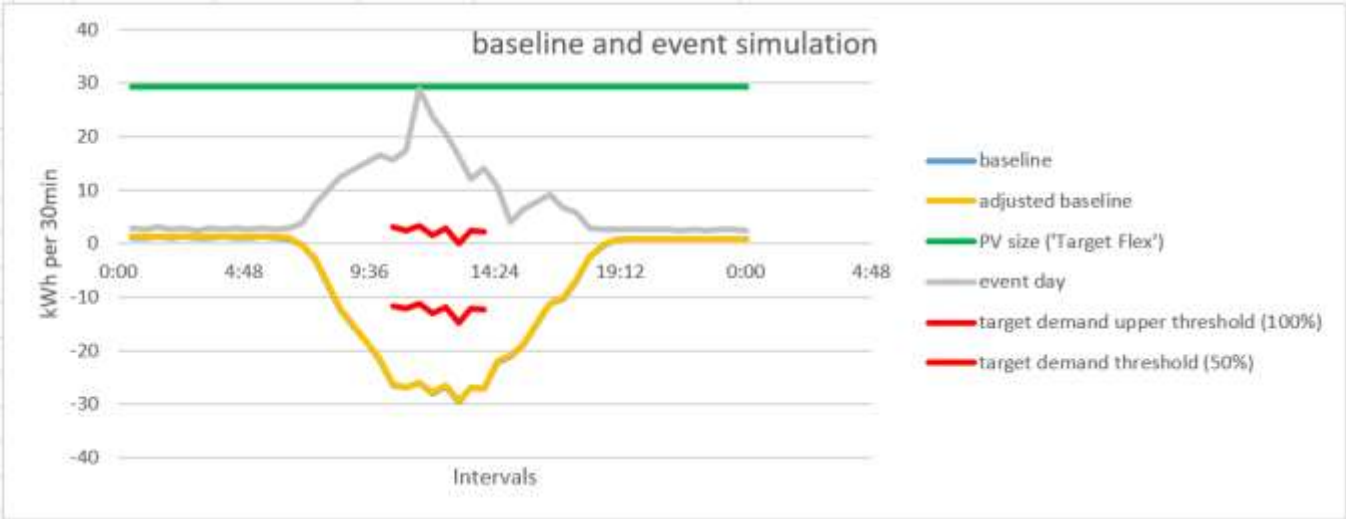
Saturday behaviour





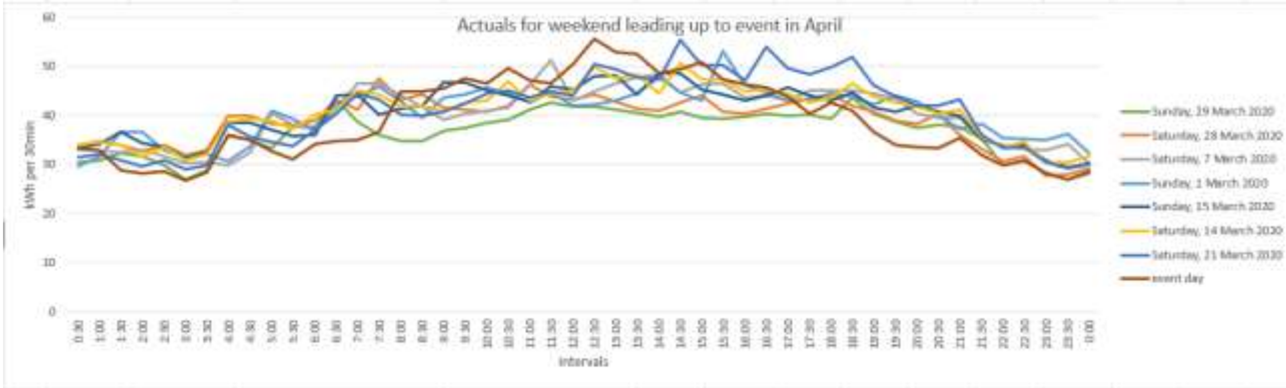
Sunday behaviour

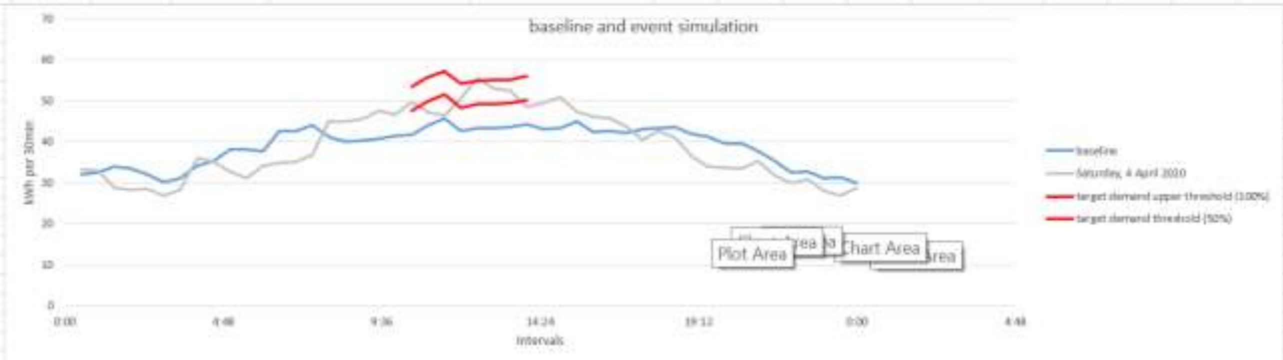


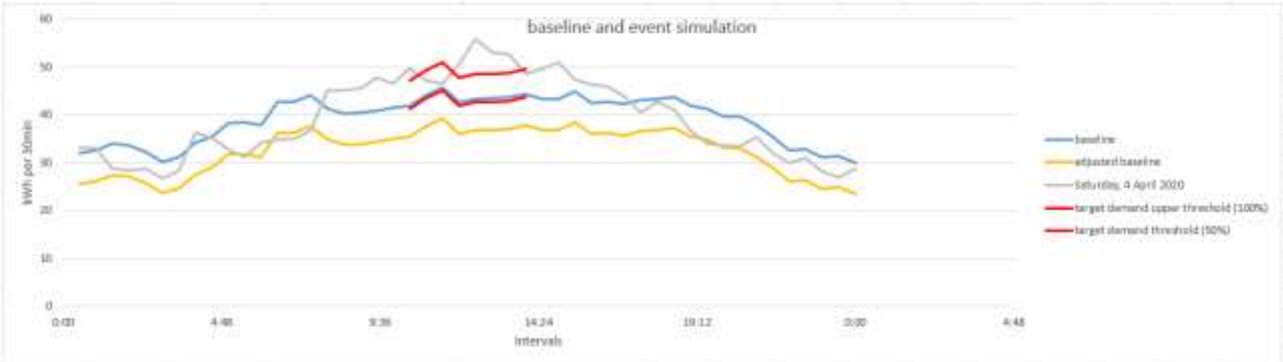


NMI E.

PV Size	30kW
Baseline	Basic weekend baseline, adjustment required
Classification	Doubtful
Explanation	Size of the PV is not quite big enough compared to average load to be easily detected by the baseline. However, since there is little variation between days, baseline adjustment can work well (as is demonstrated here). The first graph shows the actuals (including the event day with PV shutdown simulated). It shows that the event day between 5 and 7am starts off much lower than usual. The standard baseline (graph 2) doesn't work very well as a couple of intervals are non-conforming. The last graph shows the result of the adjusted baseline where all intervals between 10am and 2pm are conforming.







Calculation of difference between Sat and Sun

Let's consider the actual meter reading data for a NMI (800100XXXX) in spring 2019. The following demand curves show the actuals for the Saturdays and Sundays:

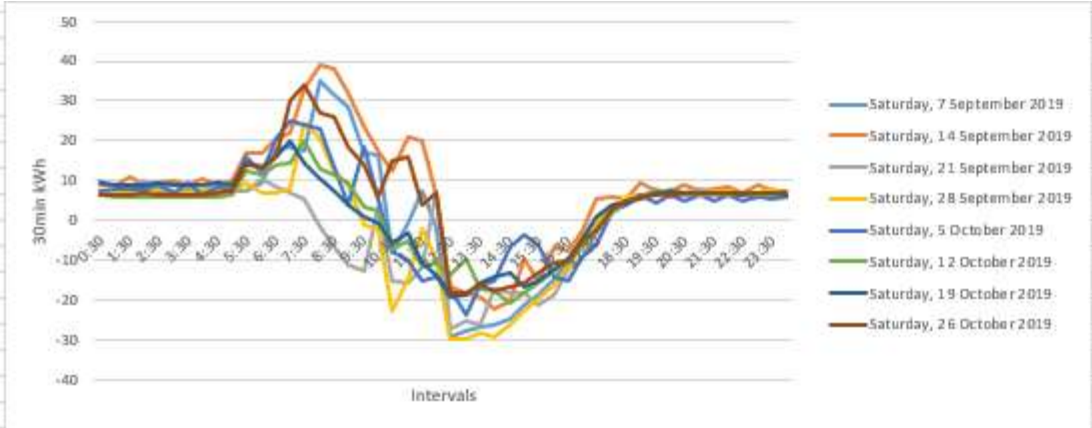


Figure 7 - Spring Saturday demand curves

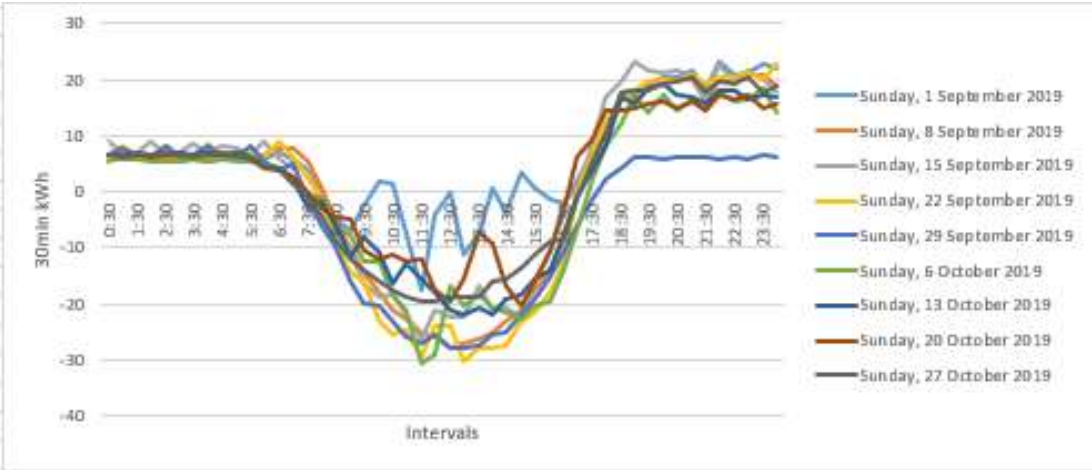


Figure 8 - Spring Sunday demand curves

Looking at this data more closely tells us that on average Saturday mornings look quite different from Sunday mornings. How do we calculate this difference in a generic way so we can allocate a Sat/Sun baseline in the cases like above?

The following definitions are used in the calculation (all have the same Unit of Measure: kWh for 30min interval):

- FT: Flexibility Target, for this NMI = 39kWh
- avgDiff, Average difference between Sat and Sun, between 10am and 2pm.
- avgSat: Average Sat demand, between 10am and 2pm
- avgSun: Average Sun demand, between 10am and 2pm
- avgStdSat: average Sat demand *variation,* between 10am and 2pm. This tells us how much variation there is on a typical Saturday.
- avgStdSun: average Sun demand *variation,* between 10am and 2pm

- avgSS: average System Size (sat/sun combined), this is the average size of the Account/NMI (or customer system). It is calculated as:
    - max(abs(avgSat), abs(avgSun)) + average(avgStdSat, avgStdSun)

These definitions will then give us the following ratios:

a) avgDiff / FT % ➔ Sat/Sun difference as a percentage of the Flex Target

b) avgDiff / avgSS% ➔ Sat/Sun difference as a percentage of the System size

As explained earlier in the document these ratios are put on the following bands to tell us whether to apply a Sat/Sun baseline or not:

Difference as % of Target Flex	**no: < 40%**	**yes: > 40%**
Difference as % of System Size	**no: < 60%**	**yes: > 60%**

As we will see for this example NMI, the respective ratios are:

a) 54%, and

b) 80%

So, both ratios are above the threshold and a Sat/Sun specific baseline will be applied. Even if one of the ratios was in the green it would be enough for a Sat/Sun baseline to be allocated. Only if both ratios are in the red a standard weekend baseline will be used.

Let's take a closer look at how the individual definitions are calculated using the following raw metering data:

avg	stdev	day	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00
-5.674	6.0998	Sunday, 1 September 2019	1.47	-7.32	-17.37	-4.26	-0.12	-11.16	-7.38	0.75
-14.14	13.908	Saturday, 7 September 2019	-8.01	-0.45	7.17	-1.86	-29.07	-27.9	-26.82	-26.16
-25.08	2.0303	Sunday, 8 September 2019	-21.24	-22.56	-25.14	-25.86	-27.72	-26.85	-26.16	-25.11
-2.029	17.574	Saturday, 14 September 2019	12.6	21	20.07	6.18	-16.56	-18.3	-19.17	-22.05
-21.24	2.5773	Sunday, 15 September 2019	-18.45	-21.96	-26.1	-21.24	-22.11	-22.32	-16.86	-20.91
-16.4	10.552	Saturday, 21 September 2019	-15.06	-15.63	-11.67	7.47	-27.06	-25.5	-26.34	-17.37
-26.6	2.3212	Sunday, 22 September 2019	-25.35	-24.57	-29.46	-23.91	-23.91	-30.09	-27.81	-27.66
-20.78	10.064	Saturday, 28 September 2019	-22.83	-14.61	-2.04	-9.57	-29.91	-29.76	-28.32	-29.16
-26.14	1.4834	Sunday, 29 September 2019	-23.1	-25.68	-26.88	-25.38	-27.81	-27.69	-27.24	-25.35
-14.98	4.4869	Saturday, 5 October 2019	-7.44	-10.38	-15.3	-14.25	-17.13	-23.67	-16.47	-15.21
-21.88	4.7645	Sunday, 6 October 2019	-18.12	-21.15	-30.66	-28.89	-16.89	-20.22	-18.51	-20.58
-11.65	4.0916	Saturday, 12 October 2019	-7.2	-5.25	-11.55	-10.86	-13.71	-9.93	-17.01	-17.7
-18.54	3.1622	Sunday, 13 October 2019	-16.44	-12.87	-15.51	-17.85	-21.21	-21.87	-20.79	-21.78
-12.62	5.3681	Saturday, 19 October 2019	-5.73	-3.18	-10.89	-13.47	-19.17	-18.54	-15.69	-14.31
-13.1	3.8849	Sunday, 20 October 2019	-11.34	-12.48	-12	-17.52	-19.41	-15.63	-7.17	-9.21
-3.607	14.48	Saturday, 26 October 2019	15.09	15.81	3.75	6.9	-18.09	-18.18	-16.17	-17.97
-18.42	1.061	Sunday, 27 October 2019	-17.4	-18.54	-19.35	-19.44	-18.9	-18.9	-18.75	-16.08

To compare Saturday to Sunday behaviour we look at two different aspects for each interval:

a) How does the average demand on Saturday compare to a Sunday (per interval), and;

b) How does the variation (stdev) on Saturday compare to a Sunday (per interval).

Let's look at the averages first. Taking the above data, we can calculate the average demand per interval for Sat and Sun as well as the differences between them:

		10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00
avg	SAT	-4.8225	-1.58625	-2.5575	-3.6825	-21.3375	-21.4725	-20.74875	-19.99125
avg	SUN	-16.66333	-18.57	-22.49667	-20.48333	-19.78667	-21.63667	-18.96333	-18.43667
avg	diff	**11.84083**	**16.98375**	**19.93917**	**16.80083**	**1.550834**	**0.164166**	**1.785417**	**1.554583**

This difference already gives us a good indication: differences in first 4 intervals are much higher than in the last four intervals. However, just looking at the differences between the averages wouldn't always give us the correct information. In some cases, the averages might appear similar, but the variations on Saturdays are much bigger than on Sundays. To take these fluctuations between Saturdays (or Sundays) into account we need to also compare those:

		10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00
avg	SAT	-4.8225	-1.58625	-2.5575	-3.6825	-21.3375	-21.4725	-20.74875	-19.99125
avg	SUN	-16.66333	-18.57	-22.49667	-20.48333	-19.78667	-21.63667	-18.96333	-18.43667
avg	diff	**11.84083**	**16.98375**	**19.93917**	**16.80083**	**1.550834**	**0.164166**	**1.785417**	**1.554583**
stdev	SAT	12.0032	12.62041	11.41482	8.878375	5.915836	6.059903	5.084047	4.971181
stdev	SUN	7.460243	5.932605	6.231556	6.797658	7.80195	5.687596	7.30165	8.551154
stdev	diff	**4.542961**	**6.687802**	**5.183264**	**2.080717**	**1.886114**	**0.372306**	**2.217602**	**3.579973**

So even if the averages weren't telling us that there was different behaviour on a Saturday compared to a Sunday, the standard deviation per interval for Saturdays compared to that same interval for Sundays will.

The sum of the difference between average and standard deviation per interval is the total difference between Sat and Sun behaviour.

		10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00
avg	SAT	-4.8225	-1.58625	-2.5575	-3.6825	-21.3375	-21.4725	-20.74875	-19.99125
avg	SUN	-16.66333	-18.57	-22.49667	-20.48333	-19.78667	-21.63667	-18.96333	-18.43667
avg	diff	**11.84083**	**16.98375**	**19.93917**	**16.80083**	**1.550834**	**0.164166**	**1.785417**	**1.554583**
stdev	SAT	12.0032	12.62041	11.41482	8.878375	5.915836	6.059903	5.084047	4.971181
stdev	SUN	7.460243	5.932605	6.231556	6.797658	7.80195	5.687596	7.30165	8.551154
stdev	diff	**4.542961**	**6.687802**	**5.183264**	**2.080717**	**1.886114**	**0.372306**	**2.217602**	**3.579973**
total	diff	**16.38379**	**23.67155**	**25.12243**	**18.88155**	**3.436947**	**0.536473**	**4.003019**	**5.134556**

Now we know the difference between Sat and Sun per interval, we have a few more question to solve:

- Which intervals do we consider so we can determine an overall conclusion whether a Saturday is different from a Sunday? Do we look at them all or only the biggest difference?
- How do we know if this difference is "big enough to worry about"? Is it significant enough?

Which intervals should we consider?

Instead of having 8 differences (one per interval) to deal with, we want to have a single figure (single measure for the difference between Sat and Sun). We can't simply take an average across the total differences because the differences in the last 4 intervals would "dilute" the real differences that occur in the morning (first 4 intervals). Just taking the biggest interval (11:30am = 25.122 kWh) might not give a good indication if that was just an outlier and all other intervals showed no difference between Sat and Sun.

Instead we take the 4 biggest differences and average those:

	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00
avg diff	*11.84*	*16.98*	*19.94*	*16.80*	*1.55*	*0.16*	*1.79*	*1.55*
avg std diff	*4.54*	*6.69*	*5.18*	*2.08*	*1.89*	*0.37*	*2.22*	*3.58*
total avg difference between Sat & Sun	16.38	23.67	25.12	18.88	3.44	0.54	4.00	5.13
Ranking of intervals	4	2	1	3	7	8	6	5

In this table the intervals are ranked according to the size of the differences between Sat an Sun. The ones highlighted in yellow are ranked top 4 (out of 8 intervals). The average of the differences for those intervals is:

- avgDiff: Average difference between Sat and Sun = sum($diff_i$) / 4,
    - where $diff_i$ is difference of interval that is ranked top 4 (biggest difference is ranked 1)
- avgDiff in our example this is (25.12 + 23.67 + 18.88 + 16.38) / 4 = 21.015 kWh-30min

Is the difference big enough to worry about?

So, we have come a long way. We can express the average difference between Sat and Sun in a single figure: 21.015 kWh-30min. What does this mean? Is this enough? Well the answer really depends on what you compare it against. Obviously, a difference between Sat and Sun of 21kWh is negligible on a load of over 1MWh, but it is significant on a load of 40kWh. It is also worth comparing this difference to the target flex. If the Sat/Sun difference is small compared to the load (eg. 500kWh), but the PV size (e.g. 60kW system) is in the same range as the Sat/Sun difference, it is still worth having a Sat/Sun baseline.

This brings us back to the two % ratios we discussed earlier: the avg difference between Sat and Sun will be compared against

- Flex Target: avgDiff / FT % = 21.015 / 39 = 54%
- System size: avgDiff / avgSS %

The last definition we need to resolve is the avgSS: how do we calculate this?

The System Size (avgSS) for comparison

avg	stdev	day	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00
-5.674	6.0998	Sunday, 1 September 2019	1.47	-7.32	-17.37	-4.26	-0.12	-11.16	-7.38	0.75
-14.14	13.908	Saturday, 7 September 2019	-8.01	-0.45	7.17	-1.86	-29.07	-27.9	-26.82	-26.16
-25.08	2.0303	Sunday, 8 September 2019	-21.24	-22.56	-25.14	-25.86	-27.72	-26.85	-26.16	-25.11
-2.029	17.574	Saturday, 14 September 2019	12.6	21	20.07	6.18	-16.56	-18.3	-19.17	-22.05
-21.24	2.5773	Sunday, 15 September 2019	-18.45	-21.96	-26.1	-21.24	-22.11	-22.32	-16.86	-20.91
-16.4	10.552	Saturday, 21 September 2019	-15.06	-15.63	-11.67	7.47	-27.06	-25.5	-26.34	-17.37
-26.6	2.3212	Sunday, 22 September 2019	-25.35	-24.57	-29.46	-23.91	-23.91	-30.09	-27.81	-27.66
-20.78	10.064	Saturday, 28 September 2019	-22.83	-14.61	-2.04	-9.57	-29.91	-29.76	-28.32	-29.16
-26.14	1.4834	Sunday, 29 September 2019	-23.1	-25.68	-26.88	-25.38	-27.81	-27.69	-27.24	-25.35
-14.98	4.4869	Saturday, 5 October 2019	-7.44	-10.38	-15.3	-14.25	-17.13	-23.67	-16.47	-15.21
-21.88	4.7645	Sunday, 6 October 2019	-18.12	-21.15	-30.66	-28.89	-16.89	-20.22	-18.51	-20.58
-11.65	4.0916	Saturday, 12 October 2019	-7.2	-5.25	-11.55	-10.86	-13.71	-9.93	-17.01	-17.7
-18.54	3.1622	Sunday, 13 October 2019	-16.44	-12.87	-15.51	-17.85	-21.21	-21.87	-20.79	-21.78
-12.62	5.3681	Saturday, 19 October 2019	-5.73	-3.18	-10.89	-13.47	-19.17	-18.54	-15.69	-14.31
-13.1	3.8849	Sunday, 20 October 2019	-11.34	-12.48	-12	-17.52	-19.41	-15.63	-7.17	-9.21
-3.607	14.48	Saturday, 26 October 2019	15.09	15.81	3.75	6.9	-18.09	-18.18	-16.17	-17.97
-18.42	1.061	Sunday, 27 October 2019	-17.4	-18.54	-19.35	-19.44	-18.9	-18.9	-18.75	-16.08

The left-most column shows the average demand for that day between 10 and 2pm. If we only take the values from that left column for the Saturdays, we can take the average across the days again:

avg	stdev	day	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00
-5.674	6.0998	Sunday, 1 September 2019	1.47	-7.32	-17.37	-4.26	-0.12	-11.16	-7.38	0.75
-14.14	13.908	Saturday, 7 September 2019	-8.01	-0.45	7.17	-1.86	-29.07	-27.9	-26.82	-26.16
-25.08	2.0303	Sunday, 8 September 2019	-21.24	-22.56	-25.14	-25.86	-27.72	-26.85	-26.16	-25.11
-2.029	17.574	Saturday, 14 September 2019	12.6	21	20.07	6.18	-16.56	-18.3	-19.17	-22.05
-21.24	2.5773	Sunday, 15 September 2019	-18.45	-21.96	-26.1	-21.24	-22.11	-22.32	-16.86	-20.91
-16.4	10.552	Saturday, 21 September 2019	-15.06	-15.63	-11.67	7.47	-27.06	-25.5	-26.34	-17.37
-26.6	2.3212	Sunday, 22 September 2019	-25.35	-24.57	-29.46	-23.91	-23.91	-30.09	-27.81	-27.66
-20.78	10.064	Saturday, 28 September 2019	-22.83	-14.61	-2.04	-9.57	-29.91	-29.76	-28.32	-29.16
-26.14	1.4834	Sunday, 29 September 2019	-23.1	-25.68	-26.88	-25.38	-27.81	-27.69	-27.24	-25.35
-14.98	4.4869	Saturday, 5 October 2019	-7.44	-10.38	-15.3	-14.25	-17.13	-23.67	-16.47	-15.21
-21.88	4.7645	Sunday, 6 October 2019	-18.12	-21.15	-30.66	-28.89	-16.89	-20.22	-18.51	-20.58
-11.65	4.0916	Saturday, 12 October 2019	-7.2	-5.25	-11.55	-10.86	-13.71	-9.93	-17.01	-17.7
-18.54	3.1622	Sunday, 13 October 2019	-16.44	-12.87	-15.51	-17.85	-21.21	-21.87	-20.79	-21.78
-12.62	5.3681	Saturday, 19 October 2019	-5.73	-3.18	-10.89	-13.47	-19.17	-18.54	-15.69	-14.31
-13.1	3.8849	Sunday, 20 October 2019	-11.34	-12.48	-12	-17.52	-19.41	-15.63	-7.17	-9.21
-3.607	14.48	Saturday, 26 October 2019	15.09	15.81	3.75	6.9	-18.09	-18.18	-16.17	-17.97
-18.42	1.061	Sunday, 27 October 2019	-17.4	-18.54	-19.35	-19.44	-18.9	-18.9	-18.75	-16.08

- avgSat = (-14.14 + -2029 + -16.4 …. + -3.607) / 8 = -12.025 kWh-30min

and for the Sunday:

- avgSun = -19.630 kWh-30min

Similarly, to the average demand for a specific Sat and/or Sunday, we can calculate the amount of variation using the standard deviation of the values between 10am and 2pm (second column from the left). Taking the averages of those values for Sat and Sun gives us:

- avgStdSat = (13.908 + 17.574 + … + 14.48) / 8 = 10.065 kWh-30min
- avgStdSun = 3.043 kWh-30min

With these averages and variations, we can define a formula that gives us an indication of the average size of the system:

- avgSS = max(abs(avgSat), abs(avgSun)) + average(avgStdSat, avgStdSun)
- in our example this is: (19.630 + 6.554) = 26.184 kWh-30min

➔ avgDiff / avgSS % = 21.015 / 26.18 = 80%

There are two components to this formula:

- an “average” component: we take the maximum average of either Sat or Sun
- a “standard deviation” component: we take the average between Sat and Sun.

The reason why we are not simply using the average across all readings or even the average over avgSat and avgSun is that some values could be positive as well as negative, resulting in an average of close to zero and that would not reflect the correct size of the system. Instead we simply take the avgSat or avgSun (whichever is biggest).

On top of the max-average we add the average of the Sat and Sun standard deviations. This is for the same reason as we included an average and a stdev component when calculating the difference between Sat and Sun.

The resulting avgSS value is not necessarily the same as the size of the demand. If generation (negative values) on a Sunday outweighs demand (positive values) on a Saturday the “average size” is determined by the Sunday average. All this avgSS (kWh-30min) value gives us is a consistent “scale” of the size of the account that we can use to compare differences between Sat and Sun against.