WHEN TRUST MATTERS

Operational Metering Requirements

WP3 Impact Assessment
08.01.2025

1. Impact Assessment Scope & Methodology

Last engagement (August 2024)

- Examined CER characteristics and expectations of growth in CER capacity
- Confirmed OM is crucial for meeting the Security and Quality of Supply Standards (SQSS).
- Confirmed challenge with OM requirements applies to assets less than 1 MW in size: cost of achieving the required 1% inaccuracy and 1-second frequency requirements
- Compared GB vs. international approaches
- Based on feedback from aggregators and suppliers DNV recommended that NESO specify OM accuracy requirements at the portfolio level and allow the aggregator to develop their solutions to meet those requirements.

Progress since last update

Completed:

- Modelling to support impact assessment completed:
  - Sensor accuracy impact, potential for reduction via aggregation
  - Impact of different asset meter read intervals (10s, 30s, 60s)
  - Communication latency impact
  - Assessed performance of options to reduce errors to inform recommendation

  (Measured as difference in kW/MW between real power output and value in control room)

Ongoing:

- Work to determine the full impact of meter error on NESO control room, and potential for increased error tolerance (in-progress)
- Work to quantify financial impacts (in progress)

Key findings:

- Sensor error for aggregated portfolios of approximately 100 assets or greater will reduce to less than 1%
- An additional error is present for CERs since they do not meet 1s update frequency at asset level, the error is largest during ramping.
- With 10s read interval, and solutions to improve accuracy applied, aggregated meter signals still have an additional inaccuracy much greater than 1% due to the additional latency.
- For any new accuracy requirement, aggregators will likely need to implement some combination of:
  - Updating asset meters more frequently
  - Slower portfolio ramp rates
  - Applying adjustments or alternative sampling techniques to meter signals

Methodology

1. Accuracy impact

- Use input from WP1/2 to determine manufacturers capability (e.g. accuracy, frequency and latency)
- Apply mathematical error propagation theory to demonstrate that independent errors are reduced when you aggregate assets.

2. Frequency and latency impact

- Construct a syntethic expected delivery profile for EVs based on real meter data shared by the Power Responsive stakeholders
- Run Monte Carlo simulations to empirically assess both the mean error and its standard deviation
- Visualise and quantify the meter error expected, given the latency in communication and meter read frequency, both for ramping periods and during service delivery.
- In the absence of real data for specific technologies (V2G, home batteries, heat pumps and solar rooftops), conduct a qualitative assessment to assess how the error might vary compared to the EV errors based on the technology specific characteristics.

3. Assess different methods to reduce errors

- Use different methods to reduce the errors due to meter frequency and latency lag
- Visualise and quantify the meter error reduction, for each method, both for ramping periods and during service delivery.
- Assess advantages, disadvantages for each method

4.Financial impact

- Use findings from accuracy, frequency and latency impact to establish the amount of overall error
- Understand how CR mitigate meter risk errors and the maximum error they can tolerate without taking extra actions
- Develop actions taken based on scenario and methods used to reduce error (e.g. carry extra response, reserve)
- Estimate the cost of actions

5. Counterfactual impact

- Estimating cost of keeping current requirements on market participants – performed in WP1/2 and validated with stakeholders
- Compare cost of running other type of generation compared with CERs

2. Impact Assessment – High Level Findings

Summary of meter read interval impact assessment methodology

**Modelling used a synthetic dataset created from an EV Smart Charging Dataset filtered for assets with 10s update frequency
The validity of the findings was checked for other technologies using statistical data provided by a second aggregator.**

Data received:

The analysis used records from an EV smart charging portfolio that met minimum requirements to support our analysis:

- Tens of assets
- Lower frequency measurements (≤60-second intervals)
- One-day time range
- No dispatch instruction data

DNV examined additional data sources across other technologies, but identified no other suitable datasets which could be accessed for the study (reflecting the early stage of this market).

Analysis Method:

Since the data did not include a dispatch signal, a synthetic dataset was constructed to assess the error during ramping periods. Mathematical models were built to examine how meter read interval and portfolio size affect overall accuracy. Monte Carlo Simulation (1000 runs) was used to account for variations in the update time of individual assets.

Since suitable real data for asset types other than EVs was not available we assessed the validity of the EV findings for other technologies, using the statistical data for other technology types received from a second aggregator.

Simulation Structure

Individual meter update time:

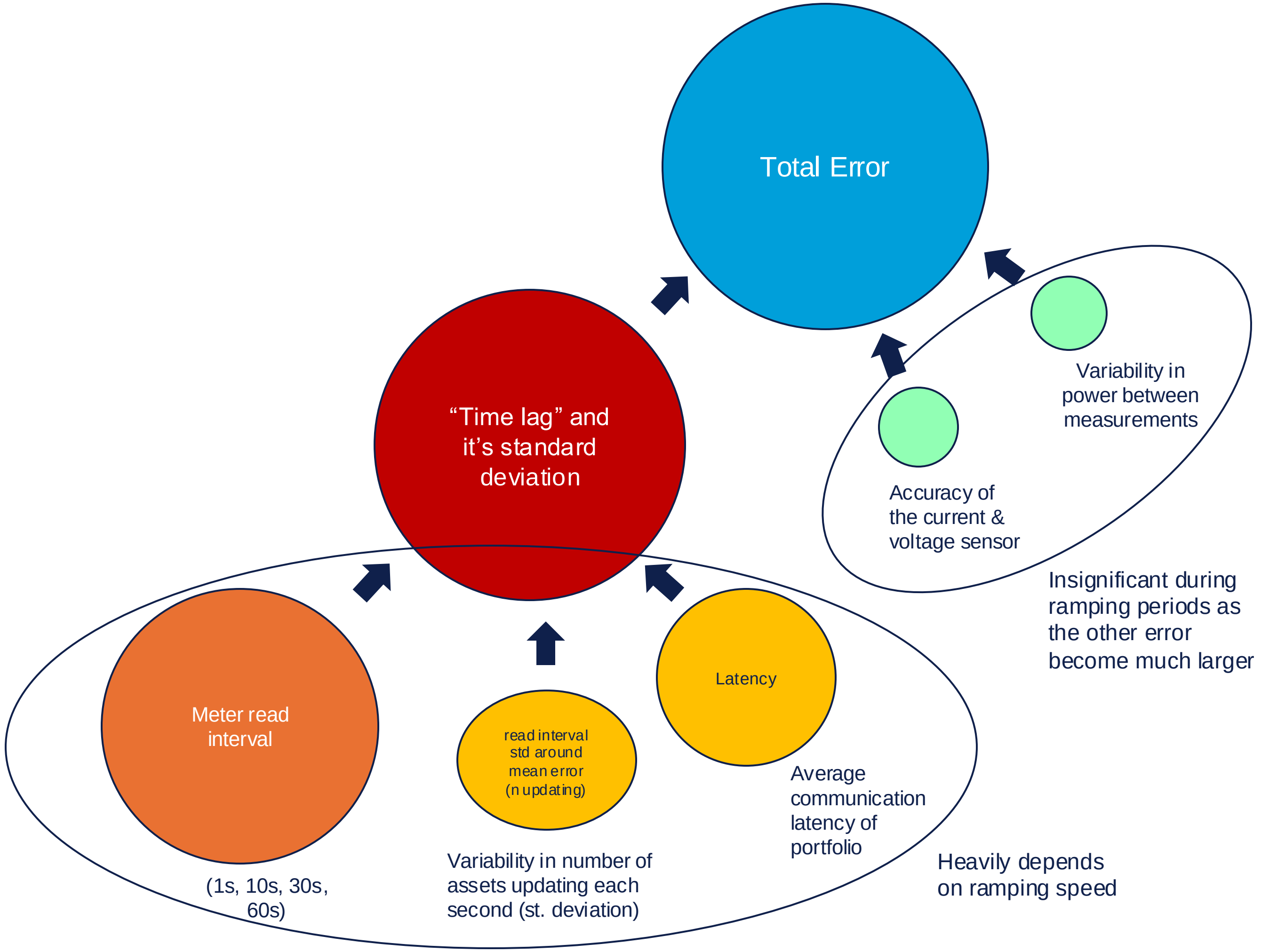
- Each asset's meter update time is randomly created using a uniform distribution. Example: For a 30-second read interval, each asset's update time is randomly set between second 0 and second 30. Aggregated meter reading:
- The aggregated meter reading is updated every second. Each update includes new data from approximately (100% / read interval) of the portfolio. With a 30-second read interval, about 3.33% of asset's update each second, however due to random variation for some seconds higher or lower than this resulting in standard deviation in mean error.

The validity of our analysis relies on the assumption that aggregated portfolios will have a uniform distribution of measuring times

Overview of error components

In most situations the error from meter read interval is significantly larger than the other error components

Total error is formulated by the expression $Total\ error = \Delta readinterval\ mean\ error + \Delta latency + \sqrt{(\Delta readinterval\ std\ around\ mean)^2 + \Delta accuracy^2 + \Delta power\ variability\ between\ measurements^2}$



Sensor Accuracy Impact

Measurement error from sensor accuracy is reduced by aggregation according to the Law of Large Numbers to below 1% for 1MW portfolios

Even with only 100 assets, the law of large numbers results in the error associated with sensor inaccuracy and standard deviation reducing by a factor of 10, so that a 2% inaccuracy would be reduced to 0.2%.

We have:

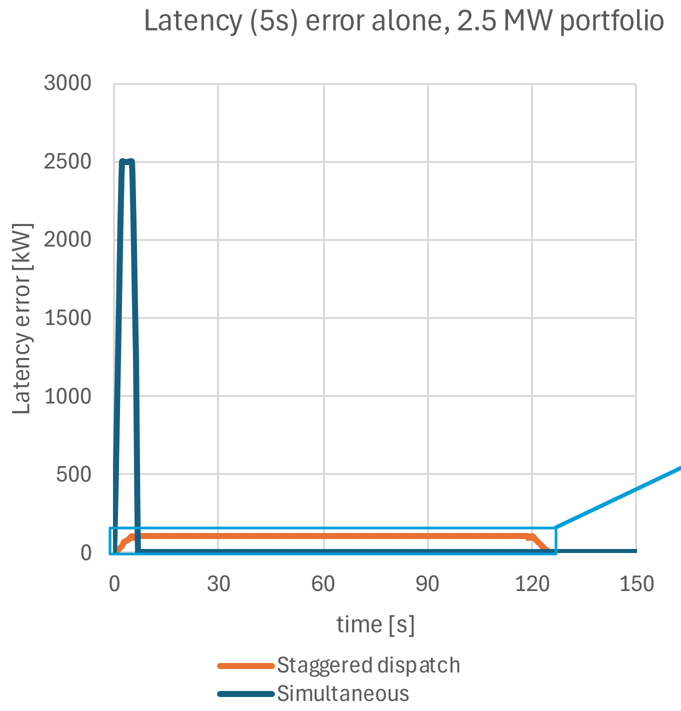
- Determined that applying LLN approaches to different metering solutions was a viable approach.
- Considered effect of systematic measurement errors: we will be recommending NESO advocate for similar provisions to prevent systematic measurement errors as present in EV Smart Charging Regulations for other CER types

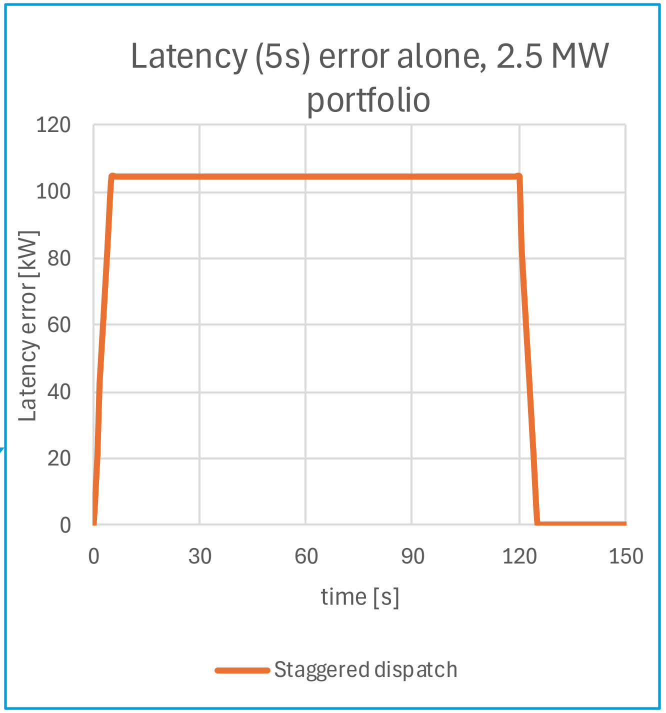
MEASUREMENT ACCURACY IMPACT – NUMBER OF ASSETS NEEDED TO MEET 1% ACCURACY

				1MW Portfolio		30MW Portfolio	
Technology	Size (kW)	Accuracy	Number of Assets to meet 1% accuracy	Number of assets	Maximum inaccuracy (MW) (1MW portfolio)	Number of assets	Maximum innaccuracy (MW) (30MW portfolio)
EV	7	2%	4	143	0.17%	4286	0.03%
EV	7	10%	100	143	0.84%	4286	0.15%
Home BESS	14	2%	4	72	0.24%	2143	0.04%
Home BESS	14	3.5%	13	72	0.41%	2143	0.08%
Heat Pump	3	3.5%	13	334	0.19%	10000	0.04%
Heat Pump	3	10%	100	334	0.55%	10000	0.10%
Solar PV	5	2%	4	200	0.14%	6000	0.03%
Solar PV	5	10%	100	200	0.71%	6000	0.13%

Latency impact on error in control room (representative of both CERs and traditional assets)

Communication latency results in a similar error to the meter read interval, however there are no post processing options to reduce this error, and there is current no established process to validate operational metering latency.





- In WP1, the survey showed that 5 second latency from asset through to ENCC is achievable. This figure will be used in the next part of the study.

Effect of ramp time on communication latency error in control room using 5s latency as an example. Simultaneous dispatch (2 second ramp) results in very high (100%) error. Staggered dispatch (2 minute ramp) significantly reduces the maximum absolute error seen in control room, but the error persists for the duration of the increased ramp time.

Meter read interval: four error components

In most cases, portfolio ramping speed and meter read interval are the most important components

The four error components from read interval are, in order of importance:

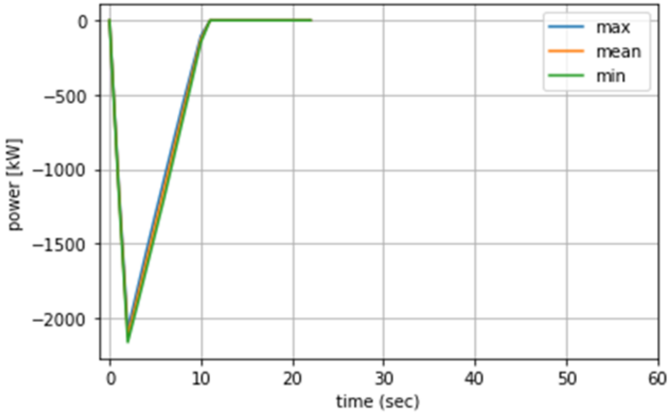
1. Portfolio ramping speed (time taken for the portfolio to ramp to full delivery)
2. Chosen meter read interval, determining lag in aggregate signal
3. Standard deviation in the meter read interval error, caused by variability in the number of assets updating each second
4. Variation in power between measurements (excluded from modelling)

   (for EVs was found to be insignificant and therefore excluded from modelling using the EV data provided for the study. It was quantified for other technologies and is discussed later) (Comparison of Technology Types)

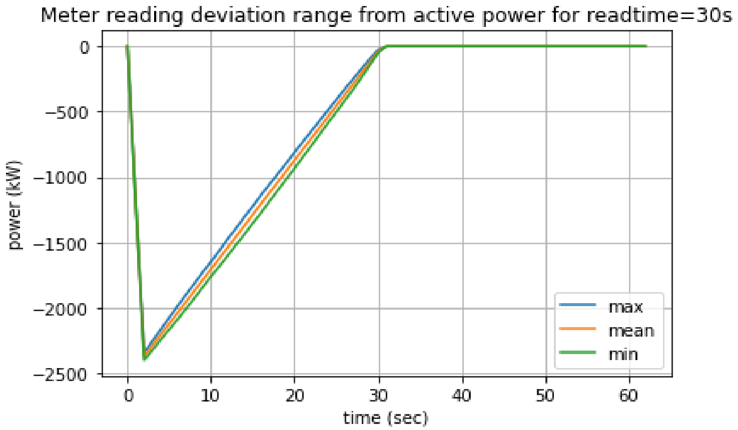
A longer meter read interval causes a larger, and longer lasting error

Comparison of 10s vs 30s vs 60s read-interval for simultaneous activation illustrates the effect of read interval on aggregated meter error

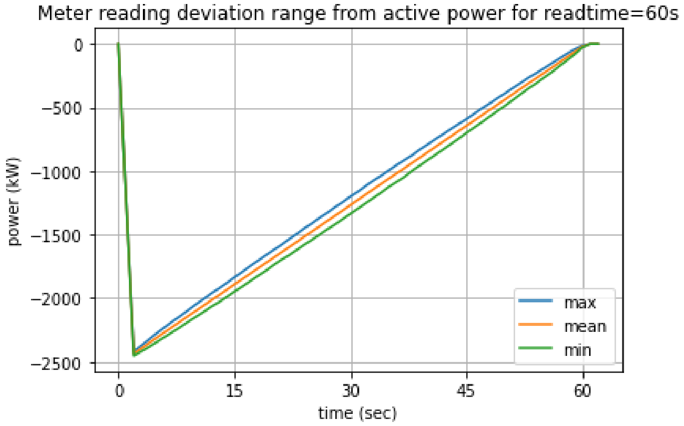
10s



30s



60s



2500 kW portfolio (simultaneous activation)

Key Points:

- The error from meter read frequency starts at nearly 100% during ramp initialisation and reduces to 0% over a time period equal to the read interval.
- All three scenarios show an almost linear reduction in error from 100% to 0% over their respective intervals.

Meter read interval impact and portfolio ramp impact

Error is increased by longer meter read intervals and faster portfolio ramp times

Portfolio Ramp Timeframe		15MW fully dispatched portfolio with aggregate metering (i.e. no correction)		
		Meter Read Interval	Maximum Error (%)	Maximum Error (MW)
	Simultaneous Dispatch (2s ramp)	10s	81%	12.15
		30s	94%	14.1
		60s	96%	14.4
	Staggered Dispatch (1 minute ramp)	10s	7.8%	1.17
		30s	25%	3.75
		60s	50%	7.5
	Staggered Dispatch (2 minute ramp)	10s	4.0%	0.6
		30s	12.6%	1.89
		60s	25%	3.75

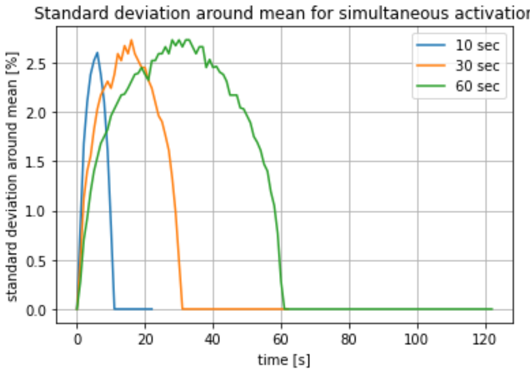
Variation in number of assets updating each second creates a standard deviation of the mean read interval error

The maximum standard deviation occurs when exactly half the meters have updated, which happens at the midpoint of any interval.

Standard deviation in mean meter interval error is caused by variations in:

1. The proportion of meters in the portfolio updating per second (i.e. considering a slightly non-uniform distribution of meter updates)
2. Of those updated meters, the proportion which are activated (i.e. dispatched)

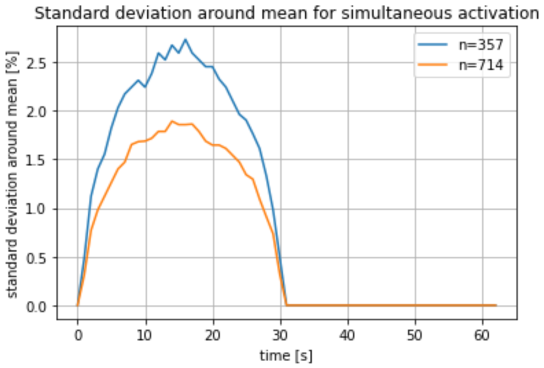
St. deviation around the mean meter interval error (10s, 30s, 60s readinterval, (simultaneous activation)



Standard deviation for different read intervals during simultaneous activation of a portfolio assets.

The standard deviation is caused by variability in the number of assets updating each second, and can be considered a measure of how choppy or smooth the meter signal is over time. In our analysis we consider the worst-case impact of standard deviation during the ramping period (the second where the most, or least, number of meters provide an update, and the error is furthest from the mean).

The standard deviation around the mean reduces if you increase # of assets



Standard deviation around the mean error (caused by differences in meter measuring times) reduces as the number of assets increases.

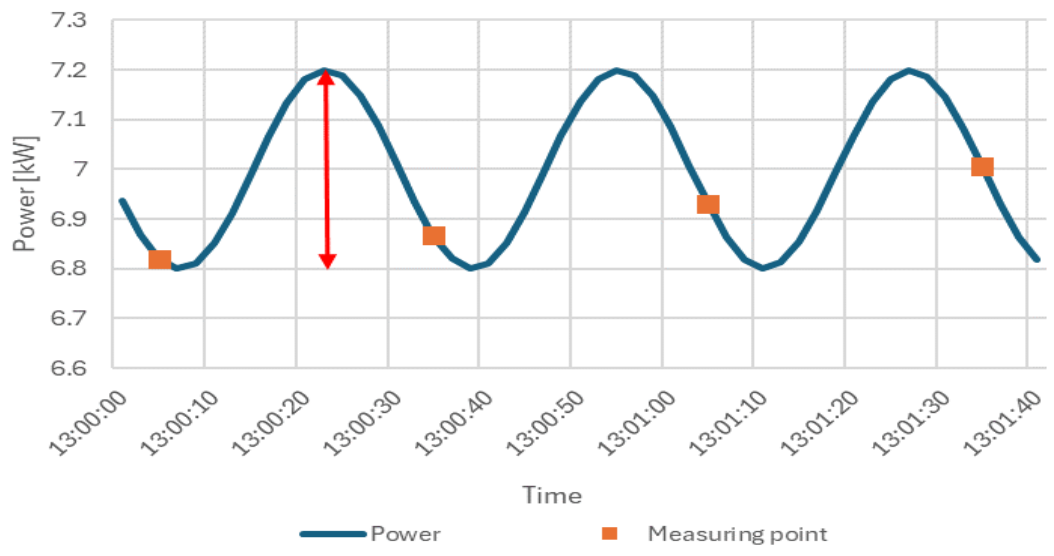
Additional error is caused by variability in asset power between measurement two points

In EVs this error is very small, and further reduced to insignificance by the law of large numbers, therefore it was excluded from modelling. Data received later in the project showed this error to be a larger component for Solar PV and Heat Pumps (see Technology Comparison) .

We quantified the impact of inter-sample variation (where fluctuations in active power occur between measurement intervals and are thus not captured by the meter) on the accuracy of the power measurement. The top-right chart visualises the effect of inter-sample variation.

Key Points:

- The size of the error increases with longer meter read intervals, and decreases with larger portfolio sizes.
- For EV Smart Chargers at 30s interval the error is 0.6% at the individual asset level.
- For EVs this error can therefore be considered insignificant at the aggregated level.



Fluctuations occurring within measurements are not registered by the meter.

During stable operation, the load of a 7kW EV charger is likely to be within ± 0.04 kW compared to a measurement at maximum 30 seconds ago. This represents a maximum error of 0.6%; the error grows with increasing measurement interval, possibly up to 2.2% for 1-minute measurement intervals.

3. Options to mitigate meter error

Potential solutions to mitigate meter error were assessed

In the next phase of the project, we will be engaging with industry on the potential opportunities and challenges for implementation of these solutions

Reason for analysing potential solutions to mitigate meter errors:

- Understand potential performance of solutions to calibrate impact of meter lag on ENCC.
- Understand whether potential changes to Operational Metering standards we might recommend would be achievable by market participants.

We are **not** planning to make recommendations that NESO mandate a given solution for market participants.

We **are** planning to make a recommendation on the overall level accuracy (yet to be determined) that should be achieved. For clarity this will consider accuracy from sensor accuracy and meter read interval.

In the next phase of the project, we will be engaging with industry on the potential opportunities and challenges for implementation of these solutions.

Overview of options assessed

Two activation schedules and four methods of aggregating the meter signal were modelled. Two additional approaches were investigated.

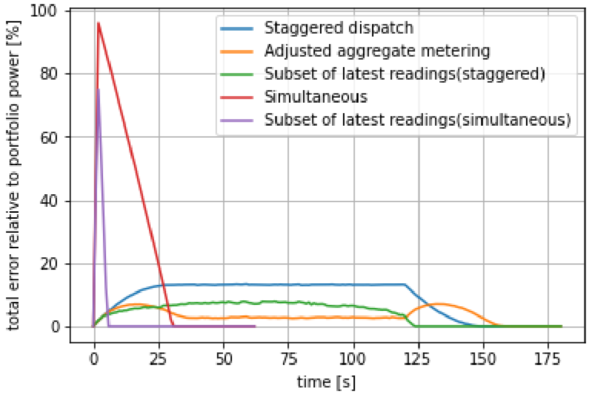
Activation schedules assessed	Meter aggregation methods assessed
Simultaneous Activation (fast ramp up rate – 2 seconds)	Aggregate metering
	Subset of latest readings
Staggered Dispatch (slower ramp up rate – 1 to 2 minutes)	Aggregate metering
	Adjusted aggregate metering
	Subset of latest readings
	Timeshifted aggregation
	Other solutions investigated:
	Report on change*
	Synthetic meter readings

*not modelled because reporting with a 1s meter read interval on activation results in no meter lag, and the remaining error is caused by the meter reporting threshold which requires more investigation – see Report on Change

Meter read error is presented as either % of total portfolio power, or as its power equivalent in kW or MW

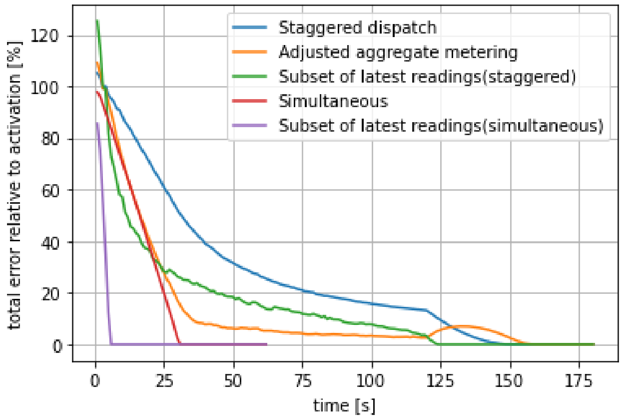
Two methods of calculating error were compared: as a % of total portfolio power (left) and as % of active power at each 1s timestep (right)

Error as % of portfolio power capacity $= absolute\ error\ /\ 2500\ kW\ *\ 100\%$



The plot of absolute error (shown here as % of total portfolio) shows that the options assessed reduce the magnitude of the error during the initial ramp. However, this is achieved by spreading the inaccuracy over a longer ramp period (by staggering dispatch of assets). The y-axis could be changed to kW / MW and the chart would look identical.

Error as % of assets activated at timestep $= absolute\ error\ (kW)\ /\ active\ power\ at\ timestep\ (kW)\ *\ 100\%$



When error is calculated as a % of active power at each timestep, the options assessed do not appear to be effective at reducing the inaccuracy from read frequency. However, this presentation of the results does not communicate that the absolute error during ramping has been reduced by activating fewer assets, so in kW this error would be significantly smaller.

DNV chose to present the results of our analysis as per the left-hand chart ‘Error as % of portfolio power capacity’, or as the equivalent error in kW / MW (which is interchangeable). This portrayal of the results was chosen since it gives the most informative view to ENCC of the true magnitude of the error.

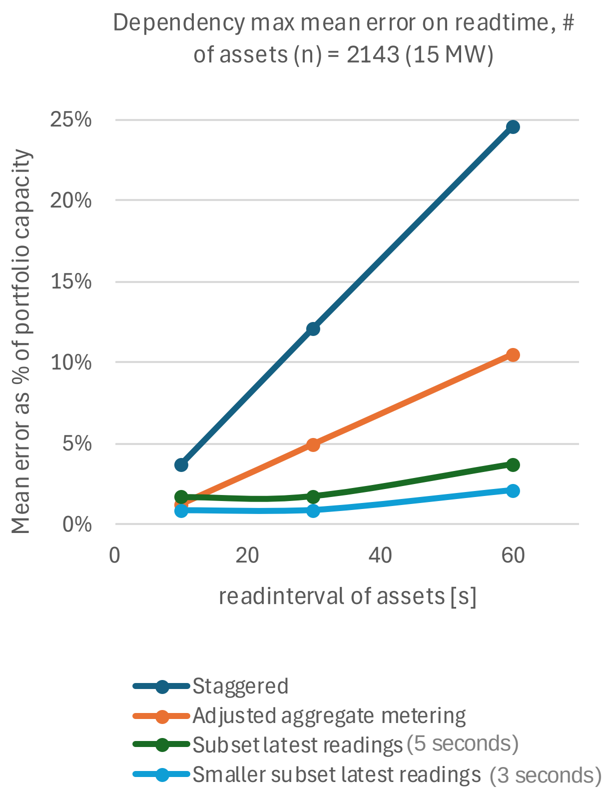
Error from meter read interval can be reduced to <3% with ramp limits and a subset of latest reading metering solution

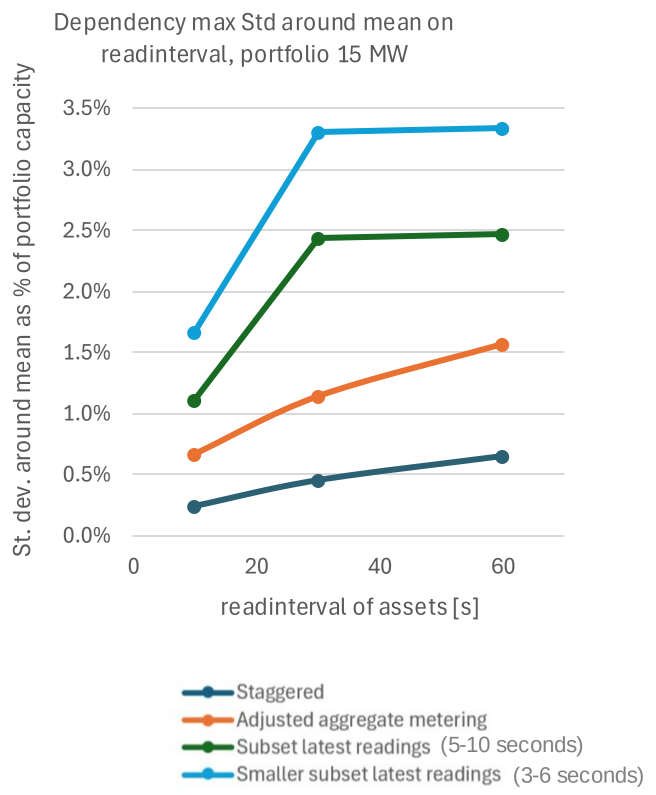
Using subset of latest readings or adjusted aggregate metering an error of <3% is achievable with a read interval of 10 seconds, whilst error of <6% can be attained even with 1 minute ramp and 30s meter read interval

		Metering solution and resulting maximum error (15MW portfolio) (error is shown as % of portfolio capacity, fully dispatched portfolio)			
		Meter Read Interval	Aggregate Metering (no correction)	Small Subset of atest Readings	Adjusted Aggregate Metering
Portfolio Ramp Timeframe	**Simultaneous Dispatch (2s ramp)**	10s	81%	42%	50%
		30s	94%	43%	87%
		60s	96%	69%	95%
	Staggered Dispatch (1 minute ramp)	10s	7.8%	3.3%	3.2%
		30s	25%	5.0%	10.9%
		60s	50%	7.4%	22%
	Staggered Dispatch (2 minute ramp)	10s	4.0%	2.5%	1.7%
		30s	12.6%	4.3%	5.7%
		60s	25%	5.5%	11.6%

Meter read interval influence on solution performance

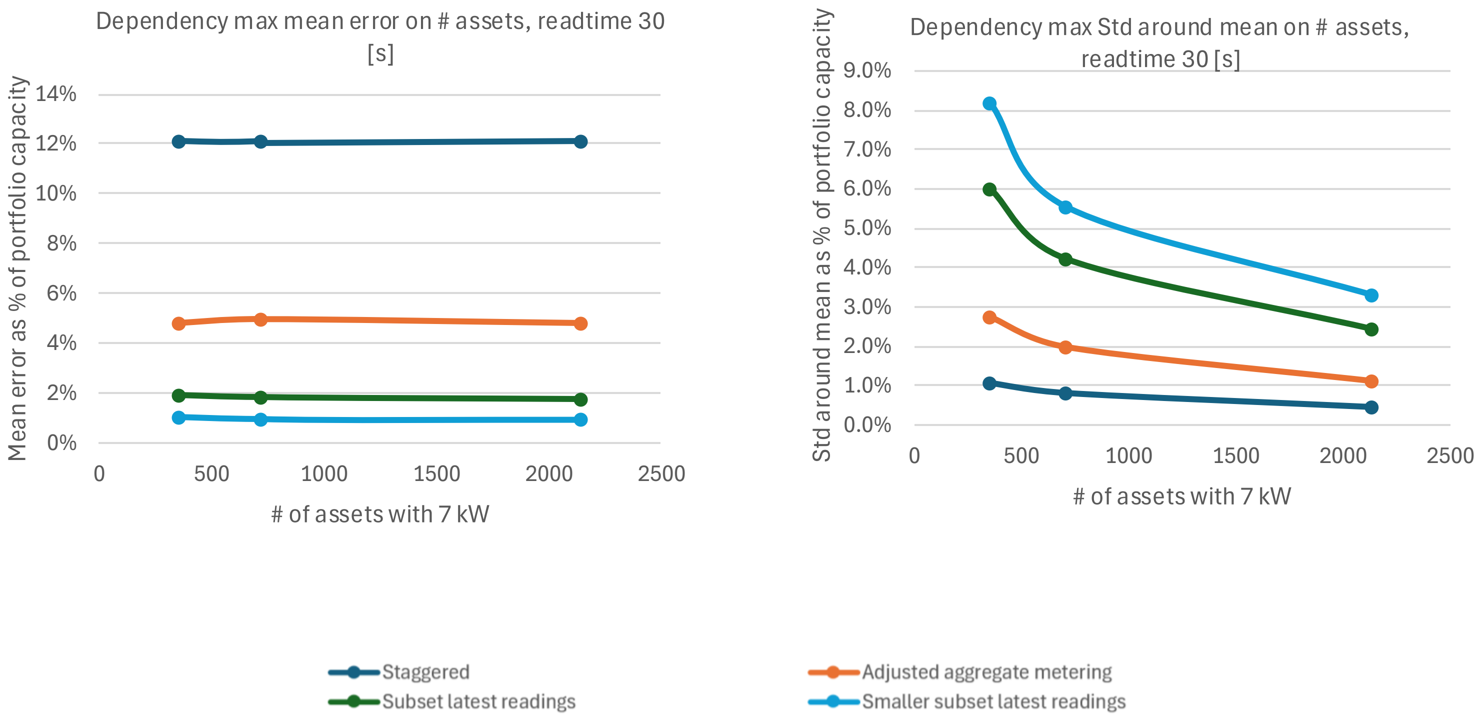
Subset of latest readings solutions, among the simultaneous and staggered dispatch methods, perform best over a wide range of read intervals
Adjusted aggregate metering performs best at short read intervals (approximately 15s and under)





Portfolio size influence on solution performance

Mean error is largely independent of the number of assets in the portfolio, standard deviation reduces with increasing portfolio size



The error contribution from standard deviation is the worst-case scenario and would be most likely to occur once per ramp period at the mid-point of the ramp.

For standard deviation, all solutions demonstrate a common characteristic: the maximum standard deviation decreases with increasing portfolio size according to a $\sqrt{1/n}$ relationship, similar to the law of large numbers.

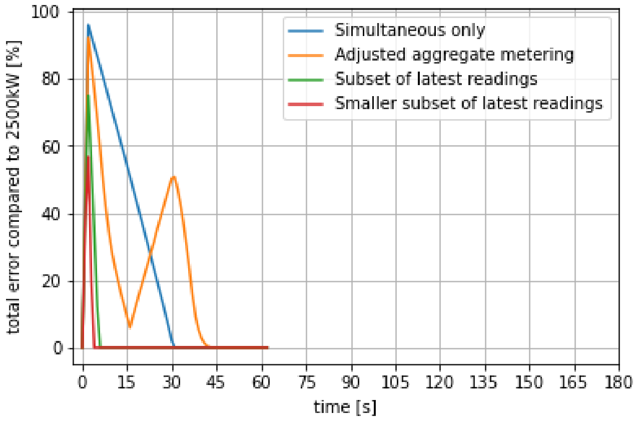
Ramp timeframe has a significant impact on aggregated meter error

Slower ramping through staggered dispatch significantly reduces aggregated meter errors compared to simultaneous activation

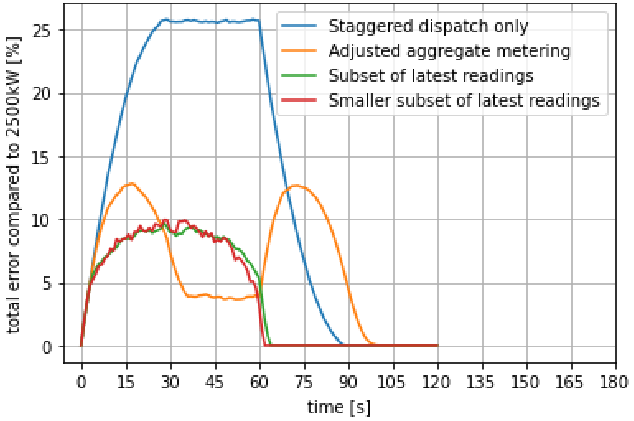
- Maximum error decreases linearly as ramp timeframe increases, with relationship $^1/_{timeframe}$
- For example, extending ramp time from 1 to 2 minutes cuts maximum error roughly in half
- Trade-off: Lower peak errors but sustained over longer period

Short ramp timeframe, higher error → **Long ramp timeframe, lower error**

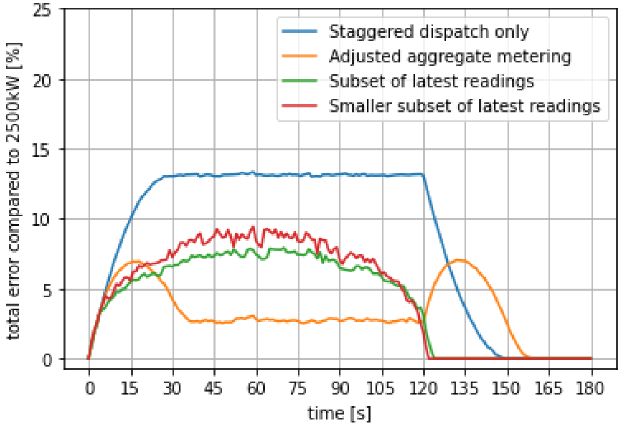
Simultaneous activation in 2 seconds



Staggered dispatch over 1 minutes



Staggered dispatch over 2 minutes



All examples are for a 2500kW portfolio

Report on Change is a viable alternative solution, especially for EV Smart Chargers

Report on change can eliminate or significantly reduce meter read interval error, however there are possible implementation challenges

Benefits:

The primary benefit is that very short meter read intervals (1-5s) can be provided on substantial load changes, which significantly reduces read interval error (or eliminates it with 1s read interval).

Implementation Challenges:

The asset meter must be capable of measuring and transmitting data with an interval of 1-5s. All modern EV charge point equipment is capable of this, but for other technology types this may not be the case if the firmware was not programmed to provide measurements with this frequency.

Setting the appropriate update threshold is crucial:

- Too low a threshold leads to excessive data transmission
- Too high a threshold introduces unacceptable uncertainty
- For EV smart charging, even a small threshold of 0.07 kW (1%) proves valuable

Limitations:

This approach becomes less suitable when load changes are frequent and significant. In such cases, aggregators face a trade-off between:

- Managing excessive data transfer
- Accepting higher inaccuracy due to threshold settings (where inaccuracy per asset = threshold / active power)
- It is possible that some asset types and communication protocols may be limited in their ability to implement a report on change solution

This method was not modelled because the chosen threshold determines the majority of the error. Further analysis on this option should focus on determining the appropriate thresholds and suitability of this approach to different technologies (especially on how quickly power can change, and capability to measure at 1s intervals when the threshold is activated)

Synthetic meter readings are a potential solution but there are risks from adopting this approach

Submitting a synthetic meter reading, followed by a real reading several seconds later, may be the optimum solution to resolve both real-time and offline data uses, however more data on the performance of aggregated CERs is needed to determine the viability of this approach

A potential solution to the problem of aggregated meter error impacts on the control room is to submit two meter feeds:

1. A synthetic meter feed based on the activation schedule of the portfolio, submitted <5 seconds before the portfolio is activated. This would be similar to submitting a PN with more granularity (e.g. secs), however this approach could have issues with accuracy similar to PN's.

2. A traditional meter reading submitted (or ex-post data submission)

The viability of synthetic meter readings depends on the reliability and accuracy of aggregated portfolios in following their activation schedules, understanding the risk of portfolios failing to activate, and the risk appetite of control room in utilising a synthetic meter reading. In our interviews with control room opinion on the benefits of this solution was split. This option could be explored as more data is collected on the performance of different market participants and aggregated CER technology types.

4. Other technology types assessment

The modelling is more representative of EVs and Home BESS, and less representative of Heat Pumps and Solar PV

The higher underlying variability in asset power output of Heat Pumps and Solar PV, as well as potential weather correlation effects reduce our confidence in applying EV modelling findings to these asset types

Technology	Findings from data received	Validity of applying EV modelling conclusions for this technology
Home Battery	<1% variability between measurements ([expected to behave similarly to EVs])	High
EV (communication directly with vehicle) EVSE, V2G EVSE (EVSE refers to EV smart charge points)	Slightly higher variability compared to other datasets but still marginal at maximum 2.2% for smaller EV chargers based on 1 minute readinterval	High
Heat Pumps	Potential variability up to 6% between measurements, based on 5 minute readinterval. Simultaneous dispatch scenario unlikely to be achievable.	Low (Due to variability, weather dependency, and potential ramp limits)
Household Solar PV	Potential variability up to 6% between measurements, based on 5 minute readinterval	Low (Due to variability and weather dependency)

Questions:

- Ability of heat pumps and solar to communicate 1s to 1-minute intervals
- Dispatch and (operational) ramping constraints of heat pumps

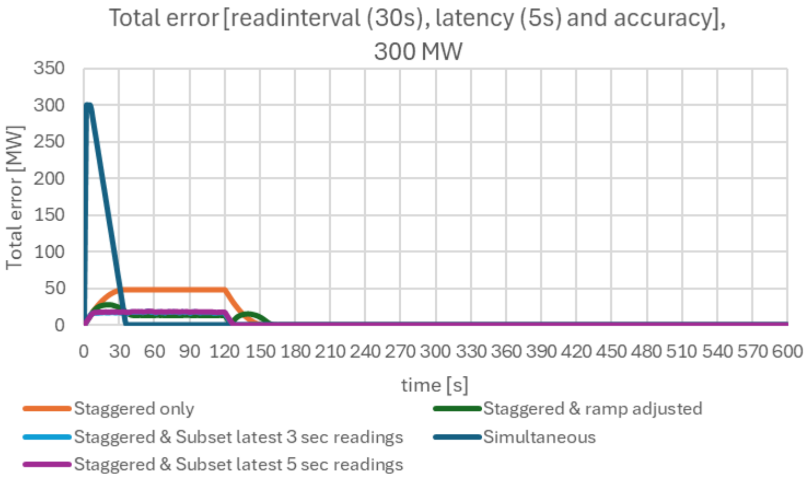
Comparison with traditional technology types (assuming worst-case 5s latency for all assets)

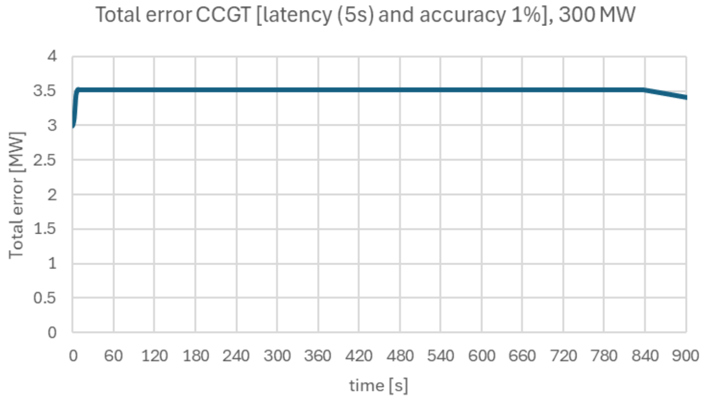
With ramp limits and metering solutions applied, CER portfolios result in roughly double the error of interconnectors

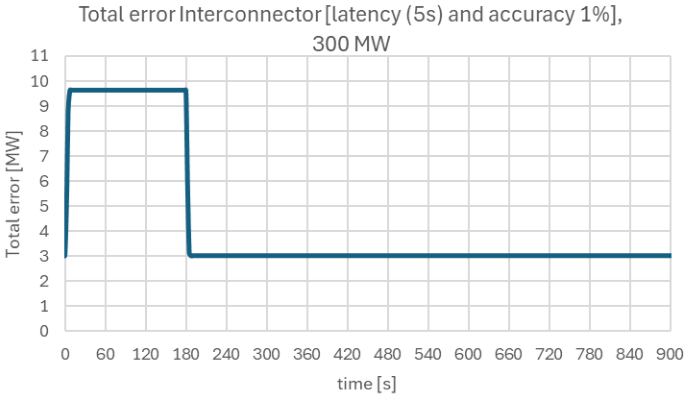
CER errors in this report were calculated as worst-case scenarios. To make a fair comparison the worst-case error (1% sensor accuracy and 5s latency) from traditional technology types (represented by CCGT, interconnector, and grid scale BESS) was calculated using representative ramp rates.

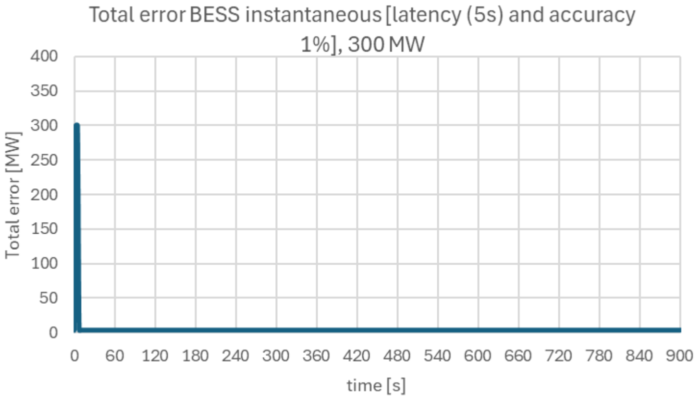
Conclusion: Metering errors from CERs, **when using a metering correction solution**, are of the same order of magnitude (roughly double) that of interconnectors with a similar ramp limit (in this example the **CERs ramped in two minutes** and the interconnector in three minutes).

Caveat: traditional technology types are likely to have a lower communication latency than aggregated CER portfolios









Ramp rates: CCGT: 20MW / min; Interconnectors: 100MW / min; Grid BESS: instantaneous ramp (2s) based on wholesale market participation (batteries have ramp rate limits in the BM).

5. Next Steps

Project schedule and stakeholder engagement

Work packages	Scope	Starts in	Duration (Months)	Stakeholder Engagement
WP3 - Impact Assessment - cont	Impact Assessment of CERs based on FES, risk mitigation and impact on costs Counterfactual: Optimising costs and savings	January	3	Power Responsive Webinar (Feb, March) Ad-hoc engagement
WP4 - Monitoring & Implementation	Assess practicalities of adopting recommendations across different asset types and providers e.g. processes, data requirements, communication systems.	Mid-February	2.5	Survey PR Webinar (April)
WP5 - Reporting & Recommendations	Recommendations & Final reporting	May	1	PR Webinar (May)

Next Steps

Working closely with NESO and PR stakeholders to harness the value of CERs

WP3: OM requirements aggregated errors

Input: FES data + Operational scenario (e.g. systems splits)

Assumptions:

- Meter accuracy as per manufacturer
- 10sec, 30sec and 60 sec MeterRead (uniform distribution of measurements)
- 5 sec latency
- Ramp up rates capabilities

Method:

- Stress test modelling and assumptions
- Update and run plexos and sensitivity analysis on adoptions rates

Output:

- Optimised hourly CERs profile over 2035
- Aggregated meter errors due to relaxed requirements

WP3: Mitigation actions and costs associated

Input:

- Aggregated meter errors

Method:

- Use meter reduction methods to reduce overall error
- Mitigate overall meter errors using reserve and response products and control room operational actions
- Assess the cost of mitigating errors over 2035 and operational scenario

Output:

- Mitigation actions and costs
- Meter error acceptable by NESO
- Mitigation error methods to take forward

WP3: Counterfactual

Input:

- CERs marginal costs and Bid/Offer prices
- Mitigation costs
- Cloud and transfer data costs
- Hours/year CERs capacity available to cover all ramping down/up needs of BM

Method:

- Assess savings in BM due to higher CERs penetration (calculate the costs of CERs and next available technology)
- Counterfactual costs/benefits

Output:

Optimised costs/benefits (keeping requirements vs new requirements*)

WP4: Implementation survey

Input:

- Meter error acceptable by NESO
- Mitigation error methods to take forward

Method:

- Survey to evaluate the feasibility of implementation of metering requirements
- Resilience of comm infrastructure
- Mitigation errors implementation and testing

Output:

- CERs OM requirements
- Viable error reduction methods

WP3 additional scope shown in red

Appendix

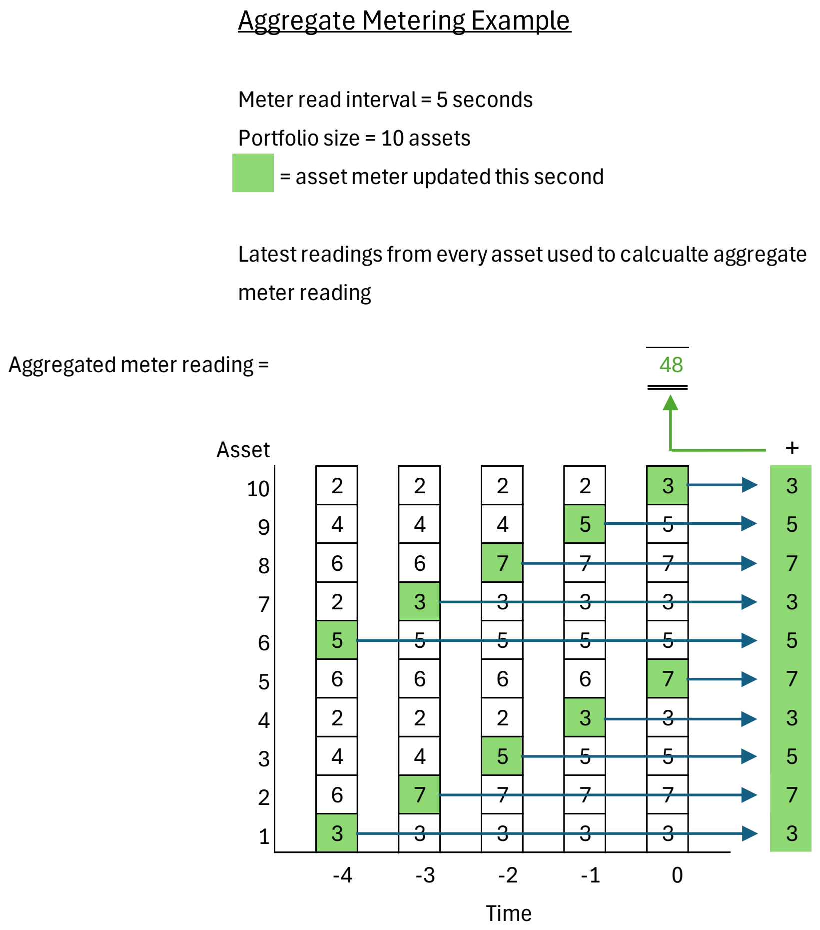
Representation of meter solutions

DNV

Meter aggregation method: Aggregate metering

The latest reading from each asset in the portfolio is used to calculate the aggregate meter reading

Solution Option	Metering Basis	Description
Simultaneous dispatch with aggregate metering (counterfactual, potentially quick simultaneous activation)	Real measurements	All assets are fully activated simultaneously (in our analysis within 2 seconds). The resulting ramp rate of the portfolio is very high. Error is very high (>95%) in the first seconds after ramping begins, since the portfolio achieves its maximum response faster than the measurement interval of most of the asset meters within the portfolio.
Staggered dispatch with aggregate metering	Real measurements	In staggered dispatch activation the assets is spread out over time rather than happening simultaneously. The change in active power of the portfolio occurs gradually and predictably, which enables the ramp to be approximately matched to the capability of the meter read interval to detect changes in portfolio active power. The error from meter read interval is not eliminated, but is spread over a longer ramping period, reducing the magnitude of maximum absolute error observed with simultaneous activation.



Meter aggregation method: Adjusted aggregate metering

The aggregate meter signal is adjusted to correct for error resulting from meter read interval

Solution Option	Metering Basis	Description
Adjusted aggregated metering (ramp error correction). This method performs best in combination with staggered dispatch	Real measurements plus artificial adjustment (based on ramp of aggregate meter read signal)	A weighted average smoothened ramp factor is added to the aggregate meter signal, this compensates for error from readinterval, especially during ramping. This adjustment is based on the change in aggreged portfolio power in the previous x seconds (2.5-15 seconds was analysed during our study, depending on readinterval). The above approach is one method to adjust the aggregate meter error, it is possible that other methods exist which might have better performance.

<u>Adjusted aggregate metering example</u>

Meter read interval = 5 seconds

Portfolio size = 10 assets

■ = asset meter updated this second

Aggregate meter reading = current sum + (smoothened ramp x timelag)

Smoothened ramp = ramp x (weights (1, 1/2) / sum of weights)

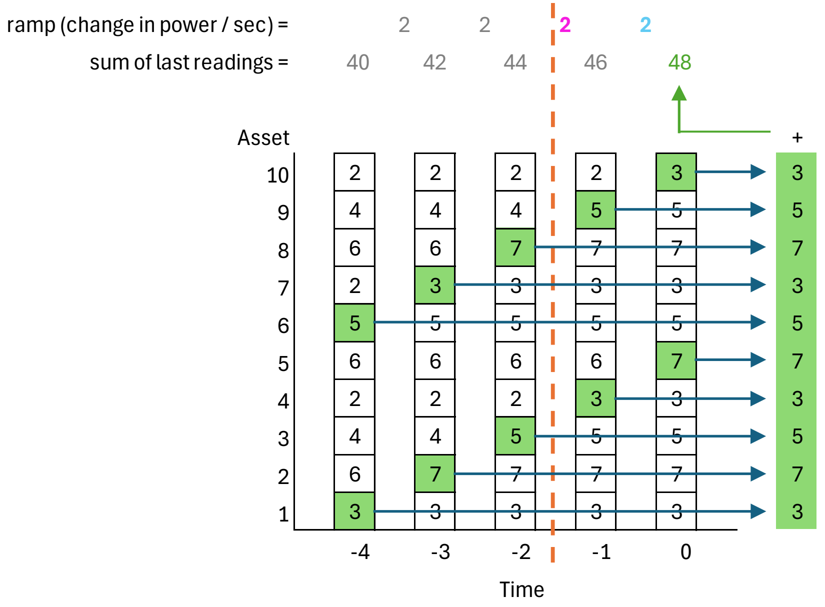
timelag = (meter interval - 1) / 2 = (5-1)/2 = 2 seconds

<u>Adjustment calcuation for t=0</u>

	ramp	x	weights			sum (t=0, t=1)		smoothened ramp
t=0	2	x	(1) / (3/2)	=	+	0.66	=	2
t= -1	2	x	(1/2) / (3/2)	=		1.33		

sm'd. ramp	x	timelag	=	adjustment
2	x	2	=	4

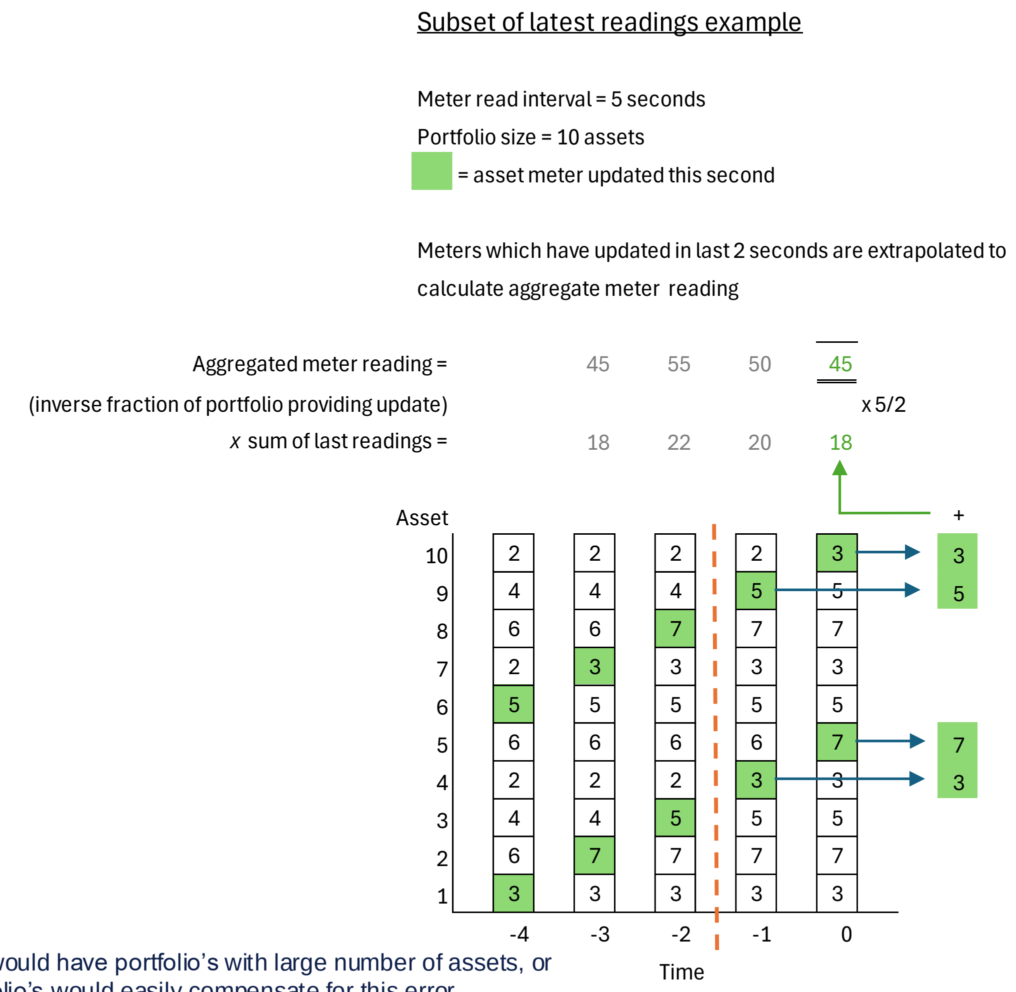
	current sum	+	adjustment	=	current sum
Aggregated meter reading =	48	+	4	=	52



Meter aggregation method: Subset of latest meter readings

The most recent asset meter readings received (e.g. within 3-10 secs) are extrapolated to calculate the portfolio meter reading

Solution Option	Metering Basis	Description
Subset of latest meter readings with staggered dispatch	Most recent real measurements multiplied by a factor (total portfolio power / assets within latest signal range) to estimate total portfolio power output	Latest readings from the previous x seconds (3, 5, 6 and 10 seconds was analysed in our study, depending on readinterval) are used to establish the aggregated meter reading, for instance 10% of the portfolio. The output of those assets is multiplied to estimate the total power output of the portfolio. Using the latest updates will reduces the timelag between active power and visibility in the meter readings but increases the standard deviation around the remaining mean error. All measurements are taken into account even if it is not different compared to the last measurement
Subset of latest meter readings with simultaneous activation	As above	Method as above. Subset of latest meter readings techniques is applicable to both short and long ramp timeframes, and so its performance was assessed with simultaneous activation.



10 assets are shown just to show how the method works. In reality, you would have portfolio's with large number of assets, or the impact of 1 portfolio on the system would be so small that other portfolio's would easily compensate for this error.

Meter aggregation method: Timeshifted

The time lag introduced by meter read interval of the assets is calculated, and the timestamp of the aggregated signal is changed accordingly. This solution does not correct the error in real-time; it provides an accurate reading after a delay equal to timelag.

Solution Option	Metering Basis	Description
Staggered dispatch plus timeshifted aggregation	Real measurements plus artificial adjustment at beginning and end of ramp	With staggered dispatch, the aggregate meter reading lags behind by (readinterval-1)/2 seconds. By shifting timestamps earlier by this lag amount, we can largely eliminate the mean error. At the start and end of the timeframe, additional synthetic adjustments are necessary. **The timeshifted signal is not available in real time (available timelag seconds later)** **It works best with a gradual ramp, because an error remains at the point of ramp change (i.e. especially at the start and end of ramping).** **Because this solution is not available in real-time it is not compared with the real time options in the results section which follows.**

Timeshift Example

Meter read interval = 5 seconds

Portfolio size = 10 assets

= asset meter updated this second

Timestamps are changed to account for lag in aggregate meter reading. An additional adjustment is used to reduce the error at the beginning and end of ramp (not shown here)

timelag = (meter interval - 1) / 2 = (5-1)/2 = 2 seconds

Aggregated meter reading =	40	42	44	46	48
Asset					
10	2	2	2	2	3
9	4	4	4	5	5
8	6	6	7	7	7
7	2	3	3	3	3
6	5	5	5	5	5
5	6	6	6	6	7
4	2	2	2	3	3
3	4	4	5	5	5
2	6	7	7	7	7
1	3	3	3	3	3
Time	-4	-3	-2	-1	0
↓	-6	-5	-4	-3	-2