Verified Carbon Standard

Draft VCS Methodology

CN0157

GRID-CONNECTED ENERGY STORAGE SYSTEMS

Draft Version 1.0

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Sectoral Scope 01: Energy (renewable/non-renewable)

This draft methodology was developed by REsurety, Inc., in collaboration with Meta Platforms, Inc., Engie Energy Marketing, Tierra Climate, Inc., and Carbonomics, LLC. collectively on behalf of The Energy Storage Solutions Consortium.

CONTENTS

1 SUMMARY DESCRIPTION

Additionality, Crediting Method, and Mitigation Outcome	
Additionality	Existing facilities: Activity method or Project method Greenfield facilities: Project method
Crediting Baseline	Project method
Mitigation Outcome	Reductions

This methodology quantifies the greenhouse gas (GHG) emission reductions from the operation of grid-connected energy storage systems (ESS). It is globally applicable to both existing and greenfield ESS.

ESS are composed of energy storage technologies (e.g., chemical batteries) of different sizes, which are net consumers of energy (due to round-trip efficiency being less than 100%) with the ability to control timing of dispatch. These technologies have the potential to accelerate the decarbonization of the electric sector by discharging electricity in periods of high carbon intensity (i.e., when the marginal emissions rate (MER) is higher) and charging in periods of lower carbon intensity (i.e., when the marginal emissions rate is lower). Moreover, an ESS can reduce the curtailment of renewable energy resources by charging when the MER is zero. This methodology credits the ESS for operations that achieve GHG emission reductions by accepting a loss in net revenues to increase emissions reductions.

ESS projects today are not financially incentivized to dispatch in a way that maximizes emission reductions. Instead, ESS aim to maximize net revenues, by providing services according to the market prices at the project location, which may or may not align with the marginal emissions rate at the project location. An ESS operating to maximize may result in increased emissions[1], have a net neutral impact, or sub-optimal emission reductions that fall short of the ESS' full potential.

The overall impact of the operation of an ESS in a given time interval can be calculated as a product of the electricity either charged (i.e., withdrawn from the grid) or discharged (i.e., injected into the grid) by the ESS and the marginal emissions rate at its location in the same time interval. The net emissions impact of the ESS project can be calculated over a selected time period as the sum of the emissions impacts in each time interval.

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[1] Induced emissions from energy storage are a phenomenon that is well explored in published literature. For more information on how and why this may occur, see Hittinger and Azevedo (2015) and Konet et al. (2023).

2 SOURCES

This methodology uses the most recent version of the following tool:

- *VT0009 Combined Baseline and Additionality Assessment*

3 DEFINITIONS

Ancillary services (A/S)
Ancillary services help balance the transmission system as it moves electricity from generating sources to retail consumers.[2] Wholesale market operators procure ancillary services from facilities to keep the grid in balance, and ESS can sell one or more of those ancillary services. Examples of A/S include frequency regulation, spinning reserves, and non-spinning reserves.

Dispatch
The charging and discharging of electricity of an ESS. To maintain a constant sign convention, we will assume that the injection of electricity into the grid (discharging) is a positive dispatch value, and the utilization of grid electricity (charging) is a negative value.

Energy storage system (ESS)
For the purpose of this methodology, energy storage indicates only grid-connected systems that can charge electricity that is produced at a given time, store it and discharge for future use, and do not produce direct greenhouse gas emissions from their dispatch. Examples include but are not limited to battery energy storage systems (BESS), compressed air energy storage systems, and flywheels.

Energy services (E/S)
The sale or purchase of electricity by an ESS through a wholesale market.

Existing ESS
Existing ESS projects are defined as having already started commercial operations or construction work.

Greenfield ESS
Greenfield ESS projects are defined as projects that have started construction work at the time of project validation.

Grid-connected electricity generation
The generation of electricity primarily for delivery to a national or regional grid where at least 50% of annual electricity generation (by quantity of energy, not capacity) is planned to be

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[2] https://learn.pjm.com/three-priorities/buying-and-selling-energy/ancillary-services-market.aspx

delivered to such a grid. Generation of electricity for on-site self-consumption, delivery to a micro-grid, distributed mini-grid, or off grid consumption is not included in this definition.

Grid region
A defined geographical area where electricity generation, transmission, and distribution are managed and operated under a unified market structure, regulatory framework, or coordination entity. In the context of electricity markets, a grid region may correspond to a Regional Transmission Organization (RTO) or Independent System Operator (ISO) in the U.S. or a national electricity market outside the U.S. and can also include sub-regions with distinct operational or market rules.

Marginal emissions rate (MER)
The emissions per unit of energy (tCO_2e/MWh) of the marginal generator where the marginal generation is resulting from the increase or decrease of an incremental unit of energy (e.g., one MWh) at a given location and point in time. This emissions rate is a function of the marginal generator(s) at that moment in time, the efficiencies of those generators and the type of fuel they consume, congestion on the transmission grid, and their locations on the grid relative to the location of the ESS. The MER is constantly changing as variations in real-time electricity supply and demand impact which generators are marginal.

Marginal cost
The cost of producing one additional unit of electricity.

Marginal generator
The unit(s) in an electric grid that are “on the margin”, i.e., the unit(s) that respond to changes in system demand by increasing or reducing output. There may be more than one marginal generator in an electric grid at any given time due to transmission constraints. Any grid-connected generator may be marginal, with technologies including coal, gas, oil, wind, solar, and nuclear, among others.

Merit order
A ranking of available power generation units based on their marginal costs, from the lowest to the highest. The units with the lowest marginal costs are dispatched first.

Net revenues
The sum of the revenue from producing A/S, revenue from producing E/S when discharging, and cost of purchasing E/S when charging.

Organized wholesale power market
Also known as an organized electricity market, regional transmission organization (RTO), or independent system operator (ISO), an Organized Wholesale Power Market is a structured marketplace where electricity is bought and sold in bulk. The market must have independent management and transparent market-based pricing, where generation is dispatched in merit-order and prices are established by marginal generators.

Perfect hindsight (PHS)

An ex-post schedule of operation of an ESS derived from an optimization model in order to maximize net revenues from ESS operation, taking into consideration commercial strategies to provide E/S and A/S. The PHS quantifies the total volume of electricity (MWh) in each hour that would have been dispatched by the ESS assuming that the price of E/S and A/S were known at the time of dispatch. PHS dispatch is calculated using an open-source, publicly available and reputable model as detailed in *Appendix IV: Description of the DER VET model*.

Regulated Power Market

A power market structure where a utility company owns and controls the entire flow of electricity from generation to the customer's meter. This includes owning generation and transmission infrastructure and dispatching generation assets to meet customer demand.

Round trip efficiency

When batteries are charged with electricity from the grid, some power is lost. When batteries discharge this electricity back to the grid, some is lost as well. The total percentage of electricity that is withdrawn from the grid and returned to the grid via a battery system (total power minus losses to/from the ESS) is referred to as round-trip efficiency.

State of Charge (SOC)

A measure of the amount of energy currently stored in an ESS compared to its maximum energy capacity, typically expressed as a percentage. It provides an indication of how much usable energy remains in the ESS.

Spearman Rank Correlation Coefficient

A measure of the strength of a monotonic function between two variables, which is used to describe whether there is a relationship between power prices and the MER on a grid. ESS in grids with a weak correlation would charge and discharge at different intervals depending on whether they are maximizing for revenue generation or minimizing MER.

4 APPLICABILITY CONDITIONS

This methodology is applicable to existing and greenfield energy storage systems (ESS). It is globally applicable.

This methodology is applicable under the following conditions:

1) The ESS technology employed is capable of both storing electrical energy from the grid and dispatching stored energy back to the grid, including chemical, flow, and thermal batteries, compressed air energy storage (CAES), pumped hydro storage, mechanical storage (e.g., capacitors, flywheels), and gravity storage.

2) Existing ESS included in the project activity operate under the revenue maximization scheme prior to the project start.
3) The ESS must be directly connected to the grid.
4) Existing ESS operate in an organized wholesale power market. Greenfield ESS may operate in organized wholesale power markets or regulated power markets where MER data can be calculated, provided the MER data conforms to the requirements outlined in *section 9.4* and *Appendix V: Description of the MER Estimation Method*.
5) ESS fire suppression systems do not release chlorofluorocarbons, hydrochlorofluorocarbons, or uncontained substances with global warming potential greater than 5000 when deployed and comply with the relevant industry standards for the BESS siting and application. Some examples of potential standards include the following: NFPA 855, UL 9540A, IEC 62933-5-2, FM Global 5-33, EN 50272-2.
6) ESS demonstrates conformity with the design, operations, and disposal specifications of the ESS technology deployed as required by local/national regulations in the jurisdiction where the activity is implemented. If domestic regulations do not exist, internationally available best practices for ESS operations must be followed.
7) ESS has not reached the end of the rated lifetime of the ESS (provided by the manufacturer of the ESS). Crediting of an ESS may still continue after the rated lifetime has been reached within the crediting period, but in this case the ESS operator must replace the technology with an identical one that provides at least the same level and quality of service.
8) For existing ESS that are using the activity method (positive list) to demonstrate additionality, the project activity must be connected to one of the grids listed in *Appendix III: Spearman Correlation Analysis*.

This methodology is not applicable under the following conditions:

9) The project activity is located in jurisdictions where an ETS is in place.
10) The project activity includes facilities that participate in schemes that require the provision of carbon-free energy on a continuous basis (e.g., 24/7 renewable energy commercial constructs).[3]
11) The project activity includes other types of storage technologies that produce operational emissions, behind-the-meter (BTM) energy storage systems, or off-grid applications.

Note — There is no requirement regarding the location of the ESS system within the power grid. Further, there is no minimum or maximum project size.

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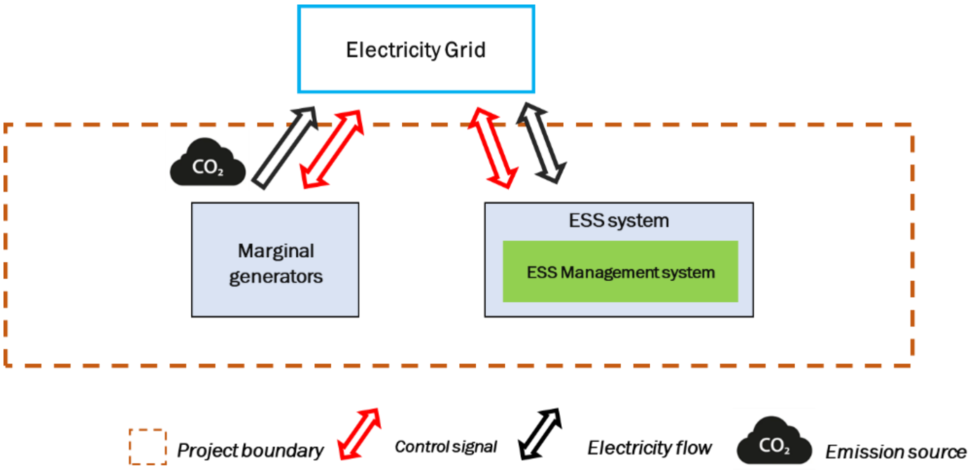
[3] For a description of the 24/7 carbon free energy please visit this website

5 PROJECT BOUNDARY

The spatial extent of the project boundary encompasses the physical location of the ESS and the marginal generator(s), which is the only emission source relevant for the methodology in the applicable grid region.

The following diagram presents a schematic view of the project boundary.

Figure 1. Project boundary



The following table shows the main emission sources that are included within the boundary of the project. CO_2 emission sources are required to be included in the project boundary. Other gases that can be converted to CO_2 equivalent, such as CH_4 and N_2O should be included in the project boundary if available.

Table 1. GHG sources included in or excluded from the project boundary

Source		Gas	Included?	Justification/Explanation
Baseline	Grid connected (fossil fuel) power plants	CO_2	Yes	Major source, included in the calculations of MER
		CH_4	Yes	Minor source, if available, included in the calculations of MER
		N_2O	Yes	Minor source, if available, included in the calculations of MER
		Other	No	Not relevant for MER calculation
Project	Electricity dispatch for the ESS operations	CO_2	Yes	Major source, included in the calculations of MER
		CH_4	Yes	Minor source, if available, included in the calculations of MER
		N_2O	Yes	Minor source, if available, included in the calculations of MER
		Other	No	Not relevant for MER calculation

6 BASELINE SCENARIO

This section prescribes the procedure for determination of baseline scenario for existing and greenfield ESS. To be considered "greenfield", project proponents must demonstrate that the project is neither under construction nor commercially operating. If a project has begun construction, project proponents fall under the baseline determination and additionality demonstration tests outlined for existing facilities, as described in *section 6.1 and section 7.1* below respectively. If construction has not started, project proponents must use the baseline determination and additionality demonstration tests outlined for greenfield facilities, as described in *section 6.2* and *section 7.2* below respectively.

6.1 Existing ESS

For existing ESS operated to optimize emission reductions, the baseline scenario is the continuation of the existing operating mode, where the ESS is operated to maximize revenues and there is no financial incentive to optimize for reduce emissions[4].

6.2 Greenfield ESS

To determine the baseline scenario for greenfield ESS projects that optimize for emission reductions, proponents must follow the procedures and requirements of Step 1 to 3 in the most recent version of *VT0009 Combined Baseline and Additionality Assessment,* as indicated in the following.

6.2.1 Step 1a: Define Alternative Scenarios to the Proposed Project Activity

The alternative scenarios that must be considered are:

1) **S1:** The proposed project activity (i.e., the greenfield ESS operated to optimize emission reductions) implemented without being registered under a GHG program
2) **S2:** The continued operation of the electricity grid without implementation of the greenfield ESS.
3) **S3:** The implementation of a greenfield ESS operated to maximize revenues

Note – These are the only alternative scenarios that must be assessed in the next steps. The procedures and requirements of Step 1a of VT0009 *do not need to be applied.*

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[4] Additional information and analysis are provided in *APPENDIX II: ACTIVITY METHOD*

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6.2.2 Step 1b: Consistency with Mandatory Applicable Laws and Regulations

Follow the procedures and requirements of *VT0009* to identify the alternative scenarios from Step 1a that comply with all mandatory applicable legal and regulatory requirements within the applicable geographic region.

Where the only alternative scenario is S1, the proposed project activity is not additional. Otherwise, proceed to Step 3 of *VT0009* (investment analysis).

Note – Step 2 of VT0009 *(barrier analysis) is not applied under this methodology.*

6.2.3 Step 3: Investment Analysis

The objective of Step 3 is to compare the economic or financial attractiveness of the alternative scenarios remaining after Step 1 by conducting an investment analysis. The analysis must include all alternative scenarios that comply with all mandatory applicable legal and regulatory requirements in Step 1b.

The investment analysis must be conducted in accordance with the procedures and requirements in *VT0009*, applying "Option 1: Investment comparison analysis." The project proponent must calculate either the NPV or IRR for S1 and S3 if they remain after Step 1. For scenario S2, apply the following value, depending on the financial indicator selected:

a) The NPV is equal to zero.
b) The IRR is equal to the financial benchmark as determined in Appendix 2 of *VT0009*.

Where the sensitivity analysis confirms the result of the investment comparison analysis per steps 3-5 in section 5.4.1 of *VT0009*, the baseline scenario is the most economically or financially attractive alternative scenario. Where S1 is the baseline scenario, the project is not additional.

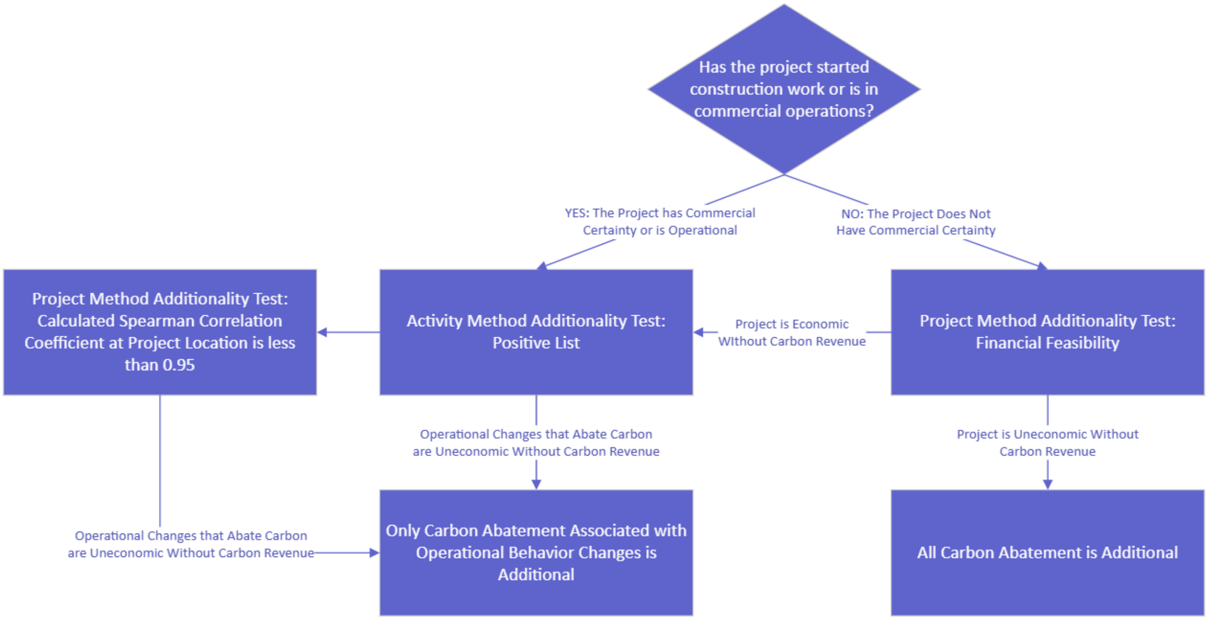
Where the sensitivity analysis is not conclusive per steps 3-5 in section 5.4.1 of *VT0009*:

1) Where S1 remains one of the most economically or financially attractive alternative scenarios within the range of uncertainty, S1 is the baseline scenario, and the project is not additional.
2) Where S2 and S3 (without S1) remain the most economically or financially attractive alternative scenarios within the range of uncertainty, the one with the lower emissions is the baseline scenario.

7 ADDITIONALITY

For existing ESS that meet all the applicability conditions, additionality is demonstrated by an activity method (positive list). Greenfield ESS or existing ESS that do not meet the positive list must follow the project method for demonstration of additionality. Additionality is thus demonstrated as presented in Figure 2 below.

Figure 2. Decision Tree for Additionality Test



7.1 Existing ESS

Additionality for Existing ESS (activity method)

Additionality is demonstrated based on the activity method applying the following steps:

<u>Step 1: Regulatory Surplus</u>

Project proponents must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the latest version of the VCS Methodology Requirements.

<u>Step 2: Positive List</u>

Criteria in the applicability conditions that corresponds to the positive list criteria for the demonstration of additionality under the activity method is condition 9. The project must demonstrate that it meets all applicability conditions, and in so doing, it is deemed as complying with the positive list. The positive list was established utilizing Option B Financial feasibility, according to the latest version of the VCS Methodology Requirements.

Detailed assessment of the activity method is provided in *APPENDIX II: ACTIVITY METHOD*

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Additionality for Existing ESS (project method)

Step 1: Regulatory Surplus

Project proponents must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the latest version of the *VCS Methodology Requirements*.

Step 2: Implementation Barriers

For existing ESS that meet all applicability conditions *except* applicability condition 8 (positive list jurisdiction), project proponents must conduct a project-level analysis to demonstrate the Spearman rank correlation coefficient between the MER and real-time energy price at an hourly or sub-hourly granularity for one calendar year prior to project registration. Where the Spearman rank correlation coefficient does not exceed 0.95, proceed to Step 3: Common Practice. Otherwise, the project is not additional.

Step 3: Common Practice

Project proponents must demonstrate that the project is not common practice using section 4 of *VT0009*,
Where the analysis confirms that the project is not a common practice and passes all previous steps of the additionality analysis, the project is additional. If the project is considered common practice, it is not additional.

7.2 Greenfield ESS

Additionality for Greenfield ESS (project method)

Step 1: Regulatory Surplus

Project proponents must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the latest version of the *VCS Methodology Requirements*.

Step 2: Implementation Barriers

Project proponents must demonstrate that the project faces an investment barrier. To demonstrate an implementation barrier, the project proponent may follow the latest version of the VCS Tool *VT0008 Additionality Assessment*. Investment barriers must demonstrate that the ESS facility is not economically or financially feasible without the revenue from the sale of Verified Carbon Units. This could include an inability to secure offtake and/or financing without the sale of VCUs or can be demonstrated through a benchmark analysis, (i.e. use of an indicator such as Net Present Values (NPV) or Internal Rate of Return (IRR) or another indicator suitable for the sector) and evaluate against a selected benchmark. The input values that will be used to perform the additionality test as described above are those valid at the moment of the investment decision.

Step 3: Common Practice

Project proponents must demonstrate that the project is not common practice using the following formula, which demonstrates penetration level of energy storage technology:

$$P_{ESS_{y,r}} = \frac{I_{ESS_y}}{G_{fossil_y}} \quad (1)$$

Where:

$P_{ESS_{y,r}}$	=	Penetration of ESS in reference year y and grid region r
I_{ESS_y}	=	Total MWhrs of injected power from all ESS in reference year y and grid region r
G_{fossil_y}	=	Total fossil fueled electricity generation in MWhrs in reference year y and grid region r
y	=	A continuous 12 month reference period within the prior 2 years
r	=	Grid region in which the project will operate

To fully decarbonize electricity, fossil fuel generation must be replaced with a combination of baseload carbon-free generation (such as nuclear or geothermal), variable renewable production, and ESS. Grid regions are capacity-balanced, meaning the existing generation stack in a grid region is sufficient to meet demand.

This penetration test compares the total potential injection from ESS, regardless of operating strategy, with the total fossil-fuel-generated electricity required to balance supply and demand. If exceeds 20%, ESS activities are considered common practice, and the methodology does not apply.

The data to support this common practice analysis is publicly available in many grid regions. If it is not publicly available, project proponents may produce an estimate for the above based on in the installed capacity of fossil fuel power plants and ESS.

Where the analysis confirms that the project is not a common practice and passes all previous steps of the additionality analysis, the project is additional. If the project is considered common practice, it is not additional.

8 QUANTIFICATION OF REDUCTIONS AND REMOVALS

8.1 Baseline Emissions

8.1.1 Baseline emissions for existing ESS

For existing facilities, baseline emissions is the emissions impact that would have been achieved following the dispatch scenario where the ESS operator would be maximizing the revenues following the price signal to charge and discharge the ESS. Emissions impact can be positive (induced emissions), negative (emission reductions), or zero (neutral impact). The project emissions impact are then subtracted from the baseline emissions impact to calculate net reductions in emissions.

This methodology outlines two distinct methods of calculating the baseline emissions for existing facilities. The first, Dynamic Baselining, establishes the baseline via an operator's historical price forecasts, operating constraints, and production optimization model. Dynamic Baselining requires the following conditions be met:

1) Use an optimization model that includes a MER forecast and carbon price as inputs
2) Store timestamped historical forecasts feeding the production (live) optimization model
3) Store timestamped parameters feeding the production optimization model, including carbon price

4) Comply with the VCS model requirements outlined in the *VCS Methodology Requirements*

If Dynamic Baselining conditions are not met and the ESS has three full years of operating data, project developers must use Approach 2, Performance-Adjusted Universal Dispatch Model, which establishes a more conservative baseline via a performance-adjusted "perfect hindsight" dispatch from a universal, open-source optimization model called DER-VET.

If Dynamic Baselining conditions are not met and a project developer does not have three years of operating data, the ESS may not participate in the methodology.

Approach 1: Dynamic Baselining

The steps to define a dynamic baseline are as follows:

1. Establish the baseline
    a) Using supplied timestamped parameters and supplied timestamped historical forecasts, backcast a battery's optimal dispatch schedule with a carbon price of $0/ton to produce a set of counterfactual bids and offers. This backcast should have the same interval granularity as the data used to calculate Project Emissions and as required by the data requirements outlined in *section 9.4*. Heretofore, this time granularity will be referred to as an "interval".

       For each interval, simulate E/S and A/S awards using the counterfactual bids and offers against realized prices and model impact to the ESS state of charge (SOC) to produce a counterfactual dispatch schedule. If the ESS would have been a marginal provider of the E/S or A/S (i.e., bid price equal or higher than the realized price), assume the A/S or E/S was not awarded to the ESS.

       Note – this eliminates the potential for the counterfactual to be inflated by a dispatch schedule that is not volumetrically feasible

    b) Calculate baseline emissions by multiplying counterfactual dispatch schedule by MER to establish baseline emissions, given by:

$$BE_y = \sum_{i=0}^{n} A_{baseline,i,y} \times (E_{i,y}) \times (-1) \qquad (2)$$

Where:

$A_{baseline,i,y}$ = Estimated real-time electricity dispatch inclusive of E/S and A/S deployment, (positive for discharging, negative for charging) in case the ESS is operated to maximize net revenues in interval *i* at project location in crediting period y (MWh)

n = Total number of intervals in crediting period (integer)

$E_{i,y}$ = MER in interval *i* at project location in crediting period y (tCO_2e/MWh)

2. Calculate project emissions PE_y as described in *section 8.2*.

3. Forecast Verification to calculate appropriate discount factor:

a) Using the same supplied timestamped parameters and supplied timestamped historical forecasts as step 1, backcast a battery's optimal dispatch schedule with timestamped carbon price used in real operations to produce a set of expected bids and offers.

b) For each interval, simulate E/S and A/S awards using the expected bids and offers against realized prices and model impact to the ESS SOC to produce the expected dispatch schedule.

c) Calculate the expected emissions by multiplying the expected dispatch schedule by the marginal emissions rate, given by

$$E_{expected,y} = \sum_{i=0}^{n} A_{expected,i,y} \times (E_{i,y}) \times (-1) \quad (3)$$

Where:

$A_{expected,i,y}$ = Estimated electricity dispatch (positive for discharging, negative for charging) in case the ESS is operated to reduce emissions at a given carbon price in interval *i* at project location in crediting period y (MWh)

n = Total number of intervals in crediting period (integer)

$E_{i,y}$ = MER in interval *i* at project location (tCO_2e/MWh) in crediting period y

d) Calculate EE_y, the emissions error (tCO_2e) in crediting period y, as follows:

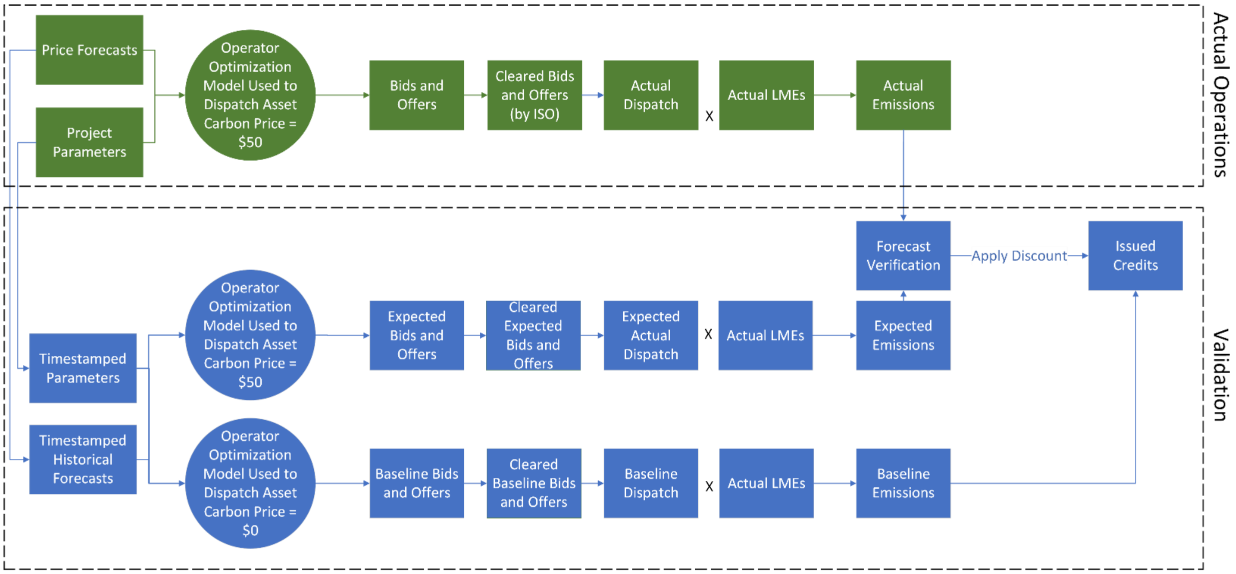
$$EE_y = abs\left(E_{expected,y} - PE_y\right) \quad (4)$$

Where:

PE_y = Project emissions in crediting period y (tCO_2e) (described in *section 8.2*)

A simplified visual diagram of this entire process is given below for an optimization with a carbon price set to \$50/tCO_2e for illustrative purposes:

Figure 3. Example diagram demonstrating the steps required for Dynamic Baselining



Approach 2: Performance-Adjusted Universal Dispatch Model

When an operator cannot meet the requirements set forth in Dynamic Baselining but has three years of historical operating data, the estimation of the baseline emissions will be performed ex-post calculating the scenario utilizing PHS that maximizes net revenues ($PHS_{revenues}$). This mode of operation represents the maximum revenue an ESS could achieve if it had knowledge of prices ahead of making dispatch decisions. In reality, it is impossible for an ESS to achieve the revenue associated with PHS dispatch. To account for an operator's ability to achieve this maximum revenue value, the methodology incorporates a project-specific variable representing how close they have been to achieving $PHS_{Revenues}$ historically. This project-specific variable is a performance-based metric calculated by comparing the most recent three years of historical data for marginal emissions rates against those of $PHS_{Revenues}$ using the optimization model, bounded between zero and one. This is called the performance factor (PF) as shown in the following equation:

$$PF = \max\left(\min\left(\frac{\sum E_{actual,x}}{\sum E_{PHS,revenues,x}}, 1\right), 0\right) \quad (5)$$

Where:

PF = Performance factor of the ESS operation's demonstrated ability to approach perfect hindsight for maximizing profits (fraction bounded between [0,1])

$E_{actual,x}$ = Actual emissions in the historical situation, based on actual electricity dispatch and corresponding MER at project location in historical year x (tCO_2e)

$E_{PHS,revenues,x}$ = GHG emissions that would have been generated by the ESS operation at project location if perfectly following the PHS for maximizing profits without consideration of the MER to operate the ESS in historical year x (tCO_2e)

x = [-1, -3] Historical three years prior to the start date of the project activity

$E_{actual,x}$ is calculated as follows:

$$E_{actual,x} = \sum_{i=0}^{n} A_{i,x} \times (E_{i,x}) \times (-1) \tag{6}$$

Where:

$A_{i,x}$ = Actual project electricity dispatch (negative for charging, positive for discharging) in interval i at project location in historical year x (MWh)

n = Number of intervals in crediting period (integer)

$E_{i,x}$ = MER in interval i at project location in historical year x (tCO_2e/MWh)

The estimated emissions under the $PHS_{revenues}$ scenario are calculated as follows:

$$E_{PHS,revenues,x} = \sum_{i=0}^{n} A_{PHS,revenues,i,x} \times (E_{i,x}) \times (-1) \tag{7}$$

Where:

$A_{PHS,revenues,i,x}$ = Estimated electricity dispatch (negative for charging, positive for discharging) in case the ESS is operated to maximize net revenues in interval i at project location in historical year x (MWh)

n = Total number of intervals in crediting period (integer)

$E_{i,x}$ = MER in interval i at project location in historical year x (tCO_2e/MWh)

This performance factor will be used to limit the volume of emission reductions to an upper range of baseline emissions that is demonstrably achievable by the operator.

With PHS data for E/S and A/S prices, dispatches done under a revenue-maximizing approach will be determined using DER-VET, an open-source optimization model that utilizes a set of parameters that reflect the operation of the ESS in a specific location. By multiplying the site-specific performance factor by the emissions from the PHS dispatch schedule, we can quantify the baseline emissions of an ESS in year y once the ESS has implemented project activity in year y. It should be noted that even when maximizing profits, the emissions impact at PHS$_{\text{revenue}}$ could itself result in a negative value, while the demonstrated emissions of the project could be positive. This would create a PF that is negative, which would cause unintended effects in the baseline calculation. To account for this possibility and to ensure conservativeness in the baseline estimation, the PF is bounded between [0 and 1]. If the calculated PF is negative, the PF is set to 0. If the calculated PF is greater than 1, the PF is set to 1, per equation 4. We set the baseline emissions to the minimum of PHS with and without the performance factor. Finally, we apply a model correction factor to account for model uncertainties in accordance with IPCC good practice guidance. This model correction factor modifies the baseline to be two percent more conservative and is therefore set to 0.98 for baseline emissions greater than zero, and 1.02 for baseline emissions impact less than zero. The baseline emissions impact must be calculated as follows:

$$BE_y = \min\left(E_{PHS,revenues,y} * PF\ , E_{PHS,revenues,y}\right) * UF_{BL} \qquad (8)$$

And

$$UF_{BL} = \begin{cases} 1.02, & for \quad \min\left(E_{PHS,revenues,y} \times PF\ , E_{PHS,revenues,y}\right) \leq 0 \\ 0.98, & for \quad \min\left(E_{PHS,revenues,y} \times PF\ , E_{PHS,revenues,y}\right) > 0 \end{cases} \qquad (9)$$

Where:

BE_y	=	Baseline emissions in crediting period y (tCO$_2$e)
$E_{PHS,revenues,y}$	=	Level of emissions that would have been generated by the ESS operation at project location if perfectly following the PHS for maximizing profits without consideration of the MER to operate the ESS in baseline crediting period y (tCO$_2$e)
PF	=	Performance factor of the ESS operation's demonstrated ability to approach perfect hindsight for maximizing profits, according to equation 4) (fraction)
UF_{BL}	=	Model correction factor to account for model uncertainties (default value introduces a 2% correction factor)[5]

The estimated emissions under the *PHS$_{revenues}$* scenario for the crediting period are calculated as follows:

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[5] UNFCCC/SBSTA/2003/10/Add.2, page 25.

$$E_{PHS,revenues,y} = \sum_{i=0}^{n} A_{PHS,revenues,i,y} \times (E_{i,y}) \times (-1) \tag{10}$$

Where:

$A_{PHS,revenues,i,y}$ = Estimated electricity dispatch (positive for discharging, negative for charging) in case the ESS is operated to maximize net revenues in interval i at project location in crediting period y (MWh)

n = Number of intervals in crediting period (integer)

$E_{i,y}$ = MER in interval i at project location in crediting period y (tCO_2e/MWh)

VCUs will be generated when emissions from the ESS operations are below the baseline emissions according to an aggregation for the crediting period. This ensures the consideration of the net impacts on total emission of the ESS and does not exclude periods where the ESS may in fact increase overall emissions.

It should be noted that the baseline emissions could be a negative number while using the revenue-maximizing approach. Thus, emission reductions will only be generated if the ESS operations result in a further reduction of the emissions in the power grid beyond the baseline emissions. Furthermore, emission reductions can only be issued as a net benefit resulting from previous operations, i.e., any instances of occasionally operating with an emission-minimizing approach will be reflected in the project's baseline through calculation of the performance factor, effectively discounting the crediting opportunity in the project activity instance.

8.1.2 Baseline emissions for greenfield ESS

For greenfield facilities, the baseline is set to the minimum emissions associated with the baseline scenario, as identified in *section 6*. If the baseline scenario is S2, the baseline emissions are 0 because no time shifting of energy occurs under S2. If the baseline scenario is S3, the baseline emissions may be calculated using either Dynamic Baselining or Performance-Adjusted Universal Dispatch Model baselining as described above for existing ESS. If there is uncertainty in the baseline between S2 and S3, baseline emissions are calculated using the following formula:

$$BE_y = \min(BE_{S2_y}, BE_{S3_y}) \tag{11}$$

Where:

BE_y = Baseline emissions in crediting period y (tCO_2e)

BE_{S2_y} = 0, Baseline emissions associated with Scenario 2 in crediting period y (tCO_2e)

BE_{S3_y} = Baseline emissions associated with Scenario 3 in crediting period y, calculated using Dynamic Baselining or Performance-Adjusted Universal Dispatch Model baselining (tCO_2e)

8.2 Project Emissions

Project emissions are defined as the emissions impact achieved by the actual ESS operations when the emission signal is followed. This impact can be positive (induced emissions), negative (emission reductions), or zero (neutral impact). The emissions impact is expected to be less positive or more negative than the baseline emissions. Actual project emissions over a given period must be calculated as:

$$PE_y = \sum_{i=0}^{n} A_{i,y} \times (E_{i,y}) \times (-1) \qquad (12)$$

Where:

PE_y = Project emissions in crediting period y (tCO_2e)

$A_{i,y}$ = Actual project electricity dispatch (positive for discharging, negative for charging) in interval i at project location in crediting period y (MWh)

n = Number of intervals in crediting period (integer)

$E_{i,y}$ = MER in interval i at project location in crediting period y (tCO_2e/MWh)

8.3 Leakage Emissions

No leakage emissions are expected under this methodology.

$$LE_y = 0 \qquad (13)$$

8.4 Net Reductions and Removals

GHG emissions reductions are calculated as follows:

$$ER_y = DF_y \times (BE_y - PE_y) \qquad (14)$$

Where:

DF_y = Discount factor as defined below (percentage)

BE_y = Baseline emissions in crediting period y defined by either Dynamic Baselining or Performance-Adjusted Universal Dispatch Model in *section 8.1* (tCO_2e/period),

PE_y = Project emissions in crediting period y defined in *section 8.2* (tCO_2e/period)

Discount Factor for Dynamic Baselining:

DF_y is given by:

$$DF_y = \begin{cases} 1, & for \frac{EE_y}{2 \times EER_y} \leq 8\% \\ 1 - \frac{EE_y}{EER_y}, & for \frac{EE_y}{2 \times EER_y} > 8\% \end{cases} \quad (15)$$

Where:

EER_y = Expected GHG emissions reductions in crediting period y (tCO_2e/period)

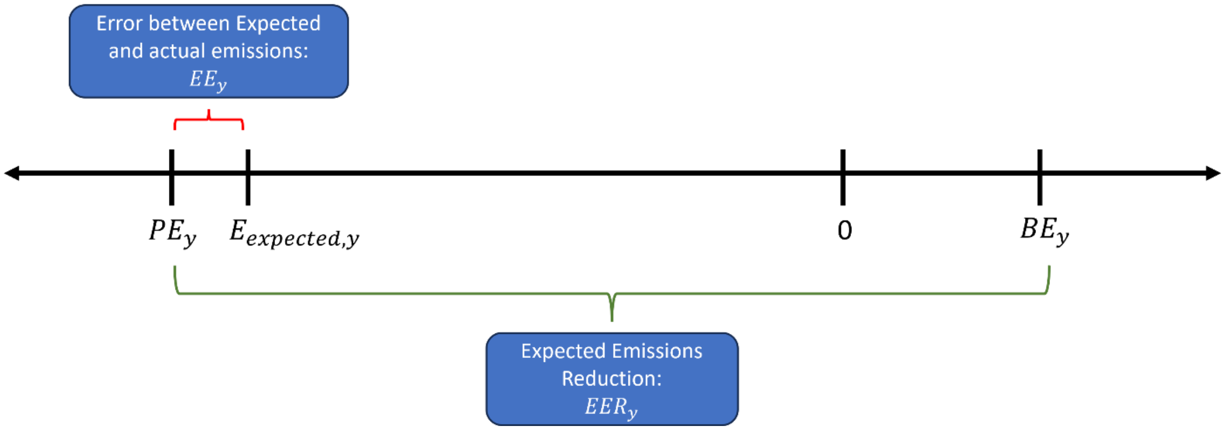
DF_y = Discount factor in crediting period y (percentage)

EER_y is calculated as follows:

$$EER_y = BE_y - PE_y \quad (16)$$

The threshold of 8% that triggers the application of a discount factor is discussed below. To illustrate the values described above, consider the following example.

Figure 4. Diagram representing expected error for emission reduction measurement using Dynamic Baselining



VCUs will be generated when emissions from the ESS operations are below the baseline emissions according to an aggregation for the crediting period and discounted based on expected error in the baseline according to the discount factor, DF_y. This ensures the consideration of the net impacts on total emission of the ESS and does not exclude periods where the ESS may in fact increase overall emissions.

Discount Factor for Performance-Adjusted Universal Dispatch Model:

$$DF_y = 1$$

The DER-VET model is a convex optimization that uses realized power prices as inputs to determine a perfectly optimal dispatch schedule. This dispatch schedule therefore does not contain uncertainty and represents the carbon abatement of an ESS optimizing to maximize revenues given perfect knowledge on realized prices. The baseline is then scaled by the historical performance of the ESS and an adjustment factor is applied for conservatism within the calculation of BE_y. This assures that the baseline dispatch is sufficiently conservative given the uncertainty is 0. The uncertainty associated with PE_y is less than the 6%, which falls below the threshold for which a discount factor must be applied.

Estimating Uncertainty:

Emission reductions are calculated as the difference of baseline and project emissions where both terms are calculated as the product of a dispatch (A_y) and related marginal emission rates (E_y). Equation (14) can therefore be expanded to represent terms that contain uncertainty as follows:

$$ER_y = DF_y \times [(A_{baseline_y} \times E_y) - (A_{actual_y} \times E_y)] \quad (17)$$

To propagate the uncertainty associated with the emissions reduction estimation of an ESS, we consider the following approach:

1) Evaluate the error associated with A_{actual_y}:
    a) The error associated with A_{actual_y} (the measurement of actual dispatch) used for the calculation of project emissions is assumed to be negligible. The actual dispatch data is returned by a revenue-grade electrical meters attached to the ESS project at the point of interconnection. This meter is monitored by the utility and is used to settle power purchases and sales from the wholesale electricity grid. These meters are extremely high fidelity and are not prone to uncertainty, and are calibrated and monitored according to guidance set forth in *section 9.4*.
2) Evaluate the error associated with E_y :
    a) As discussed in *Appendix V: Description of the MER Estimation Method*, MER estimation methods attempt to quantify the emissions impact of marginal generators being re-dispatched in response to incremental generation. Because it is impossible to empirically validate the expected change in emissions for a given

change in dispatch, models that estimate MERs must be validated through natural experiments or grid simulations.

   i) A 2022 article in Environmental Science and Technology, authored by Elenes et al., evaluated different methods of producing marginal and average emissions factors against an electricity system dispatch model to understand how well emissions factors approximate emissions changes, and found that prevailing estimation methods that comply with the data requirements outlined in *section 4*, produce an absolute value of estimation error of less than 6%.
   ii) A 2024 article (preprint) submitted to Elsevier, authored by Koebrich et al., uses hourly CAMD data to calculate the total change in emissions and the corresponding total change in load (adjusted for confounding variables) to produce an empirical MER which is used to evaluate the uncertainty in MER estimation models. This paper finds similarly small errors (<2.9%) for allowable MER estimation methods.
   iii) A 2024 article published by Environmental Science: Energy, authored by Steinsultz et al., uses natural a natural experiment involving variation in relative changes in wind generation potential at wind farms in the ERCOT power grid to examine the relative accuracy of several common classes of MEF models. This paper finds “clear evidence that both the dispatch and statistical MEF models considered can accurately predict the changes in emissions that are caused by changes in net load”.

b) For the purposes of error propagation in this methodology, we consider 6% the upper bound of expected errors referenced in the articles above.

3) Finally, infer the allowable error associated with $A_{baseline_y}$ before a discount must be applied:

The uncertainty associated with the Dispatch schedule for the baseline cannot be explicitly verified because it represents a counterfactual in a world where the carbon market did not invoke action from the ESS. However, the uncertainty can be assessed for existing and greenfield ESS as described below:

a) Using Dynamic Baselining:

The uncertainty can be implicitly verified for Dynamic Baselining as described in Baseline Emissions, Approach 1, Step 3. Per VCS Methodology Requirements, a discount factor must be applied if the uncertainty (halfwidth of the 90 percent confidence interval) exceeds 10% of the estimated value. The allowable error in the baseline dispatch can therefore be solved for using appropriate error propagation technique:

$$\sqrt{0.06^2 + x^2} \leq 0.1$$

$$x = 0.08$$

As such, the DF_y is applied when the uncertainty around the baseline dispatch exceeds 8%, as described in equation (15).

b) Using the Performance-Adjusted Dispatch Model

The DER-VET model is a convex optimization that uses realized power prices as inputs to determine a perfectly optimal dispatch schedule. This dispatch schedule therefore does not contain uncertainty and represents the carbon abatement of an ESS optimizing to maximize revenues given perfect knowledge on realized prices. The baseline is then scaled by the historical performance of the ESS and an adjustment factor is applied for conservatism. This assures that the baseline dispatch is sufficiently conservative given the uncertainty is 0.

c) Greenfield ESS

The baseline for greenfield ESS is 0 and contains no uncertainty. This represents the case where the ESS would not exist and thus would cause no emissions changes to the grid in the counterfactual scenario. The total error uncertainty for greenfield ESS is therefore solely derived from the MER data used to calculate Project Emissions, which is assumed to be 6% (as discussed above). This is below the tolerance band of 10% and therefore no discount must be applied.

9 MONITORING

9.1 Data and Parameters Available at Validation

Data / Parameter	$A_{i,x}$
Data unit	MWh
Description	Actual project electricity dispatch (positive for discharging, negative for charging) in interval i (MWh) at project location in historical lookback year *x*
Equations	6
Source of data	Meter readings
Value applied	To be determined based on specific project circumstances
Justification of choice of data or description of measurement methods and procedures applied	Measurement from a calibrated electricity meter connected to the ESS and metering the exchange of electricity to/from the grid. Monitored continuously and aggregated hourly or daily. Can be crosschecked with invoices from the ESS operator used for financial settlements. The meter will be calibrated and maintained according to national regulations and industry best practices.
Purpose of Data	Calculation of actual emissions in the historical year for existing ESS using Universal Dispatch Model Baselining
Comments	N/A

Data / Parameter	$\mathbf{E_{actual,x}}$
Data unit	tCO_2e/MWh
Description	Actual emissions in the historical year x based on actual electricity dispatch and corresponding MER at project location in historical year x
Equations	5, 6
Source of data	System operators, other providers, or calculated based on available grid data.
Value applied	To be determined based on specific project circumstances

Justification of choice of data or description of measurement methods and procedures applied	Calculation of actual emissions in a historical year to enable calculation of a performance factor to establish the baseline
Purpose of Data	Calculation of the performance factor for an existing ESS using Universal Dispatch Model baselining
Comments	N/A

Data / Parameter	$\mathbf{E}_{\mathbf{i,x}}$
Data unit	tCO_2e/MWh
Description	Marginal emission rate that represents the additional emissions associated with an additional MWh of load at a specific location and time on the electricity grid at project location in historical year x
Equations	6, 7
Source of data	System operators, other providers, or calculated based on available grid data.
Value applied	To be determined based on specific project circumstances
Justification of choice of data or description of measurement methods and procedures applied	The MER is crucial to accurately quantify the emissions associated with ESS operation, ensuring that the methodology captures the true marginal impact of dispatch on grid emissions in year y
Purpose of Data	Calculation of the performance factor for an existing ESS using Universal Dispatch Model baselining
Comments	The calculation methodology for MER will be adapted to the specific design of each electricity market and the available data for calculation. It should be as geographically and temporally high-resolution as possible, accurately capturing the change in emissions due to the change in dispatch

Data / Parameter	ρ
Data unit	Unitless
Description	Spearman rank correlation coefficient, which describes the strength of a monotonic relationship.
Equations	N/A

Source of data	Determined based on MER data and E/S price data as described in *APPENDIX II: ACTIVITY METHOD* .
Value applied	To be determined based on specific project circumstances
Justification of choice of data or description of measurement methods and procedures applied	The Spearman rank correlation coefficient assesses how well the relationship between two variables can be described by a monotonic function. This has more explanatory power for MERs and E/S prices than the Pearson correlation because MERs and E/S prices do not necessarily have a linear relationship.
Purpose of Data	Additionality demonstration
Comments	N/A

9.2 Data and Parameters Monitored

Data / Parameter:	$A_{baseline,i,y}$
Data unit:	MWh
Description:	Estimated electricity dispatch (negative for discharging, positive for charging) in case the ESS is operated to maximize revenue in interval *i* at project location (MWh) in crediting period y
Equations	2
Source of data:	Historical E/S and A/S price forecasts and realized E/S and A/S prices
Description of measurement methods and procedures to be applied:	The value is estimated utilizing the methodology described in *section 8*
Frequency of monitoring/recording:	At least once per crediting period
QA/QC procedures to be applied:	N/A
Purpose of data:	Baseline emissions for an existing ESS using Dynamic Baselining
Calculation method:	Calculated using dispatch model of the ESS

Comments:	N/A

Data / Parameter:	$A_{expected,i,y}$
Data unit:	MWh
Description:	Estimated electricity dispatch (negative for discharging, positive for charging) in case the ESS is operated to reduce emissions at a given carbon price in interval *i* at project location (MWh) in crediting period y
Equations	3
Source of data:	Historical E/S and A/S price forecasts and realized E/S and A/S prices
Description of measurement methods and procedures to be applied:	The value is estimated utilizing the methodology described in *section 8*
Frequency of monitoring/recording:	At least once per crediting period
QA/QC procedures to be applied:	N/A
Purpose of data:	Discount factor calculation, baseline emissions for an existing ESS using Dynamic Baselining
Calculation method:	Calculated using dispatch model of the ESS
Comments:	N/A

Data / Parameter:	$A_{i,y}$
Data unit:	MWh
Description:	Quantity of electricity actually dispatched by the ESS (negative for discharging, positive for charging) in each time interval i at project location in year y
Equations	12
Source of data:	Metered data

Description of measurement methods and procedures to be applied:	Measurement from a calibrated electricity meter connected to the ESS and metering the exchange of electricity to/from the grid. Monitored continuously and aggregated hourly or daily. Can be crosschecked with invoices from the ESS operator used for financial settlements. The meter will be calibrated and maintained according to national regulations and industry best practices.
Frequency of monitoring/recording:	Continuously monitored, recorded hourly
QA/QC procedures to be applied:	The value from the meter must be crosschecked with invoices of the electricity purchase and sale by the project operator
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	$A_{PHS,revenues,i,y}$
Data unit:	MWh
Description:	Estimated dispatch (positive for discharging, negative for charging) in case the ESS is operated to maximize net revenues in interval *i* at project location (MWh) in crediting period *y*
Equations	10
Source of data:	Realized A/S and E/S prices and physical constraints of the ESS
Description of measurement methods and procedures to be applied:	Calculated using the methodology described in *section 8* and *Appendix IV: Description of the DER VET model*
Frequency of monitoring/recording:	At least once per crediting period
QA/QC procedures to be applied:	N/A
Purpose of data:	Calculation of baseline for an existing ESS using the Universal Dispatch Model Baselining
Calculation method:	Calculated using DER-VET
Comments:	N/A

Data / Parameter:	BE_y
Data unit:	tCO_2e
Description:	Baseline emissions in crediting period y
Equations	8, 14, 16
Source of data:	Calculated using a modeling tool coupled with MER data.
Description of measurement methods and procedures to be applied:	The value is estimated utilizing requirements in *section 8*
Frequency of monitoring/recording:	Calculated at the end of the crediting period
QA/QC procedures to be applied:	N/A
Purpose of data:	Calculation of baseline emissions
Calculation method:	Calculated using MERs and dispatch schedules from either DER-VET or the dispatch model of the ESS for Dynamic Baselining or Universal Dispatch Model Baselining
Comments:	N/A

Data / Parameter:	BE_{S3_y}
Data unit:	tCO_2e
Description:	Baseline emissions for baseline scenario 3 in crediting period y
Equations	11
Source of data:	Calculated using a modeling tool coupled with MER data.
Description of measurement methods and procedures to be applied:	The value is estimated utilizing requirements in *section 8*
Frequency of monitoring/recording:	Calculated at the end of the crediting period
QA/QC procedures to be applied:	N/A
Purpose of data:	Calculation of baseline emissions

Calculation method:	Calculated using MERs and dispatch schedules from either DER-VET or the dispatch model of the ESS for Dynamic Baselining or Universal Dispatch Model Baselining
Comments:	N/A

Data / Parameter:	$E_{expected,y}$
Data unit:	tCO_2e
Description:	Expected real world emissions in crediting period y
Equations	3, 4
Source of data:	Calculated using the dispatch model of the ESS coupled with MER data
Description of measurement methods and procedures to be applied:	The value is estimated utilizing the requirements in *section 8*
Frequency of monitoring/recording:	Calculated at the end of the crediting period
QA/QC procedures to be applied:	N/A
Purpose of data:	Calculation of discount factor and estimation of error for an existing ESS using Dynamic Baselining
Calculation method:	Calculated using the dispatch model of the ESS
Comments:	N/A

Data / Parameter:	EE_y
Data unit:	tCO_2e
Description:	Estimated emissions error for real world emissions in crediting period y
Equations	4, 15
Source of data:	Calculated using the dispatch model of the ESS coupled with MER data
Description of measurement methods and procedures to be applied:	The value is estimated utilizing the requirements in *section 8*

Frequency of monitoring/recording:	Calculated at the end of the crediting period
QA/QC procedures to be applied:	N/A
Purpose of data:	Calculation of discount factor and estimation of error for an existing ESS using Dynamic Baselining
Calculation method:	Calculated using the dispatch model of the ESS
Comments:	N/A

Data / Parameter:	$E_{i,y}$
Data unit:	tCO_2e/MWh
Description:	Marginal emission rates represent the additional emissions associated with an additional MWh of load at a specific location and time on the electricity grid in crediting period y
Equations	2, 9, 11
Source of data:	System operators, other providers, or calculated based on available grid data.
Description of measurement methods and procedures to be applied:	The value is estimated utilizing the methodology described in *Appendix V: Description of the MER Estimation Method*
Frequency of monitoring/recording:	Continuously monitored, recorded hourly
QA/QC procedures to be applied:	N/A
Purpose of data:	Calculation of emission error Calculation of baseline emissions Calculation of project emissions
Calculation method:	Estimated value that satisfies the conditions described in *Appendix V: Description of the MER Estimation Method*
Comments:	N/A

Data / Parameter:	EER_y
Data unit:	tCO_2e
Description:	Expected Emission reductions in crediting period y

Equations	14, 15
Source of data:	Calculated using the dispatch model of the ESS coupled with MER data
Description of measurement methods and procedures to be applied:	The value is estimated utilizing the requirements in *section 8*
Frequency of monitoring/recording:	Calculated at the end of the crediting period
QA/QC procedures to be applied:	N/A
Purpose of data:	Calculation of discount factor for and existing ESS using Dynamic Baselining
Calculation method:	Calculated using the dispatch model of the ESS
Comments:	N/A

Data / Parameter:	$E_{PHS,revenues,y}$
Data unit:	tCO_2e
Description:	Estimated emissions under the perfect hindsight scenario for crediting period y
Equations	8, 9, 10
Source of data:	Realized A/S and E/S prices and MER data
Description of measurement methods and procedures to be applied:	Calculated using the requirements described in *section 8* and *Appendix IV: Description of the DER VET model*
Frequency of monitoring/recording:	Calculated at the end of the crediting period
QA/QC procedures to be applied:	N/A
Purpose of data:	Calculation of baseline for existing ESS using the Universal Dispatch Model baselining
Calculation method:	Calculated using DER-VET
Comments:	N/A

9.3 Description of the Monitoring Plan

Project proponents must establish a reliable and transparent monitoring plan including procedures for obtaining, recording, compiling, and analyzing monitored data and parameters.

All data collected must be recorded and stored (physically and/or electronically, as needed) for at least 2 years after the completion of the last monitoring period. Where meters are required, the project participant must adhere to revenue-grade meter standards and ensure consistency with calibration requirements as mandated by industry standards and national regulations. The monitoring plan will clearly describe the roles and responsibilities, as well as required skills, for the staff involved in the monitoring activities. The monitoring plan will provide clear guidance on how to perform the monitoring, what data will have to be collected and at what frequency, as well as procedures for analysing and processing the data gathered to demonstrate additionality and to estimate GHG emissions for both baseline and project scenario.

Regarding the list of parameters listed in *section 9.2*, project proponent must describe the procedures and devices for collecting and reporting all data and parameters. The monitoring plan must cover at least the following data and information:

- Parameters to be monitored, especially quantity of electricity dispatched (charging and discharging) by the ESS, the MER
- A description of each monitoring task to be undertaken, and the technical requirements therein
- Expected frequency of the monitoring of each parameter
- Data archiving procedures, both in physical form and through the use of digitalized databases

The monitoring plan will also describe QA/QC procedures that will increase the confidence and accuracy of the monitoring results and the correctness of the calculations. It will also allow detecting potential errors or hardware malfunctions and provides options to address them. The QA/QC procedures will cover (non-exhaustive list):

- Ensure integrity of hardware (e.g., meters) and of the recorded data
- Ensure compliance with industry standards and domestic regulations
- Checking data quality (e.g., identification of outlier values, detect material errors in data collection and recording, transcription mistakes, etc.)
- Checking results of calculations (re-perform the calculation to detect errors that may have occurred, compare results also with previous series to identify potential errors (e.g., order of magnitudes)
- Ensure involved staff is properly trained and has the required expertise for the tasks to be performed
- Data sources and calculation methods are duly described and documented

9.4 Data Requirements

ESS must be operated in a power market for which marginal emissions data and electricity dispatch data of sufficient granularity and reliability are fully available. Existing ESS using DER-VET to calculate the baseline must be operated in a power market for which price data of sufficient granularity and reliability are fully available. Specifically, this means the following:

a) Marginal Emissions Data:

  i) Reliability: The marginal emissions data must either be sourced from publicly available government or grid operator sources or from other sources that can be accessed and verified by third parties if requested (e.g., paid datasets, data from professional providers) in accordance with the VCS standard.

  ii) Granularity: This data must be available at hourly or sub-hourly granularity for the relevant location of the project. The geographic granularity must be no coarser than the grid in which the project operates, and preferably is higher resolution (e.g., the project node) when such data is available.

  iii) Availability: MER data from one or more sources must be available for all hours

  iv) Method: MER estimation methods must meet the following criteria:

    (1) All fuel types must be allowed to be marginal in the method, including renewable energy.

    (2) The method should account for physical flows of electricity, including import and export of electricity between regions, and transmission constraints within regions.

  v) Hierarchy: Only MER data that meets the requirements outlined in *Appendix V: Description of the MER Estimation Method* can be used. Thereafter, the primary selection criterion is the data source's relative performance across the following attributes described: reliability, granularity, and availability. Preference is given to the source that demonstrates the highest performance across these attributes. If data sources exhibit similar levels of performance across these attributes, the second selection criterion is based on the perceived transparency and capacity of the source to produce the data, which is as follows: 1) Government entity for corresponding market; 2) Wholesale or regulated energy market; 3) Third-party provider. If multiple third-party sources have identical performance in reliability, granularity, and availability, the project developer may choose the data source at their discretion.

b) Price Data for DER-VET Baseline:

Reliability: publicly available grid operator data must be used.

Granularity: the power market must make hourly or sub-hourly wholesale E/S prices (e.g., USD/MWh) and A/S prices publicly available at the settlement location of the ESS.

Availability: price data must be available for all hours.

c) Dispatch Data:

   i) Accuracy: The meter must be tested and calibrated in accordance with the recommendations/specifications of the meter manufacturer and in accordance with national or international testing and calibration procedures, such as ANSI C12.20 or IEC 62052-11:2020 (E) and succeeding updated standards, wherever applicable.

   ii) Granularity: The energy charged/discharged from the ESS must be available at hourly or sub-hourly temporal granularity from the above-mentioned meter. If the ESS is paired with renewable energy generator, this meter must be a separate, calibrated device from the meter measuring the output of the connected renewable energy generator.

   iii) Separately Metered: If the ESS is paired with a renewable energy facility, (e.g. co-located solar plus storage project), the ESS dispatch data must be metered separately from the renewable facilities energy generation.Availability: Dispatch data must be available for all hours (i.e., at least 99%).

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APPENDIX I: AVOIDANCE OF CARBON LOCK-IN

The proposed methodology aims to support the deployment of renewable energy since its mitigation potential is achieved when ESS are utilizing electricity with the lowest carbon content for charging. Avoidance of lock-in and ensuring alignment with the long-term goals of the Paris Agreement, i.e., keeping temperature increase within 1.5 degrees Celsius, indicates (in this specific context) the need to generate and utilize clean electricity from renewable sources and progressively phase out fossil-based power generators. When renewables are on the margin, the carbon content of the electricity used by the ESS is 0 and thus the mitigation potential is maximized (as opposed to the ESS operating in the baseline scenario in which the ESS may be incentivized by revenue maximization to spur additional fossil-based electricity production). The methodology does not contribute to the lock-in of carbon technologies and does not provide any incentive to the continued use of fossil fuels as the mitigation potential that can be achieved by an ESS is generated when energy produced from higher emitting units (e.g., fossil-based power generators) is displaced with energy produced from lower emitting units (e.g., renewables). The ESS operators and the generating facilities cannot control which facility is on the margin in each time interval, as this is mandated by the grid operators and also by the grid characteristics. On the contrary, applying this methodology will contribute to the installation and dispatch of renewable energy, as it is prioritized by the operator to charge the ESS, displacing fossil-based electricity and contributing to the progressive expansion of the renewable generation. The methodology actively contributes to addressing issues related to the renewable energy deployment, such as intermittency, and generates a financial incentive when renewable electricity is prioritized. Supporting renewable energy development, the methodology contributes to the achievement of the pledge made by 124 signatories at the Conference of the Parties 28 held In United Arab Emirates in 2023 to triple the world’s installed renewable energy generation capacity as a key action to achieve the long-term goals of the Paris Agreement.[6]

It is expected that in the long-term, projects applying this methodology will experience a progressive reduction of the mitigation potential that can be achieved: as more renewable generators will come online and will be able to dispatch the electricity produced, MERs will progressively move towards 0. In the situation where only renewable generators exist, the methodology would not generate any emission reductions. This scenario will materialize when renewables penetration reaches a high level in a specific grid and fossil-based power generators are not utilized to meet electricity demand, and this can be achieved with the contribution of the proposed methodology. Thus, the methodology is fully aligned with the goal of the Paris Agreement and is specifically contributing to displace carbon intensive electricity and avoids any lock-in effect.

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[6] For more information visit this website

APPENDIX II: ACTIVITY METHOD

Positive List

The positive list was established using the financial viability option (Option B In the VCS Methodology Requirements) which indicates that under the selected option B the methodology must demonstrate that the project activity is less financially or economically attractive than the alternatives to the project activity using the procedures for investment analysis set out in the latest version of the VCS Tool *VT0008 Additionality Assessment*.

Applicability Condition

Per the applicability condition 9 set forth in *section 4*, ESS facilities are eligible under this methodology for projects where the Spearman rank correlation coefficient (ρ) of the real-time energy price and MER at an hourly granularity (or higher) is less than or equal to 0.95, where ρ is defined as:

$$\rho = 1 - \frac{6\sum {d_i}^2}{n(n^2-1)} \tag{18}$$

Where:

d_i = Difference between the ranks of each observation

n = Number of observations

A battery operated to maximize revenue in the energy market yields a separate and distinct dispatch schedule than a battery operated to reduce emissions unless ρ is 1. The analysis below demonstrates that for a “worst case” scenario at a ρ of 0.95, the ESS operating to reduce emissions incurs an opportunity cost that represents a financial barrier to the proposed activity. Any project with a ρ less than or equal to 0.95 will face this financial barrier in pursuit of the project activity and is therefore additional.

Assessment of Baseline Scenario and Additionality

In the absence of regulations or incentives specifically requesting or promoting ESS dispatch (i.e., charging and discharging of electricity) to reduce emissions, and excluding ESS participating in 24x7 offtake structures as described in eligibility criteria, ESS dispatch will follow price signals to maximize net revenues from E/S and A/S.

For existing facilities, the baseline scenario is thus the continuation of the current mode of operation where the ESS dispatch follows the price signals to maximize net revenues from E/S and A/S. The following steps as contained in the VCS Tool *VT0008 Additionality Assessment* have been applied:

Sub-step 1a: Define alternatives to the project activity

The following alternatives exist related to the dispatch of an ESS system:

- **Alternative 1:** ESS operation following price signal, i.e., maximizing net revenues (continuation of current situation)

- **Alternative 2:** ESS operation following emission signal, i.e., minimizing emissions associated with the ESS operations without being registered under any other carbon offset standard that allows the generation of carbon credits.

No other alternative is considered to the ESS operating for minimizing emissions (i.e., the proposed activity), for instance the option to build a power plant (e.g., gas or wind), because it is not comparable with the change in the dispatch of an ESS.

Alternative 1 is taken into account in the demonstration of additionality.

Alternative 2 is not rational as the ESS operator would forego a certain share of revenues without any additional revenue from the sale of carbon credits. It is reasonable to expect that no operator would rationally forego revenues in absence of legal requirements and of a carbon price creating an incentive to minimize emissions and would thus rather continue to operate under revenue maximization model.

Sub-step 1b: Consistency with mandatory laws and regulations

The existing regulations and incentives applicable to the grid region that are listed under the positive list:

- Do not exclude one of the alternatives, and

- Do not require or promote one alternative over the other alternative.

As a result, Alternative 1 and Alternative 2 are applicable for further assessment.

Sub-step 2a Determine appropriate analysis method

Option II: Investment comparison analysis is selected for the assessment. The financial indicator for the assessment is “total net revenues per annum” from both E/S and A/S of the ESS operation. Please see below (i.e., Sub-step 2c) for further explanation.

Sub-step 2b: Option II: Investment comparison analysis

There are no additional operational costs (e.g., added fuel, labor, etc.) when implementing a different dispatch approach to an ESS; however, changing the dispatch approach to better optimize for minimizing GHG emissions from the ESS operations will lead to a reduction of E/S and A/S revenue when compared to a revenue-optimizing baseline.

A reduction of net revenue when compared to the baseline revenue-optimization dispatch is therefore the applied analysis. The reduction of net revenue is demonstrated if $\text{Rev}_{\text{PHS}_{\text{revenues}},x} > \text{Rev}_{\text{PHS}_{\text{emissions}},x}$

Sub-step 2c: Calculation and comparison of financial indicators

The following analysis will demonstrate that the total net revenues from E/S and A/S at $\text{PHS}_{\text{revenues}}$ are greater than the total net revenues from E/S and A/S at $\text{PHS}_{\text{emissions}}$ when ρ is 0.95. These quantities are given by:

$$\text{Rev}_{\text{PHS}_{\text{revenues,x}}} \geq \text{Rev}_{\text{PHS}_{\text{emissions,x}}} \qquad (19)$$

Where:

$\text{Rev}_{\text{PHS}_{\text{revenues,x}}}$ = Total net revenues from E/S and A/S at $\text{PHS}_{\text{revenues}}$ (i.e., operation would be optimized to maximize revenues) at project location over period x (USD).

$\text{Rev}_{\text{PHS}_{\text{emissions,x}}}$ = Total net revenues from E/S and A/S at $\text{PHS}_{\text{emissions}}$ (i.e., operation would be optimized to minimize emissions) at project location over period x (USD).

x = Optimization period

$\text{Rev}_{\text{PHS}_{\text{revenues}},\text{x}}$ is calculated as follows:

$$\text{Rev}_{\text{PHS}_{\text{revenues}},\text{x}} = \sum_{\text{i}=0}^{\text{n}} \text{P}_{\frac{\text{E}}{\text{S}},\text{I,x}} * \text{A}_{\text{PHS},\frac{E}{S},\text{revenues,I,x}} + \sum_{\text{i}=0}^{\text{n}} \text{P}_{\frac{A}{S},\text{I,x}} * \text{A}_{\text{PHS},\frac{\text{A}}{\text{S}},\text{revenues,I,x}} \qquad (20)$$

Where:

$\text{P}_{\frac{\text{E}}{\text{S}},\text{I,x}}$ = Price for the E/S in interval i at project location (USD/MWh) over period x

$\text{P}_{\frac{\text{A}}{\text{S}},\text{i,x}}$ = Price for the A/S in interval i at project location (USD/MWh) over period x

$\text{A}_{\text{PHS},\frac{\text{A}}{\text{S}},\text{revenues,i,x}}$ = Quantity of awarded A/S if the ESS is operated to maximize net revenues in interval i at project location (MWh) over period x

$\text{A}_{\text{PHS},\frac{\text{E}}{\text{S}},\text{revenues,i,x}}$ = Estimated electricity dispatch (positive for discharging, negative for charging) due to the provision of E/S if the ESS is operated to maximize net revenues in interval i at project location (MWh) over period x

$\text{Rev}_{\text{PHS}_{\text{emissions}},\text{x}}$ is calculated as follows:

$$\text{Rev}_{\text{PHS}_{\text{emissions}},\text{x}} = \sum_{\text{i}=0}^{\text{n}} \text{P}_{\frac{\text{E}}{\text{S}},\text{I,x}} * \text{A}_{\text{PHS},\frac{\text{E}}{\text{S}},\text{emissions,I,x}} + \sum_{\text{i}=}^{\text{n}} \text{P}_{\frac{\text{A}}{\text{S}},\text{I,x}} * \text{A}_{\text{PHS},\frac{A}{S},\text{emissions,I,x}} \qquad (21)$$

$\text{A}_{\text{PHS},\frac{\text{A}}{\text{S}},\text{emissions,i,x}}$ = Quantity of awarded A/S if the ESS is operated to minimize emissions in interval i at project location (MWh) over period x

$\text{A}_{\text{PHS},\frac{\text{E}}{\text{S}},\text{emissions,i,x}}$ = Estimated electricity dispatch (positive for discharging, negative for charging) due to the provision of E/S if the ESS is operated to minimize emissions in interval i at project location (MWh) over period x

It is exceedingly rare for ρ to reach 0.95, and as a result a historical dataset was treated to produce synthetic data with an improved ρ of 0.95. This was done by retrieving the MER and real time prices for E/S for a node in Texas with a relatively high ρ (0.65) for a period of one calendar year. First, MER and energy price pairs where the energy price exceeded \$500/MWh or the MER was below 1 tCO_2e/MWh were removed. Next, hourly real time prices for E/S were regressed on hourly MERs to produce a second-degree polynomial curve of best fit. Finally, any MER and energy price pair that landed greater than four units[7] of Euclidian distance from this line of best fit were discarded, resulting in a ρ of 0.95. This data treatment yielded 1331 unique hourly data points that could represent a period where the MER and real-time energy price are highly correlated.

The DER-VET model requires 8,760 unique data points to run, so these 1,331 data points were repeated until the synthetic data set included 8,760 total MER and energy price pairs. The MER values were then multiplied by 100 to match the scale of the energy prices, and each time series was input into DER-VET in a separate optimization. The parameters used for the optimization were selected to represent the conservative case where ESS operations would most closely align with an emission reduction strategy at a high value for ρ, which is a pure energy arbitrage strategy with no participation in ancillary services. These parameters are given in the following table.

Parameter	Value
Timestep	60 minutes
Battery energy capacity (kWh)	20,000
Battery power capacity (kW)	10,000
Battery round-trip efficiency (%)	85%
Upper State of Charge (SOC) limit (%)	100
Target SOC (%)	50
Lower SOC Limit (%)	0
Self-Discharge Rate (%/hour)	0
Variable O&M Costs (\$/MWh)	\$15/MWh
Daily Cycle Limit (Cycles/Day)	1
Include Degradation Due to Cycling (Y/N)	N
Apply Interconnection Constraints (Y/N)	Y
Optimization Window (Days)	30
Ancillary Services Provided	N/A
Regulation up throughput (kWh/kW-hr)	N/A
Regulation down throughput (kWh/kW-hr)	N/A
Duration for energy reservation requirements for frequency regulation (hours)	N/A
Combined market requirement for frequency regulation (Y/N)	N/A

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[7] Four units of Euclidean distance represents a tuned parameter that yields the desired correlation coefficient.

Reg up qualification[8]	N/A
Reg down qualification[12]	N/A
Reg up price time series	N/A
Reg down price time series	N/A
Energy price time series (Day Ahead)	Synthetic Series (described above)
Duration for energy reservation requirements for spinning reserves	N/A
Spinning reserves qualification[12]	N/A
Spinning reserve price time series	N/A
Duration for Energy Reservation Requirements for non-spinning reserves	N/A
Non-spinning reserves qualification[12]	N/A
Non-Spinning reserve price time series	N/A

The resulting dispatch schedule from these two optimizations are multiplied by the energy prices, yielding the total revenue paid to the ESS project from the energy market to give the following:

Opportunity costs with ρ = 0.95

$\mathbf{Rev}_{\mathbf{PHS}_{\mathbf{revenues,x}}}$	\$288,206
$\mathbf{Rev}_{\mathbf{PHS}_{\mathbf{emissions,x}}}$	\$278,004
Opportunity Cost (USD)	\$10,202
Opportunity Cost (Percent)	3.54%

The results indicate that at a 0.95 correlation, the opportunity costs incurred by an ESS project to pursue a carbon abatement strategy is over \$10,000/year, or 3.54% of total revenues, which represents the financial barrier for the activity.

Furthermore, the below table demonstrates that as ρ becomes small, the opportunity cost becomes large, which validates a maximum ρ of 0.95 as the *minimum* opportunity cost an ESS may incur. The steps above were repeated to create synthetic data sets with lower ρ values by tuning the Euclidean distance parameter, and then processed through DER-VET. The Opportunity Cost (USD) below represents $\mathrm{Rev}_{\mathrm{PHS}_{\mathrm{revenues,x}}} - \mathrm{Rev}_{\mathrm{PHS}_{\mathrm{emissions,x}}}$.

Opportunity costs at decreases values for ρ

ρ	Opportunity Cost (USD)
0.95	\$10,202
0.85	\$50,461

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[8] Unavailable in current version 1.2.3 of DER-VET, released in February 2023. The default values for ancillary service qualifications is the nameplate capacity of the asset. These parameters will be introduced in a future release of DER-VET and will become applicable once released.

0.75	$83,223

Sub-step 2d: Sensitivity analysis

The sensitivity is performed on the following parameters: prices for E/S and A/S. These are the primary revenue sources for an ESS, and thus affect the profitability of the ESS operations. A change in the behaviour of the ESS operator, triggered by the proposed methodology, would result in a change in the net revenues as well, with lower net revenues in the case of the optimization of the ESS operations to minimize emissions. In line with the description above, other investment calculation inputs (CAPEX and OPEX) are not considered as the methodology only drives a change in the behaviour of an ESS but does not affect the decision to invest in an ESS (see sub-step 2c).

Sensitivity test: E/S and A/S prices remain the same for Rev_PHS_revenues and Rev_PHS_Emissions. The difference between these two scenarios is the objective function, which changes from maximizing revenue to minimizing emissions. Therefore, it follows that $\mathrm{Rev}_{\mathrm{PHS}_{\mathrm{revenues}},\mathrm{x}} > \mathrm{Rev}_{\mathrm{PHS}_{\mathrm{emissions}},\mathrm{x}}$ even when the key input parameters, E/S and A/S prices, used for the investment comparison vary +/- 10%.

The table below shows the values for $\mathrm{Rev}_{\mathrm{PHS}_{\mathrm{revenues,x}}}$ and $\mathrm{Rev}_{\mathrm{PHS}_{\mathrm{emissions,x}}}$ when E/S prices are increased by 10%:

Opportunity costs at a 10% increase in E/S prices

$\mathbf{Rev}_{\mathbf{PHS}_{\mathbf{revenues,x}}}$	$316,879
$\mathbf{Rev}_{\mathbf{PHS}_{\mathbf{emissions,x}}}$	$305,804
Opportunity Cost (USD)	$11,075
Opportunity Cost (Percent)	3.50%

The table below shows the values for $\mathrm{Rev}_{\mathrm{PHS}_{\mathrm{revenues,x}}}$ and $\mathrm{Rev}_{\mathrm{PHS}_{\mathrm{emissions,x}}}$ when E/S prices are decreased by 10%:

Opportunity costs at a 10% decrease in E/S prices

$\mathbf{Rev}_{\mathbf{PHS}_{\mathbf{revenues,x}}}$	$259,101
$\mathbf{Rev}_{\mathbf{PHS}_{\mathbf{emissions,x}}}$	$250,203
Opportunity Cost (USD)	$8,898
Opportunity Cost (Percent)	3.43%

Step 4: Common Practice

As explained in the previous section, ESS operators have no incentive to manage the system in a manner that focuses on reducing emissions. There are several studies that point towards the fact that GHG emissions from ESS operations are hard to abate if net revenues maximization is the main driver for the operations. Lack of incentives for ESS operators to minimize emissions may result in an actual increase of the emission due to ESS operations, after round-trip efficiency is factored in. Economic incentives through the sale of carbon credits or regulatory requirements are be needed to shift the operational patterns and reduce emissions.[9]

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[9] As observed by Archiniegas and Hittinger (2018): Tradeoffs between revenue and emissions in energy storage operation. Energy journal https://www.sciencedirect.com/science/article/pii/S0360544217318145

APPENDIX III: SPEARMAN CORRELATION ANALYSIS

The Spearman rank correlation coefficient (ρ), described in equation (18) in *APPENDIX II: ACTIVITY METHOD*

was evaluated for all generation nodes in The New York Independent System Operator (NYISO), The Independent System Operator of New England (ISONE), The Midwest Independent System Operator (MISO), The Pennsylvania, Maryland, Jersey ISO (PJMISO), The Southwest Power Pool (SPP), and the Electricity Reliability Council of Texas (ERCOT). The following table shows the maximum, median, average, and minimum values for ρ, demonstrating that no location within these jurisdictions exceeds 0.95. Therefore, all BESS projects within these jurisdictions satisfy Applicability Condition 8:

Spearman rank correlation coefficient summary statistics in various jurisdictions

Jurisdiction	Max	Median	Avg	Min
ERCOT	0.74	0.43	0.45	0.31
ISONE	0.66	0.57	0.57	0.49
MISO	0.90	0.75	0.74	0.53
NYISO	0.42	0.30	0.30	0.14
PJM	0.75	0.67	0.66	0.55
SPP	0.91	0.83	0.82	0.62

APPENDIX IV: DESCRIPTION OF THE DER VET MODEL

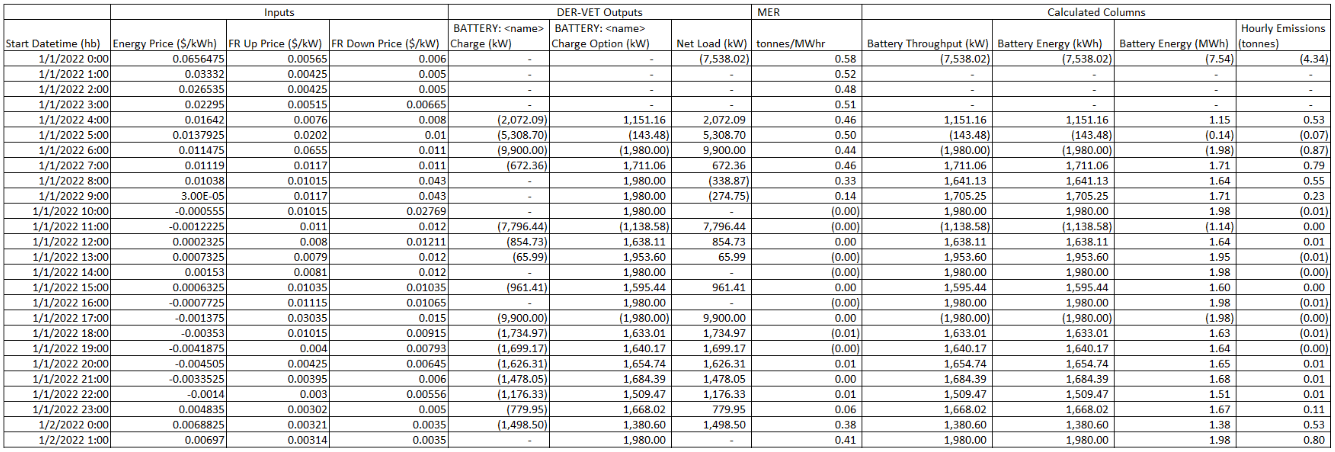
The calculation of PHS dispatch for $PHS_{revenue}$ shall be done using the DER-VET™ (or successor) software.

DER-VET provides a free, publicly accessible, open-source platform for calculating, understanding, and optimizing the value of distributed energy resources (DER) based on their technical merits and constraints. DER-VET calculates the optimal dispatch for an energy storage system by solving an optimization problem that is constrained by the technical capabilities of the storage system and the constraints of the market services that it is providing. An extension of EPRI's StorageVET® and ESVT tools, DER-VET supports site-specific assessments of energy storage and additional DER technologies—including solar, wind, demand response, electric vehicle charging, internal combustion engines, and combined heat and power—in different configurations, such as microgrids. DER-VET was developed with funding by the California Energy Commission and is maintained by EPRI.

Calculation of $E_{PHS,revenue}$:

In order to calculate $E_{PHS,revenue}$, DER-VET shall be used with actual observed energy and ancillary prices, with the result being $A_{PHS,revenues,i,x}$, the energy dispatch, as referenced in equation 7. In order to calculate the emissions associated with this dispatch, the energy charge and discharge shall be paired with MER data as detailed in *section 8*.

The below table provides an illustration of the relevant inputs and outputs for this calculation. The inputs reflect actual observed prices from the relevant market. The output from DER-VET version 1.2.3 does not include a column that captures the impact of frequency regulation energy throughput in addition to energy arbitrage throughput explicitly. The "Net Load" column captures the energy throughput from energy arbitrage (in units of kW) and represents the sum of columns "BATTERY: <name> Discharge (kW)" and "BATTERY: <name> Charge (kW)". Frequency regulation throughput is represented by columns "BATTERY: <name> Charge Option (kW)" and "BATTERY: <name> Discharge Option (kW)". These columns must be added to the "Net Load" columns to fully capture the battery energy throughput, such that "Battery Throughput (kW)" is equal to "Net Load" plus "BATTERY: <name> Charge Option (kW)" plus "BATTERY: <name> Discharge Option (kW)". This calculated column is then converted to energy (kWh) in the "Battery Energy (kWh)" column; in the case of hourly timesteps this is simply multiplying by 1. This is then converted to MWh by dividing by 1000. The MER data is sourced separately. The Hourly Emissions is a calculated column that is the product of the MER column and the "Battery Energy (MWh)" column.



	Inputs			DER-VET Outputs			MER	Calculated Columns			
Start Datetime (hb)	Energy Price ($/kWh)	FR Up Price ($/kW)	FR Down Price ($/kW)	BATTERY: <name> Charge (kW)	BATTERY: <name> Charge Option (kW)	Net Load (kW)	tonnes/MWhr	Battery Throughput (kW)	Battery Energy (kWh)	Battery Energy (MWh)	Hourly Emissions (tonnes)
1/1/2022 0:00	0.0656475	0.00565	0.006	-	-	(7,538.02)	0.58	(7,538.02)	(7,538.02)	(7.54)	(4.34)
1/1/2022 1:00	0.03332	0.00425	0.005	-	-	-	0.52	-	-	-	-
1/1/2022 2:00	0.026535	0.00425	0.005	-	-	-	0.48	-	-	-	-
1/1/2022 3:00	0.02295	0.00515	0.00665	-	-	-	0.51	-	-	-	-
1/1/2022 4:00	0.01642	0.0076	0.008	(2,072.09)	1,151.16	2,072.09	0.46	1,151.16	1,151.16	1.15	0.53
1/1/2022 5:00	0.0137925	0.0202	0.01	(5,308.70)	(143.48)	5,308.70	0.50	(143.48)	(143.48)	(0.14)	(0.07)
1/1/2022 6:00	0.011475	0.0655	0.011	(9,900.00)	(1,980.00)	9,900.00	0.44	(1,980.00)	(1,980.00)	(1.98)	(0.87)
1/1/2022 7:00	0.01119	0.0117	0.011	(672.36)	1,711.06	672.36	0.46	1,711.06	1,711.06	1.71	0.79
1/1/2022 8:00	0.01038	0.01015	0.043	-	1,980.00	(338.87)	0.33	1,641.13	1,641.13	1.64	0.55
1/1/2022 9:00	3.00E-05	0.0117	0.043	-	1,980.00	(274.75)	0.14	1,705.25	1,705.25	1.71	0.23
1/1/2022 10:00	-0.000555	0.01015	0.02769	-	1,980.00	-	(0.00)	1,980.00	1,980.00	1.98	(0.01)
1/1/2022 11:00	-0.0012225	0.011	0.012	(7,796.44)	(1,138.58)	7,796.44	(0.00)	(1,138.58)	(1,138.58)	(1.14)	0.00
1/1/2022 12:00	0.0002325	0.008	0.01211	(854.73)	1,638.11	854.73	0.00	1,638.11	1,638.11	1.64	0.01
1/1/2022 13:00	0.0007325	0.0079	0.012	(65.99)	1,953.60	65.99	(0.00)	1,953.60	1,953.60	1.95	(0.01)
1/1/2022 14:00	0.00153	0.0081	0.012	-	1,980.00	-	(0.00)	1,980.00	1,980.00	1.98	(0.00)
1/1/2022 15:00	0.0006325	0.01035	0.01035	(961.41)	1,595.44	961.41	0.00	1,595.44	1,595.44	1.60	0.00
1/1/2022 16:00	-0.0007725	0.01115	0.01065	-	1,980.00	-	(0.00)	1,980.00	1,980.00	1.98	(0.01)
1/1/2022 17:00	-0.001375	0.03035	0.015	(9,900.00)	(1,980.00)	9,900.00	0.00	(1,980.00)	(1,980.00)	(1.98)	(0.00)
1/1/2022 18:00	-0.00353	0.01015	0.00915	(1,734.97)	1,633.01	1,734.97	(0.01)	1,633.01	1,633.01	1.63	(0.01)
1/1/2022 19:00	-0.0041875	0.004	0.00793	(1,699.17)	1,640.17	1,699.17	(0.00)	1,640.17	1,640.17	1.64	(0.00)
1/1/2022 20:00	-0.004505	0.00425	0.00645	(1,626.31)	1,654.74	1,626.31	0.01	1,654.74	1,654.74	1.65	0.01
1/1/2022 21:00	-0.0033525	0.00395	0.006	(1,478.05)	1,684.39	1,478.05	0.00	1,684.39	1,684.39	1.68	0.01
1/1/2022 22:00	-0.0014	0.003	0.00556	(1,176.33)	1,509.47	1,176.33	0.01	1,509.47	1,509.47	1.51	0.01
1/1/2022 23:00	0.004835	0.00302	0.005	(779.95)	1,668.02	779.95	0.06	1,668.02	1,668.02	1.67	0.11
1/2/2022 0:00	0.0068825	0.00321	0.0035	(1,498.50)	1,380.60	1,498.50	0.38	1,380.60	1,380.60	1.38	0.53
1/2/2022 1:00	0.00697	0.00314	0.0035	-	1,980.00	-	0.41	1,980.00	1,980.00	1.98	0.80

DER-VET Inputs:

In order to ensure that DER-VET is being used consistently and appropriately, the following parameters shall be used in the model. Values marked as “project-specific” shall be adjusted to match specifics of individual project characteristics. Values marked as “regional electricity grid-specific” shall be adjusted to match the market rules of regional electricity grid. Other values shall be as specified below. If a regional electricity grid has additional reserve services, these can be added to the model in the same fashion as spinning and non-spinning reserves, with duration requirements appropriately indicated.

Because DER-VET establishes a dispatch schedule assuming markets are sufficiently deep in volume such that price-taker offers will always clear, adjustments must be made to the ancillary service qualification volumes when ancillary service markets become saturated with ESS projects. This adjustment must be made when the volume of ESS participating in the carbon methodology exceeds the volume of the ancillary service market, e.g. 600 MW of ESS are registered to provide carbon offsets under the methodology, but the frequency regulation market in a given regional electricity grid may only be 300 MW. The discount factor for the AS qualification parameter is given as follows:

$$DF_p = \min\left(\frac{AS_p}{\sum_{i=0}^{n} Cap_i}, 1\right)$$

Where:

DF_p = Discount factor for product p

Cap_i = Capacity in MW of project i participating in the methodology

n = Total projects participating in the methodology

AS_p = Market size in MW for ancillary product p

Parameter	Value
Timestep	Project-specific
Battery energy capacity (kWh)	Project-specific
Battery power capacity (kW)	Project-specific
Battery round-trip efficiency (%)	Project-specific
Upper State of Charge (SOC) limit (%)	100
Target SOC (%)	50
Lower SOC Limit (%)	0
Self-Discharge Rate (%/hour)	0
Variable O&M Costs ($/MWh)	Project-specific, between $5 and $20/MWh
Daily Cycle Limit (Cycles/Day)	Project-specific
Include Degradation Due to Cycling (Y/N)	N
Apply Interconnection Constraints (Y/N)	Project-specific
Optimization Window (Days)	30
Ancillary Services Provided	Project-specific
Regulation up throughput (kWh/kW-hr)	Regional electricity grid-specific[10]
Regulation down throughput (kWh/kW-hr)	Regional electricity grid-specific[11]
Duration for energy reservation requirements for frequency regulation (hours)	Project-specific
Combined market requirement for frequency regulation (Y/N)	Regional electricity grid-specific
Reg up qualification[11]	$DF_{reg\ up} *$ Project-specific
Reg down qualification[12]	$DF_{reg\ down} *$ Project-specific
Reg up price time series	Project-specific
Reg down price time series	Project-specific
Energy price time series (Day Ahead)	Project-specific
Duration for energy reservation requirements for spinning reserves	Regional electricity grid-specific
Spinning reserves qualification[12]	$DF_{spinning\ reserves} *$ Project-specific
Spinning reserve price time series	Project-specific
Duration for Energy Reservation Requirements for non-spinning reserves	Regional electricity grid-specific
Non-spinning reserves qualification[12]	$DF_{non-spinning\ reserves} *$ Project-specific
Non-Spinning reserve price time series	Project-specific

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[10] If data is available, the Frequency Regulation Throughput should be set to the actual hourly average throughput (deployments/procurements) for the previous calendar year. If this data is not available, the Frequency Regulation Throughput should be informed by expected deployment percentages given by the ISO/RTO. If neither of these are available, the Frequency Regulation Throughput should be set to 20%.

[11] Unavailable in current version 1.2.3 of DER-VET, released in February 2023. The default values for ancillary service qualifications is the nameplate capacity of the asset. These parameters will be introduced in a future release of DER-VET and will become applicable once released.

APPENDIX V: DESCRIPTION OF THE MER ESTIMATION METHOD

Every megawatt-hour (MWh) of energy injected into the grid displaces another megawatt-hour of electricity that would have otherwise been produced. This is because, in each moment, the total supply of electricity production must exactly match the demand for electricity – so each incremental MWh generated must be met by an equivalent reduction elsewhere in the system. The generator or group of generators whose production was displaced by that incremental injection of energy is referred to as the “marginal generator(s)”. MER estimation methods attempt to quantify the emissions impact of those marginal generators being re-dispatched in response to incremental generation. For load (or when a battery is charging), the same concept is applied but the sign is flipped: marginal generator production (and associated emissions) is increased as a result of the incremental increase of energy consumption.

Marginal Emissions Rates (MERs) may be calculated in different ways. The following methods of estimating MER are allowable assuming they meet the applicability conditions outlined in *Section 4 Applicability Conditions*.

Option 1: Operator-reported

Some grid operators make real-time marginal emissions data available. This may be provided publicly via the operator’s website or an API and may be provided without cost or for a fee. This data may be used, provided that the system operator states that it is of sufficient quality for the purpose of carbon impact evaluation.

Option 2: Statistical Operator Dispatch

MERs shall be estimated for historical operating periods using an MER model that ingests bid data (e.g. bid and offer curves), shift factors, real-time energy prices (e.g. Locational Marginal Prices, or LMPs), emissions rates, and binding constraint data from that operating period. Grid operators and/or governmental agencies may publish some or all of this information for public use. Where this data is not publicly available, it shall be derived using the methods described below.

Derivation of Inputs

1) Bid data must be:
    a) Provided by the grid operator, or if unavailable,
    b) Estimated based on published data including generator efficiency, fuel type, fuel price, and other relevant factors
2) Shift factors must be:
    a) Provided by the grid operator, or if unavailable,
    b) Estimated using constraint data and the congestion component of real-time energy prices
3) Emissions rates must be:
    a) Reported in annual filings or by government agencies, or if unavailable,

   b) Estimated using similar generators (e.g. using a simple average of emissions rates for generators that share characteristics such as fuel type, size, geographic region, year constructed, etc.)

4) Binding constraint data must be reported by the grid operator

Description of MER calculation

1) The MER model must estimate which generator(s) are marginal in each market settlement interval of the historical operating period by isolating generators for which the real-time energy price (e.g. LMP) at the node is equal to the offer price at the node.
2) The MER model must estimate the change in output of estimated marginal generator(s) in response to incremental load or generation at each generation node (i.e. “redispatch”) based on least cost dispatch, respecting power flow constraints given the nodal shift factors and respecting the power balance constraint, sometimes referred to as Security Constrained Economic Dispatch (SCED).
3) The MER model must estimate the carbon emissions resulting from that redispatch using emission rates in tCO_2e/kWh (or units that can be converted appropriately).

Option 3: Statistical Emissions

MERs shall be estimated using a statistical regression model that finds the relationship between total emissions and load with causal confounding variables controlled. The regression model must be trained on actual, not assumed, grid data and be able to produce changes in emissions given a change in supply or demand. Causal confounding variables must be controlled so that changes in emissions measured by the model can be consequentially attributed to the change in supply or demand instead of due to unrelated phenomenon (such as changes in temperature).

A statistical regression model may be used if:

1) Causal confounding variables are controlled. A causal confounding variable is any extraneous variable that influences both the independent variable and the dependent variable in a model, potentially leading to a false association between the two. In the case of MER estimation, causal confounding variables are any variables that affect both load and emissions. At minimum, hour of day and time of year must be controlled in the regression model. By controlling causal confounding variables, the change in emissions can be attributed to a change in load and not any other reason. These variables can be controlled through a variety of peer-reviewed methods. One example of a method to control causal confounding variables is binned linear regression, whereby grid conditions are binned based on similar characteristics such as generation or current real-time energy price and a regression is performed on each bin. The method used to control causal confounding variables in the model must cite a peer-reviewed study of MER estimation.
2) The regression model includes load as an input. Other inputs may be used, such as generation by fuel and real-time energy prices (e.g. LMPs)
3) The model is validated such that a change in load is statistically significant in predicting a change in emissions with p-value less than or equal to 0.05. A model may be validated in a variety of ways, such as using well-identified natural experiments such as natural changes in generation (e.g. wind or solar ramping or large generators tripping offline). Model validation techniques must cite a peer-reviewed study of MER estimation. A validated model may be applied to a region

different from the validation region only to the extent that the differences between the validation region and the application region can be parameterized and incorporated in the model. For example, if a model is validated in a region with X coal generation, it can be applied to a different region with Y coal generation if:

   a) The model includes a parameter that can consider this difference (e.g., coal generation must be a covariate in the model)
   b) The model must be validated in different regions with different coal generations to ensure that the coal generation parameter is properly incorporated in the model

4) Data used in training the regression model is recent (within the last five years) and consist of at least 365 consecutive calendar days.
5) The regression model takes as its inputs real-time data of the same form as the covariates from the training data set, and at a lower or equal temporal frequency than that of the training data set.
6) The model predicts marginal emissions in tCO_2e/kWh (or units that can be converted appropriately).

APPENDIX VI: BACKGROUND INFORMATION

Energy Storage Operations

Energy Storage Systems (ESS) are flexible assets that can provide a variety of grid services. ESS operations are only constrained by the physical characteristics of the system (e.g. duration and power constraints). ESS operators deploy varying strategies to maximize revenue given these physical constraints and the economic conditions in the market.

ESS provides two primary services: Energy/Storage (E/S), which involves selling electricity in the wholesale market, and Ancillary Services (A/S), which include functions such as frequency regulation, reserve power, reactive power, and black start capability.

These distinct operational modes have differing energy demands and associated emissions. The operator's commercial strategy determines which services to offer and when, influenced by prevailing market prices. Once an ESS operator offers and is awarded E/S or A/S services, they must adhere to the grid operator's requirements without deviation, as failure to comply may result in financial penalties.

An ESS operator’s bidding strategy, which includes decisions on pricing, service quantities, and timing, directly affects when services are awarded and the resulting emissions. Consequently, adjustments to the bidding strategy influence ESS dispatch patterns and their associated emissions.

Dynamic Baselining Rationale

An energy storage operator’s objective is to maximize revenue across the services the asset is qualified to sell, given the operational constraints of the project. The maximum revenue that an operator can achieve in a given period can be modeled using mathematical optimization. The objective function of this optimization is simply the sum-product of volume and price for each service across all intervals in the optimization period:

$$objective\ function:\ f(v_a, v_b, v_c, \dots) = v_a \cdot p_a + v_b \cdot p_b + v_c \cdot p_c + \cdots$$

Where each v_x is a vector of volumes over time for service x and each $p_x$is a vector of prices over time for service x. A service can be E/S or A/S. The optimization engine solves for the optimal volumes for each service in each time interval to maximize the total revenue returned to the project. When the prices of services are known in advance of operation, the maximum revenue returned from the optimization engine is referred to as “perfect knowledge revenues”. However, no operator knows prices ahead of time and therefore must forecast the expected value of services to make operational decisions. The objective function is therefore given by:

$$objective\ function:\ f(v_a, v_b, v_c, \dots) = v_a \cdot p_{a_f} + v_b \cdot p_{b_f} + v_c \cdot p_{c_f} + \cdots$$

Where each $p_{x_f}$is a vector for *forecast* prices over time for service x.

The introduction of a Verified Carbon Unit creates a new product for an energy storage operator to include in the objective function of the optimization:

$$objective\ function\text{:}\ f(v_a, v_b, v_c, v_{carbon}, \dots) = v_a \cdot p_{a_f} + v_b \cdot p_{b_f} + v_c \cdot p_{c_f} + v_{carbon_f} \times p_{carbon_f} + \cdots)$$

Where:

$$v_{carbon_f} = v_{rt\ energy} \cdot mer_f$$

Where mer_f is a vector of the forecasted MER at the project node over time and $v_{rt\ energy}$ is a vector that represents the total energy movement volumes, inclusive of ancillary service deployments, over time. The carbon price, p_{carbon_f} is a scalar given by either the contracted carbon price in an offtake agreement or the spot price of carbon offsets expected to be generated by the ESS. For a battery operator to alter operational decisions to account for the emissions impact of dispatch behavior, this additional term must be included in the objective function. It is mathematically true that at a carbon price of $0/ton, this additional term becomes zero, which therefore represents a battery's expected behavior without any compensation for carbon abatement. In other words, it is possible to isolate the impact of a carbon market on a battery's dispatch by holding all inputs constant (i.e. price forecasts and physical parameters) and setting the price of carbon to $0/ton.

A dynamic baseline can be established to measure the carbon impact of an ESS project by using the actual optimization model a project uses for operations and setting the carbon price to $0/ton, holding all else constant (including operating parameters and historical forecasts driving ESS operational decisions).

$$objective\ function_{actual}\text{:}\ f(v_a, v_b, v_c, v_{carbon}, \dots) \\ = v_a \cdot p_{a_f} + v_b \cdot p_{b_f} + v_c \cdot p_{c_f} + v_{carbon_f} \times p_{carbon} + \cdots)$$

$$objective\ function_{baseline}\text{:}\ f(v_a, v_b, v_c, v_{carbon}, \dots) = v_a \cdot p_{a_f} + v_b \cdot p_{b_f} + v_c \cdot p_{c_f} + v_{carbon_f} \times 0 + \cdots)$$

To ensure the price forecasts used in the baseline calculation are the same as those used in production (and not altered to inflate or change the baseline emissions estimation), the Forecast Verification step is introduced. Forecast Verification is designed to introduce a discount factor should the half-width of the two-sided 90 percent confidence interval around the estimated reduction value exceed 10 percent of the estimated value, per VCS guidelines on uncertainty, after accounting for uncertainty in MER data. The Forecast Verification step involves running the backcast optimization model with the exact same parameters as were used in real-time operations. The delta between the demonstrated actual emissions ("actual emissions") and the emissions associated with the backcast simulation ("expected emissions") represents the transformation between a predicted emissions value and real-world emissions impact. While the expected emissions at a $0 carbon price (i.e. no carbon signal in the model) cannot be explicitly verified, it is implicitly verified when the error between actual emissions and expected emissions is sufficiently small. If the delta between actual emissions and expected emissions exceeds 8% of the total emissions reduction estimation, the emissions reductions are discounted (described in detail below). This ensures that the baseline represents a verifiable and accurate measure of the carbon impact of an ESS absent a carbon market.

DOCUMENT HISTORY

Version	Date	Comment
v1.0	February 26, 2025	Draft methodology for public consultation