ATHLAS VERITY

Renewable Energy Calculation Methodology

Metered, Grid-Displacement, AI-Verified Emission Reduction Quantification

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Reference Standards: [('cdm-ams-id', 'UNFCCC CDM. AMS-I.D Grid-connected renewable electricity generation (v18+).'), ('cm-ombm', 'CDM Tool 07: Grid emission factor (OM/BM/CM combination).'), ('iso-14064-2', 'ISO 14064-2:2019. Quantification, monitoring and reporting of GHG reductions.'), ('verra-vcs', 'Verra VCS v4.3. Program-level crediting rules and avoidance of double counting.'), ('iea-emissions', 'IEA / national grid-emission-factor datasets (approved regional baselines).'), ('ipcc-2006', 'IPCC (2006). 2006 Guidelines - AFOLU & Energy Volumes.'), ('cems-integrity', 'European Network of Transmission System Operators (ENTSO-E) generation/load data.'), ('wmo-metering', 'WMO / OIML guidance on electricity metering accuracy and calibration.')]
Status: RELEASED — COMPLIANCE
Engine: Renewable Energy Verifier Engine · **Project:** Athlas Verity Carbon Verification Engine

1. Purpose & Scope

This document establishes the standardized, fully transparent mechanism for quantifying the emission reductions (tonnes CO2e) from renewable energy generation that displaces grid-connected fossil electricity, verified by Athlas Verity. It applies baseline-and-methodology-correct emission factors and independently metered output into a single auditable pipeline.

It aligns with CDM (AMS-I.D / grid emission-factor tools), Verra VCS, and ISO 14064-2, and is prepared for compliance, verification, reporting and carbon-standard publication.

Scope — Forest Project Types

- **Solar PV** — Grid-connected photovoltaics; capacity, irradiance, metered export
- **Wind** — Onshore/offshore turbines; capacity factor, curtailment, metered export
- **Hydro / Run-of-river** — Renewable hydropower with recognized baseline treatment
- **Biomass / Biogenic** — Renewable biomass displacing fossil generation (with safeguards)

Aligned Standards

- **CDM AMS-I.D (v18+)** — Grid-connected renewable electricity generation methodology
- **CDM Tool 07** — Combined-margin grid emission factor (OM/BM/CM)
- **Verra VCS v4.3** — Program-level crediting rules and avoidance of double counting
- **ISO 14064-2:2019** — Quantification, monitoring and reporting of GHG reductions
- **OIML / WMO metering** — Revenue-grade metering accuracy and calibration practice

2. Data Acquisition (Generation & Grid)

Renewable-energy crediting is not satellite-dominated, but the engine still integrates remote-sensing and environmental datasets: irradiance (solar), wind reanalysis, and land/asset verification, combined with independent grid data. No single source is trusted alone; the table defines the operational data stack.

Sensor	Type	Retrieved Variables	Resolution / Revisit	Temporal Coverage	Role in Pipeline
Meteosat / GOES (solargis/CM-SAF)	Satellite irradiance	GHI/DNI irradiance, cloud index at project site	~1-5 km, 15-min	Continuous	Cross-checks solar generation vs irradiance
ERA5 Wind Reanalysis	ECMWF reanalysis	Wind speed/direction at hub height (10/100 m)	~31 km, hourly	1979-present	Cross-checks wind output vs wind resource
Sentinel-2 (MSI)	Passive optical	Asset footprint, land-cover, PV panel extent, vegetation baseline	10 m, 5-day	Continuous	Asset verification & land-use change safeguard
Metering (revenue-grade)	On-site I&C meters	Net export (MWh), import, auxiliary load, power quality	Interval (15-min/1-hr)	Live / period	Primary crediting input (metered output)
Grid emission-factor dataset	CDM Tool 07 / IEA / national	OM, BM, combined-margin EF (tCO2e/MWh)	Yearly	Approved vintage	Baseline grid intensity per region/year
Commission & performance records	Project O&M	Capacity, commissioning date, availability, downtime	Asset-level	Operational	Capacity & additionality verification

3. Dataset Inventory

Dataset / Product	Source	Resolution	Frequency
Metered net export (MWh)	On-site revenue-grade I&C meter	15-min / 1-hr interval	Live / monthly
Auxiliary / import load (MWh)	On-site meter	Interval	Live / monthly
Grid emission factor (OM/BM/CM)	CDM Tool 07 / IEA / national	Yearly value	Approved vintage
Irradiance (GHI/DNI)	Meteosat/GOES / CM-SAF	~1-5 km	15-min
Wind resource (hub height)	ERA5 reanalysis	~31 km	Hourly
Capacity & commissioning	Project O&M records	Asset-level	Operational
Availability / downtime / curtailment	SCADA + O&M logs	Interval	Monthly
Land-cover / asset footprint	Sentinel-2	10 m	5-day / annual
Power quality & meter calibration	OIML/WMO certified	Interval	Annual
Grid load / dispatch context	ENTSO-E / national TSO	Hourly	Live

Preprocessing note: All time-series are aligned to a common 15-min/1-hr timestamp and quality-checked (gaps, drift, multi-meter reconciliation, satellite cross-check). Emission factors are taken only from approved vintages and never substituted ad hoc; metered values are validated against satellite/irradiance/resource covariates before crediting.

4. AI Engine Architecture (Data → Grid-Displacement → Credit)

The Renewable Energy Verifier Engine is a generation-and-grid-to-credit inference pipeline. Each stage is deterministic, logged, and reproducible from raw inputs to final credits.

1. **Data Ingestion & QC**
   Ingest metered generation, auxiliary load, grid factor and environmental covariates; timestamp alignment, gap & drift detection, multi-meter reconciliation.
2. **Feature Engineering**
   Capacity factor, availability, curtailment, irradiance/wind deviance, seasonal & diurnal patterns, grid-load context.
3. **Generation Cross-Verification**
   ML anomaly detection (isolation forest / autoencoder) and regression predict expected generation from irradiance/wind; large deviations flag meter drift or data anomalies.
4. **Baseline Grid Factor**
   Select approved OM/BM/CM emission factor for the region/year; conservative handling of fuel-mix uncertainty.
5. **Gross Reduction**
   gross = net_export_MWh × EF_CM; auxiliary/import load deducted where attributable to the project.
6. **Leakage & Adjustment**
   Apply any material fuel-chain or displaced-load leakage; regionally appropriate discount factors.
7. **Uncertainty Quantification**
   Quantile / Monte Carlo (N=1000) propagate meter accuracy, grid-factor and generation variability.
8. **Calibration & Bias Correction**
   Cross-check against independent grid load data and satellite irradiance; residual bias removed.
9. **Additionality & Barrier**
   Verify project additionality (financial/regulatory barrier) and registered status before crediting.
10. **On-chain Verification**
    verifiedEmissionReductionTCO2e serialized with provenance and written to the Athlas Verity registry under AURA consensus.

5. Machine-Learning Models

The AI engine is a stacked ensemble. Cross-model disagreement is treated as a source of uncertainty, not ignored. Models are trained on historical generation, irradiance and wind data, and validated against independent metering.

Model	Input	Validation	Rationale / Output
Random Forest (RF)	Tabular features (irradiance, wind, capacity factor, temperature, seasonality); quantile variant for P10/P50/P90	Held-out metering periods; RMSE / R2 / bias	Robust generation/reduction estimate & anomaly baseline
XGBoost	Non-linear interactions among environmental & operational features	Independent periods vs meter; RMSE / R2	Handles interactions; strong tabular baseline
Deep Autoencoder (Anomaly)	Reconstruction of expected generation sequences; flags meter drift & anomalies	ROC/AUC on labeled drift events	Detects data-integrity issues before crediting
Ensemble Stacker	Outputs of RF, XGBoost, anomaly model as meta-features; ridge/GBM meta-model	Ensemble spread tracked as uncertainty budget	Final consensus estimate; spread → uncertainty margin

Training & Calibration Blocks

1. Target definition: net export (MWh) and capacity factor from revenue-grade metering.
2. Spatio-temporal folds by season & site; strict no-leakage validation split.
3. Quantile regression forests + MC dropout for calibrated P10/P50/P90 intervals.
4. Validation metrics: RMSE, R2, bias, and 95% interval coverage vs independent metering.
5. Empirical residual calibration on independent grid/irradiance data before inference.
6. Annual re-training and re-calibration of meters and factors.

> **Integrity safeguard:** spatially separate folds prevent geographic leakage; held-out field plots independently validate every prediction before any credit is issued.

6. Step-by-Step Calculation Procedure

1. **Capacity & Commissioning Verification**
   Confirm installed capacity (MW) and commissioning date from O&M records; verify grid connection status.
2. **Baseline Emission Factor**
   Select approved OM/BM/CM (EF_CM, tCO2e/MWh) for the region/year; document source vintage.
3. **Metered Generation**
   net_export_MWh = measured export - auxiliary/import (MWh), from revenue-grade meters.
4. **Gross Reduction**
   gross_tco2 = net_export_MWh × EF_CM.
5. **Leakage & Adjustment**
   Apply any fuel-chain/displaced-load leakage discount factor.
6. **Uncertainty & Conservatism**
   Monte Carlo (N=1000) on meter accuracy, grid factor, generation; credit = CI-95% lower bound.
7. **Additionality & Barrier**
   Verify additionality (financial/regulatory barrier); no credit without registered renewable status.
8. **Independent Cross-Verification**
   Satellite irradiance/wind + grid-load reconciliation confirms metered output is real and attributable.
9. **On-chain Registration**
   verifiedEmissionReductionTCO2e serialized with provenance hash; credits registered under AURA consensus.

7. Uncertainty & Conservatism

The engine reinforces structural conservatism with Monte Carlo simulation (N = 1000). Meter accuracy, grid emission factor and generation variability are drawn from distributions defined by their mean and standard deviation. The crediting boundary is the lower bound of the 95% confidence interval.

```
uncertainty_margin = max(deterministic_net - lower_crediting_bound, 0)
```

```
net_verified = deterministic_net - uncertainty_margin
```

Each calculation carries an equation trace linking every input to final output, so auditors can reproduce every figure. No permanence buffer is required (avoided emissions are instantaneous), but metering integrity and additionality are strictly enforced. Issuance never exceeds the CI-95% lower bound.

8. Numerical Example (End-to-End, Pixel to Credit)

Inputs (500 ha restoration, conservative):

- **Project:** 50 MW solar PV, grid-connected, commissioned & registered renewable
- **Satellite / env stack:** Meteosat GHI/DNI irradiance + ERA5 wind + Sentinel-2 asset footprint
- **Metered generation:** net metered export = 80,000 MWh/yr
- **Auxiliary / import:** 1,000 MWh/yr attributed to the project
- **Emission factor:** EF_CM = 0.85 tCO2e/MWh (approved OM/BM/CM, regional vintage)
- **Leakage:** No material fuel-chain leakage (solar)
- **Uncertainty:** Meter uncertainty 2%

Stage	Calculation	Result
Net Export	`80,000 - 1,000 = 79,000 MWh`	**79,000 MWh**
Gross Reduction	`79,000 × 0.85 = 67,150 tCO2e/yr`	**67,150 tCO2e/yr**
Leakage Adjustment (0%)	`67,150 × 1.0`	**67,150 tCO2e/yr**
Conservatism (CI-95%)	`67,150 × (1 - meter_unc) ≈ 67,150 × 0.979`	**65,740 tCO2e/yr**
Final verified dispatch (rounded)	`Monte-Carlo floor, lower bound`	**65,660 tCO2e/yr**

Conclusion: A 50 MW solar plant displacing grid power yields ~65,660 tCO2e/yr verified reductions — directly proportional to verified metered generation and the approved grid emission factor, after metering and grid-factor conservatism.

9. Verification & On-chain Lifetime

1. The verifiedEmissionReductionTCO2e is written to the Athlas Verity registry with a serial number per vintage (AV-RE001-{serial}) and a provenance hash of metering, grid-factor source and AI cross-verification runs.
2. AURA consensus re-checks the metering reconciliation and conservatism bounds; every credit is traceable to its metered interval and approved grid-factor vintage.
3. On retirement, the credit certificate is minted and the serial is burned on-chain, preventing double claiming of the same displaced electricity.

10. Regulatory & Compliance Framework

This section defines the compliance pathway through which AV-RE001 credits are rendered eligible, additional, monitored, and independently verifiable under recognised carbon standards. It formalises the audit requirements referenced throughout this methodology.

A. Eligibility & Applicability

Project eligibility. A project is eligible for AV-RE001 crediting only where it demonstrably falls within the applicable scope of this methodology and the governing standards: **CDM AMS-I.D (v18+) · CDM Tool 07 · Verra VCS v4.3 · ISO 14064-2:2019 · OIML / WMO metering**.

- **Boundary & commencement:** a defined project boundary, a documented start date, and enforceable legal right to the carbon rights being claimed.
- **Land/asset status:** verifiable baseline land-use or asset status at commencement, with no prior registry registration of the same credits (no double counting).
- **Additionally screen:** the activity must not be required by law, regulation, or business-as-usual practice.

B. Additionality Assessment

Additionally is established using a documented, evidence-based procedure consistent with the governing registry (Verra VCS, CDM, ISO 14064-2, or Puro.earth as applicable). The assessment applies a sequential test:

1. **Legal/regulatory test** — confirm no statutory obligation to undertake the activity.
2. **Investment/financial test** — demonstrate the activity is not clearly the most economically attractive course absent carbon revenue (economic analysis against a conservative financial benchmark).
3. **Barrier test** — identify material financial, technological, institutional, or capacity barriers that the carbon revenue overcomes.
4. **Common-practice test** — confirm the activity type is not widespread within the relevant region/asset class.

All assumptions, data, and model outputs supporting the additionality determination are retained in the audit trail for independent review.

C. Monitoring, QA/QC & Sampling Plan

Monitoring plan. A written monitoring plan defines indicators, measurement frequency, instrumentation, and data-retention rules for every crediting interval. All raw inputs (satellite scenes, field records, meter logs, mass-flow data) are time-stamped, georeferenced where applicable, and retained in the auditable registry.

Sampling design. Ground-truth and field sampling follow a stratified random design with documented sample size determined by a target confidence/precision budget, giving statistically valid estimates and defensible uncertainty bounds.

QA/QC. Quality-assurance/quality-control procedures include: duplicate and independent re-measurement checks, instrument calibration traceability, outlier screening, and reconciliation against independent data sources. Any data gap or anomaly is logged and conservatively treated.

D. Third-Party Verification & Audit Trail

Independent verification. Issuance is conditioned on independent desk review and, where required, field or on-site verification by a qualified verifier. The verifier re-checks input provenance, calculation logic, uncertainty treatment, and conservatism settings against this methodology.

Audit trail. Every issued unit carries a unique serial (AV-RE001-[SERIAL]), a provenance hash of all input datasets and model runs, and an immutable on-chain record. On retirement the serial is burned, preventing double counting and enabling independent audit at any time.

Re-verification cycle. Monitoring reports, calculations, and verifier findings are re-assessed at each crediting interval; buffer and risk parameters are re-evaluated against observed disturbance events before further issuance.

E. Permanence, Leakage & Buffer

Permanence & reversal risk. Renewable-energy generation is treated as low-permanence-risk emission avoidance: once capacity is installed and monitored, avoided emissions are not subject to sequestration reversal. A minimal **buffer** covers residual operational/accounting risk; grid-emission-factor updates are applied conservatively at each crediting interval.

Leakage. Displacement of fossil generation or demand to other grids is addressed via a system boundary that aggregates the host grid; any measurable rebound is conservatively deducted.

F. SDG Contribution & Safeguards

SDG contribution. Activities are evaluated against SDG 7 (Affordable and Clean Energy), SDG 13 (Climate Action) and SDG 8 (Decent Work). **Safeguards.** Land-use, grid-interconnection, and community engagement safeguards apply; projects avoid high-conservation-value land and reflect host regulations.

11. References

ID	Reference
cdm-ams-id	UNFCCC CDM. AMS-I.D Grid-connected renewable electricity generation (v18+).
cm-ombm	CDM Tool 07: Grid emission factor (OM/BM/CM combination).
iso-14064-2	ISO 14064-2:2019. Quantification, monitoring and reporting of GHG reductions.
verra-vcs	Verra VCS v4.3. Program-level crediting rules and avoidance of double counting.
iea-emissions	IEA / national grid-emission-factor datasets (approved regional baselines).
ipcc-2006	IPCC (2006). 2006 Guidelines - AFOLU & Energy Volumes.
cems-integrity	European Network of Transmission System Operators (ENTSO-E) generation/load data.
wmo-metering	WMO / OIML guidance on electricity metering accuracy and calibration.

12. Key Glossary

Term	Definition
MWh / GWh	Megawatt/Gigawatt-hour - unit of electrical energy generated.
EF_CM / OM / BM	Combined-margin / Operating-margin / Build-margin grid emission factor (tCO2e/MWh).
Net export	Metered generation delivered to grid, net of auxiliary/import load.
Capacity factor	Actual generation / max possible generation over a period.
Curtailment	Forced reduction of renewable output by the grid operator.
GHI / DNI	Global Horizontal / Direct Normal Irradiance.
Additionally	Emission reductions occurring only because of the renewable project.
P10 / P50 / P90	10th/50th/90th percentile of the estimation distribution.
CDM AMS-I.D	CDM small-scale methodology for grid-connected renewables.
AURA consensus	Athlas Verity on-chain verification & provenance protocol.
tCO2e	Tonnes of carbon dioxide equivalent - unit of carbon credit.
SCADA	Supervisory Control And Data Acquisition - O&M telemetry.
ISO 14064-2	Standard for quantification & reporting of GHG reductions.
MRV	Measurement, Reporting and Verification.

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14. Supplementary Notes

14.1 Purpose and Status of This Document

This methodology is provided as an informative, professional reference describing the technical design and calculation approach of the Athlas Verity carbon-verification engine. It is intended to support understanding, compliance readiness, verification, and reporting by project proponents, verifiers, and standard bodies.

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This document reflects the actual metered generation, grid, and environmental-data implementation of the Athlas Verity Renewable Energy Verifier Engine and is prepared as a reference for compliance, verification, reporting, and carbon standard publication.