PV CLIMATE TOOL

PT003

Guidance for the Use of Models Validated with Measurements in PV Climate Projects

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Contents

1 Summary

The Plan Vivo Carbon Standard (PV Climate) Methodology Requirements allow estimation of expected and actual greenhouse gas emissions using models that: i) are publicly available; ii) have been reviewed and tested for use across the full scope described in the Methodology's applicability criteria; and iii) apply conservative assumptions, parameters, and adjustments to avoid over-estimation of carbon benefits (see Methodology Requirement 1.5.1).

When models are used to estimate carbon benefits achieved, methodologies must also describe approaches for estimating model uncertainty (see Methodology Requirement 1.2.2). Parameters that this tool can be used to estimate are identified in the relevant Methodology and Modules.

This tool provides guidance on the use of models in estimation of carbon baselines, and expected and actual carbon benefits in PV Climate projects, that is consistent with Methodology Requirements 1.2.2 and 1.5.1. The tool includes guidance for calibration, validation, verification and uncertainty estimation in existing models used by projects.

The tool does not specify procedures that must be followed for model calibration and validation, but rather provides guidance on data quality and summary statistics that must be calculated. The procedures followed will depend on the type of model used and must be described in a detailed model validation report that is reviewed by a suitably qualified expert at validation and/or verification.

The tool is applicable to all PV Climate project interventions and locations and can be referenced in PV Climate Methodologies that use empirical or process-based models to estimate carbon stocks and fluxes and greenhouse gas emissions.

2 Sources

This tool refers to the following PV Climate module:

PU005 Estimation of uncertainty of carbon benefit estimates in Plan Vivo projects, Version 1.1.

3 Definitions

Model calibration = Determining a unique set of model parameters that provide a good description of the system behaviour. This can be achieved by cross-validation of model predictions with actual measurements performed on the system or other approaches such as bootstrapping or split-sample validation. In this context, the 'system' is defined by the components and interactions being modelled.

Model uncertainty = A measure of model prediction error, determined from comparison of model predicted to measured values, expressed as the percentage of the measured value at a 90% confidence level.

Model validation = The process of evaluating a model's ability to predict measured values and estimating model uncertainty.

Model validation report = A report describing model calibration and validation in the context of a specific project. Data sources for calibration and validation must also be specified.

Modelling expert = An individual or organisation with demonstrated competency in applying a specific modelling approach, within the context described by the scope of the methodology.

Parameter = A numerical variable or constant contained in a model that characterises the system being modelled.

4 Applicability Conditions

This tool is applicable to all Plan Vivo projects that estimate carbon stocks and fluxes and greenhouse gas emissions using empirical or process-based models. Models used with this tool must meet the following requirements:

- The model must be publicly available – but not necessarily freely available, for example if a license fee is required to use the model;
- It must be possible for reviewers involved in verification of the carbon benefits of the project to apply the model to generate the modelled values used by the project. Depending on the type of model, this may require clear versioning and archiving of both the model and its dependencies, stable software support so that model implementation is reliable and consistent in its performance, and reporting of sources and values for all parameters used.
- The model and its application in the project must be described in a model validation report for each verification period. The model validation report must include all the information listed in Annex A.
- Model validation reports must be reviewed by a modelling expert that is contracted by Plan Vivo or the Validation and Verification Body (VVB) reviewing the project, and that meets the minimum requirements in Annex B.

This tool can be used to estimate baseline, expected project, and actual project emissions and removals from any carbon pool and GHG emission source. When used for estimating baseline and expected project emissions and removals model validation (see Section 5.3) is not required.

5 Procedures

5.1 Data quality

All data used for model calibration and validation must be derived from appropriate and reliable sources (for example from peer reviewed studies that have been used to model similar systems) or be collected by adequately trained individuals using approaches that are appropriate to the system being modelled. A description of data sources and data collection approaches must be included in the model validation report.

The data used for model calibration and validation should describe the key outputs to be modelled, and not just intermediate state variables. For example, if a model is used to predict change in soil organic carbon (SOC), data used for model calibration and validation should be for SOC change rather than SOC stocks. Or if a model is used to predict stand level tree biomass, data used for model calibration and validation should be stand level rather than tree level.

5.2 Model calibration

Model calibration is the process of determining a unique set of model parameters that provide a good description of the system behaviour. Where possible, this should be achieved by training the model with actual data derived from measurements performed on the system. It is rarely possible to calibrate all model parameters with measurements made in the project, however, so judgement is required to select parameter values from the literature or to calibrate them with data. The choices made must be justified for all model parameters.

All models used to estimate carbon benefits must be calibrated following the guidance in this section. Projects can use existing models or models developed specifically for the project. In either case, the procedures and data used for model calibration must be appropriate for the type of model used and must be described in a model validation report for each verification period.

5.2.1 Model calibration procedures

Calibration procedures must be described in the model validation report. This description should include details of all relevant data sources and analysis, or reference to publicly available, peer-reviewed literature that include these details.

- If a model is used to estimate values in the Project Design Document (PDD), e.g. baseline or expected GHG emissions, a model validation report (including Sections 1 to 3 of the template in Annex A) must be submitted with the PDD.
- If a model is used to estimate values in monitoring reports, i.e. actual GHG emissions, the model validation report must be submitted with the PDD or a monitoring report prior to the first verification when model outputs are used.
- If a model is recalibrated during the project period, a model validation report must be submitted for each version of the model that is used to estimate expected or achieved carbon benefits.

5.2.2 Model calibration data

Data used for model calibration must:

a. Meet the data quality requirements described in Section 5.1;
b. Where possible, include measured values from strata based on geographical areas or population samples that are homogeneous with the project area(s) that the model will be applied to, based on pre-defined characteristics appropriate for the model application;
c. Be independent from data used for model validation, but cover the range of data used for validation; and
d. Be made available to reviewers on request.

5.3 Model validation

Model validation is the process of testing a model's ability to predict measured values and estimating model uncertainty.

Models used to estimate carbon benefits achieved must be validated for each stratum they are applied to. Strata must be pre-defined to ensure homogeneity of characteristics appropriate for the model application, following the guidance described in Section 5.3.1.

Model validation is not required when models are used to estimate the carbon baseline or expected carbon benefits, including when the project generates future Plan Vivo Certificates (fPVCs). In these cases, model error should be estimated and appropriate adjustments made to ensure a conservative estimate of expected project removals, for example by using the lower confidence limit for predicted values .

5.3.1 Defining strata

Model validation should be carried out separately for each stratum the model is applied to. Strata must be defined based on pre-defined characteristics appropriate to the model application. As a minimum these should include relevant geographical and environmental factors, and relevant features of the project intervention. The strata used must be defined and justified in a model validation report.

5.3.2 Model validation procedures and results

Model validation procedures and results must be described in a model validation report that includes details of all relevant data sources and analysis, if these are not described in publicly available, peer-reviewed literature.

- If a model is used to estimate values in monitoring reports, e.g. actual GHG emissions, the model validation report must be submitted with the PDD or a monitoring report prior to the first verification when model outputs are used.
- If model application extends beyond the range of factors used to define strata for which the model has been validated a model validation report that covers the full range of the model's application must be submitted.

5.3.3 Model validation data

Data used for model validation must:

a. Meet the data quality requirements described in Section 5.1;
b. Include measurements of each modelled value;
c. Be sourced from measurements within the project area(s) the model is applied to;
d. Be collected following the same procedures used for collection of model calibration data;
e. At a stratum level:
    - Be representative of at least 70% of the range of environmental conditions and management activities the model is applied to; and
    - Be representative of the time domain over which the project interventions being modelled have been applied (for example including trees of the same age as those within the areas for which the impacts of tree planting will be modelled);
f. Include at least 30 measurements in each stratum of the key predicted variables;
g. Be independent from data used for model calibration; and
h. Be made available to reviewers on request.

5.3.4 Assessment of bias

Model bias refers to the presence of systematic errors in a model that can cause it to consistently make incorrect predictions.

The model must be shown to be unbiased for each modelled value and stratum it is applied to, following the guidance in this section. For example, if a model is used to estimate SOC stocks in five strata, estimates of SOC must be unbiased in each stratum.

Data used to determine model bias must meet the requirements in Section 5.3.3.

Model bias must be calculated for each stratum with Equation 1.

$$bias(x) = \frac{\sum_{i=1}^{n}(P_{x,i} - O_{x,i})}{n}$$

Equation 1

Where:

$bias(x)$	The bias of the modelled value *x*
$P_{x,i}$	The modelled value for observation *i* of modelled value *x* in the model validation study
$O_{x,i}$	The measured value for observation *i* of modelled value *x* in the validation study
n	The number of observations in the model validation study

Model bias must be calculated separately for each modelled value (*x*) and each stratum.

A positive value for bias indicates an overestimation bias, and a negative value indicates an underestimation bias. To be considered unbiased, the bias for each stratum and modelled value must be less than 20% of the mean measured value.

5.3.5 Uncertainty assessment

Model uncertainty is a measure of model prediction error, determined from comparison to measured values, expressed at the 90% confidence level.

Model uncertainty must be assessed for each modelled value and each stratum the model is applied to, following the guidance described in this section.

Data used to determine model uncertainty must meet the requirements in Section 5.3.3.

Model uncertainty must be calculated with Equation 2.

Calculation of uncertainty of modelled values

$$U_x = z \cdot \frac{RSD_x}{V_x}$$

Equation 2

Where:

U_x Uncertainty of modelled value *x* at a 90% confidence level (percent)

z Critical value for one-tailed test of significance at a 90% confidence level and *n* -1 degrees of freedom (from t distribution table)

RSD_x Standard deviation of model residuals (i.e. the root mean squared difference between observed and modelled values) for modelled value *x* for all observations in the validation study

V_x Mean of all measured values for modelled value *x* in the validation study

Model uncertainty for different project interventions must be combined for each modelled value and each project intervention following the procedures described in **PU005**. This tool provides the procedures for calculating the uncertainty of modelled values required in PU005 Section 5.1.2. This value must then be incorporated into the calculation of an appropriate uncertainty adjustment following PU005 Sections 5.2, 5.3 and 5.4.

5.4 Model usage

When models are used to measure carbon benefits achieved, models must only be used for the strata for which they have been validated. For models that use remote sensing data, any pre- and post-processing techniques applied on the calibration and validation datasets must also be applied on all datasets used to generate modelled values. Details of models used, and evidence of calibration and validation must be provided in a model validation report whenever modelled values are reported.

6 Parameters

Data/Parameter	$P_{x,i}$
Units	Dependent on the modelled value e.g. tC, tCO_2, kg of biomass, etc.
Description	The modelled value for the observation *i* of modelled value *x* in the model validation study. The modelled value *x* can be any parameter used in the estimation or measurement of carbon benefits, with a value that is derived from application of an empirical or process-based model.
Equations	Equation 1
Source	Application of any model that meets the applicability conditions described in Section 4
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	Applicability conditions are aligned with PV Climate Methodology Requirement 1.5.1
Purpose of Data	Estimation of bias in modelled values, and calculation of uncertainty in modelled values.
Comments	N/A

Data/Parameter	$O_{x,i}$
Units	Dependent on the measured value e.g. tC, tCO_2, kg of biomass, etc.
Description	The measured value for observation *i* of the modelled value *x* in the validation study
Equations	Equation 1
Source	In situ measurement or benchmark datasets that meet the data quality requirements in Section 5.1.
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	Suitability of data used in the validation study will be assessed by a modelling expert to ensure that they are suitable for the purpose. The validation report must therefore include details of Standard Operating Procedures followed for data collection.
Purpose of Data	Estimation of bias in modelled values and calculation of uncertainty of modelled values.
Comments	N/A

Data/Parameter	n
Units	Unitless
Description	The number of observations in the model validation study
Equations	Equation 1
Source	In situ measurement or benchmark datasets that meet the data quality requirements in Section 5.1.
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	The number of observations used in the validation study will be assessed by a modelling expert to ensure that they are appropriate for the purpose.
Purpose of Data	Estimation of bias in modelled values, and calculation of uncertainty of modelled values.
Comments	N/A

Data/Parameter	z
Units	Unitless
Description	Critical value for one-tailed test of significance at a 90% confidence level and *n* -1 degrees of freedom
Equations	Equation 2
Source	t-distribution table e.g. https://statscalculator.com/tcriticalvaluecalculator
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	Established statistical method.
Purpose of Data	Estimation of model uncertainty.
Comments	N/A

Data/Parameter	RSD_x
Units	Dependent on the modelled value e.g. tC, tCO_2, kg of biomass, etc.
Description	Standard deviation of model residuals for modelled value *x* for all observations in the validation study
Equations	Equation 2
Source	Model residuals are the difference between modelled and measured values (i.e. $P_{x,i} - O_{x,i}$). The standard deviation of residuals in a validation dataset should be calculated with the equation: $$RSD_x = \sqrt{\frac{\sum(residual^2)}{n-1}}$$
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	Established statistical method.
Purpose of Data	Estimation of model uncertainty.

Comments	N/A

Data/Parameter	V_x
Units	Dependent on the measured value e.g. tC, tCO_2, kg of biomass, etc.
Description	Mean of all measured values for modelled value *x* in the validation study
Equations	Equation 2
Source	Calculated from data in the validation study.
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	See $P_{x,i}$.
Purpose of Data	Estimation of model uncertainty.
Comments	N/A

7 References

PU005 Estimation of uncertainty of carbon benefit estimates in Plan Vivo projects, Version 1.1. PV Climate Module. Available from: https://www.planvivo.org/pv-climate-methodologies

PV Climate Methodology Requirements, Version 1.2. Available from: https://www.planvivo.org/pv-climate-documentation

Annexes

Annex A – Model Validation Report Requirements

Introduction

If process-based or empirical models are used to estimate or measure carbon benefits, a model validation report must be submitted with the PDD and/or monitoring reports.

Model validation reports must be project specific and cover the full range of management activities and environmental conditions that the model is applied to.

All model validation reports must be reviewed by an approved Modelling Expert contracted by the VVB or Plan Vivo. Modelling Experts must be approved by Plan Vivo for each review to ensure they meet the requirements in Annex B. Approved model validation reports will be published on the Plan Vivo website.

Model validation reports must include full details of models used and all parameters and calculations made to calibrate and validate models. On request, Modelling Experts must also be provided access to the version of the model(s) used and all datasets used for calibration and verification.

The minimum requirements for information to be included in a model validation report is specified below.

1. Model Details

- Provide a general description of the model(s) applied with details of the model developers, application outside the project, reference to the version of the model applied and details of how the model can be accessed.
- On request, Modelling Experts must be provided with a version of the model(s) used.

2. Scope of Model Application

- Describe the environmental conditions and management activities that the model is applied to, with details of any stratification used for application of predictions.
- If model predictions are generalised within strata, identify all strata the model will be applied, describe the factors used for stratification, and justify why these are appropriate to the model application with reference to relevant geographical and environmental factors and relevant features of the project intervention.

3. Model Calibration

- Describe the procedures and data used for model calibration, with details of all parameters used and/or algorithms selected and an explanation of why they are appropriate to the model application.
- Provide full details of datasets used for calibration, and the justification for splitting data for use in calibration and model validation. Details provided must include sample locations, environmental conditions and management practices at the sample sites (with reference to any strata identified in the Scope of Model Application)
- Data used for model calibration must be made available to reviewers on request.

4. Model Validation

- Describe the procedures and data used for model validation with details of all parameters used to initialise and run the model.
- Provide full details of datasets used for model validation, including sample locations, environmental conditions and management practices at the sample sites (with reference to any strata identified in the Scope of Model Application).
- Data used for model validation must be made available to reviewers on request.

4.1 Assessment of Bias

- State the level of bias for each modelled value in each stratum the model is applied to.
- Calculations for assessment of bias must be made available to reviewers on request.

4.2 Uncertainty Assessment

- State the model prediction error for each modelled value in each stratum the model is applied to.
- Calculations for assessment of model prediction error must be made available to reviewers on request.

Annex B – Modelling Expert Requirements

All model validation reports must be reviewed by a modelling expert that is contracted by the VVB carrying out a project validation or verification, or by Plan Vivo (for projects following the microscale validation and verification approaches). The modelling expert must complete a report based on a review of the model validation report that describes whether the model and its application is in compliance with the PT003 Guidance for the Use of Models Validated with Measurements in PV Climate Projects.

Modelling experts can be individuals, groups or organisations that meet the minimum requirements below:

- Demonstrated competence in the application of the modelling approaches used by the project.
- Experience of using any software programmes necessary to implement the model(s) used by the project.
- Freedom from conflict of interests with the project.

Evidence that modelling experts meet these criteria must be provided to Plan Vivo before they are contracted to review a model validation report. A list of approved modelling experts is provided on the Plan Vivo website.