Comments on the "science" of measuring carbon credits for *Human-induced regeneration of a permanent even-aged native forest* and *Avoided deforestation.* C.L. Brack

Australian carbon credit units (ACCUs) are earned when carbon is stored as a result of approved/relevant project activities. Approved projects related to *Human-induced regeneration of a permanent even-aged native forest* use the Full Carbon Accounting Model (FullCAM) tool to estimate carbon stocks. The FullCAM tool is a hybrid of empirical and process modelling that enables application to a wide range of natural resource management issues because it processes at land-management-relevant spatial (sub-hectare) and temporal resolution (monthly) while incorporating the main process and management drivers. The empirical data is used to constrain or calibrate the process modelling to observations and ensure non-measured factors (e.g. insect herbivory) are incorporated. The process model is a simplified version of a widely used and accepted model – 3PG (Physiological Processes Predicting Growth). The empirical data was originally derived from "extensive field data (both already available and specifically collected)" [1] and is continually expanded as new datasets become available or are commissioned to fill perceived gaps [2]. FullCAM development included sensitivity modelling to determine the impact/bias/imprecision of carbon stock estimates due to heterogeneity in model parameters or calibration [1]. The most significant of these (weather and site) would not be of concern for human-induced regeneration projects because stock estimates are made in retrospect once the weather and site for the project is known. Estimates of carbon stock by FullCAM at the sub-hectare level can be imprecise, but independent validation exercises, including the most recent analysis (of over 2,300 biomass estimates from environmental and mallee plantings or natural regeneration across Australia) concluded that there is "no apparent bias in FullCAM-predictions of [above ground biomass, and hence in carbon stocks]" when appropriate strata and management parameters are used [2].

FullCAM is flexible and updated calibrations can easily and transparently be incorporated. The full development and application of FullCAM has been published in peer-reviewed scientific journals at national [3] and international levels [1, 4]. The science behind FullCAM, and therefore the science behind estimating the carbon stock of *Human-induced regeneration of a permanent even-aged native forest* may be considered efficacious, robust and appropriate.

However, technical or procedural shortcomings can cause estimates of carbon stocks to be unreliable when FullCAM is provided with initial conditions or management drivers that are inappropriate or erroneous. For example, the age of regeneration becomes uncertain when land managers are unsure of when the human-induced regeneration began. Age, especially relative to the age of maximum annual increment, is a major term in the FullCAM models and an error in age would introduce a systematic distortion in the annual stock change (bias). Similarly, classifying land as being completely cleared for agriculture will introduce a bias in FullCAM when there are in fact remnant trees or shrubs. The carbon stocks in these remnants should not be included in the human-induced regeneration, but these remnants could also significantly slow down any competing human-induced regeneration. Good quality management records and detailed mapping to exclude remnant vegetation (including vegetation that is not forest) is required for unbiased estimates of *Human-induced regeneration of a permanent even-aged native forest*.

Unlike the above, estimating the carbon stocks relevant to *Avoided deforestation* does not use any process modelling or model GIS/spatial modelling to estimate carbon stocks. The method relies on empirical relationships (allometric models; root:shoot ratios; partitioning factors, emissions factors, burn efficiency, decay rates) and simple random sampling (optionally within strata). Sampling is used to develop or validation the allometric models and enumerate all the potentially harvestable trees

by diameter at breast height and species. Previously developed allometric model may be used when the project is within the domain and validated, but otherwise new allometric models need to be developed from destructively sampled data. It is recommended, but not required, that professionals are contracted to collect and analyse the tree data because the process is technically complex and errors can be easily introduced. The empirical data is selected from published *National Vegetation Information System Major Vegetation Groups*. These group data may be biased at project level.

The methods to collect the destructive sample data and the tree enumeration data are well described, use statistically credible approaches and have been peer reviewed. These methods are not particularly efficient (relatively high effort for the resulting precision) as they do not take advantage of modern sampling or mensurational theory [5], but nevertheless should produce unbiased estimates of above ground stem biomass. A long sequence of mathematical equations is detailed to convert this estimate of above ground stem biomass to biomass and carbon in the various pools for a baseline scenario; emissions caused by management requirements; and ultimately carbon stocks not emitted as a direct consequence of the project.

In addition to avoiding otherwise approved deforestation, the proponent must manage the project area to achieve a mix, in terms of composition and structure, of trees, shrubs and understory plants that occur naturally in the area of the project. Monitoring programs are required to demonstrate continued forest management as well as providing evidence that the forest remains undisturbed by fire or similar events.

In conclusion:

- Provided the input values, stratification and management drivers are appropriate, the estimates of carbon stocks for *Human-induced regeneration of a permanent even-aged native forest* rely predominately on the science of FullCAM which has been well publicised, peer reviewed and validated;
- The estimates of carbon stocks for *Avoided deforestation* rely predominately on the accurate and "good faith" implementation of the random sampling methods (for destructive sampling and stand enumeration) and development/validation of the allometric models. The stock estimates are suitable provided the samples are representative of the project area and disturbance or other events that mean the original samples are no longer representative are appropriately mapped and separately evaluated.
- Spatially precise and reliable management records are essential to demonstrate the timing and effectiveness of human-induced intervention and/or active decisions to cease previously approved and feasible deforestation activities.

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