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California air resources board forest carbon protocol invalidates offsets

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The commercial asset value of sequestered forest carbon is based on protocols employed globally, however, their scientific basis has not been validated. We review and analyze commercial forest carbon protocols and offsets, claimed to have reduced net greenhouse gas emissions, issued by the California Air Resources Board and validated by the Climate Action Reserve (CARB-CAR). CARB-CAR protocol annual offsets, resulting from forest mensuration and growth simulation models, are compared with a population of forest field sites for which annual net ecosystem exchange (NEE) of carbon was measured directly as flux by CO_2 eddy covariance, a meteorologically based method integrating forest carbon pools. We characterize differences between the protocols by testing the null hypothesis that the CARB-CAR commercial annual offset data fall within the boundaries of directly measured forest carbon NEE; gC $m^{-2}yr^{-1}$ are compared for both datasets. Irrespective of geographic location and project type, the CARB-CAR population annual mean value is significantly different from the NEE population mean at the 95% confidence interval, rejecting the null hypothesis. The CARB-CAR population exhibits standard deviation ~5x that of the NEE natural ranges; the variance exceeds the 5% compliance limit for invalidation of CARB-CAR offsets. Exclusion of the soil carbon pool typical for CARB-CAR net carbon budgets pose insuperable carbon accounting uncertainty for offsets that extend to vendor platforms and policies including the United Nations Program on Reducing Emissions from Deforestation and Forest Degradation and the Paris Agreement. NEE methodology for commercial forest carbon offsets ensures *in situ* molecular specificity, verification of claims for net carbon balance, performance-based pricing and harmonization of carbon protocols for voluntary and compliance markets worldwide, in contrast to continuing uncertainty posed by traditional estimation-based forest carbon protocols.

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Methodology Review

California Air Resources Board Forest Carbon Protocol Invalidates Offsets

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Abstract

The commercial asset value of sequestered forest carbon is based on protocols employed globally, however, their scientific basis has not been validated. We review and analyze commercial forest carbon protocols and offsets, claimed to have reduced net greenhouse gas emissions, issued by the California Air Resources Board and validated by the Climate Action Reserve (CARB-CAR). CARB-CAR protocol annual offsets, resulting from forest mensuration and growth simulation models, are compared with a population of forest field sites for which annual net ecosystem exchange (NEE) of carbon was measured directly as flux by CO_2 eddy covariance, a meteorologically based method integrating forest carbon pools. We characterize differences between the protocols by testing the null hypothesis that the CARB-CAR commercial annual offset data fall within the boundaries of directly measured forest carbon NEE; gC $m^{-2}yr^{-1}$ are compared for both datasets. Irrespective of geographic location and project type, the CARB-CAR population annual mean value is significantly different from the NEE population mean at the 95% confidence interval, rejecting the null hypothesis. The CARB-CAR population exhibits standard deviation ~5x that of the NEE natural ranges; the variance exceeds the 5% compliance limit for invalidation of CARB-CAR offsets. Exclusion of the soil carbon pool typical for CARB-CAR net carbon budgets pose insuperable carbon accounting uncertainty for offsets that extend to vendor platforms and policies including the United Nations Program on Reducing Emissions from Deforestation and Forest Degradation and the Paris Agreement. NEE methodology for commercial forest carbon offsets ensures *in situ* molecular specificity, verification of claims for net carbon balance, performance-based pricing and harmonization of carbon protocols for voluntary and compliance markets worldwide, in contrast to continuing uncertainty posed by traditional estimation-based forest carbon protocols.

Keywords: net forest carbon sequestration, carbon markets, carbon trading, California Air Resources Board, carbon offset uncertainty

1. Introduction

Carbon markets ideally conserve natural resources[1,2], limit surface warming to < 1.5 ˚C relative to the pre-industrial period[3–5], and are commercially viable[6–8]. However, uncertainty in carbon product asset value[9] and market function can negatively affect carbon markets and their efficacy to manage climate change[10–13]. For example, global carbon compliance markets have declined from ~$95B€ in 2011[14] to $41B€ in 2017[15], a decrease of ~57%, attributed to the absence of a price for carbon[16], oversupply of offsets[17,18], ambiguity of disparate trading platforms[19], and as we argue here for forest carbon, absence of direct and verifiable measurement of CO_2 and related carbon storage products[20–23]. An unprecedented 3.4 ppm surge in atmospheric CO_2 in 2016 related to the 2015/2016 El Nino event[24,25], and updated projections for warming by the Intergovernmental Panel on Climate Change (IPCC)[5], call into question the efficacy of carbon markets (e.g. cap-and-trade[26], carbon tax[27]) to manage Earth's changing climate[8,28]. Carbon markets are primarily driven by reduction/avoidance of emissions to the atmosphere from energy production and consumption[29] while investment in removal of CO_2 from the atmosphere by reforestation and conservation has not gained carbon market traction[30,31] and has declined by ~ 72% from 2011 to 2016[32,33]. To-date, global forests have been reduced by ~35-46% relative to the preindustrial period[34,35]. Deforestation continues at a rate of ~ 1.5M $km^{-2}yr^{-1}$ (e.g., 2000 to 2016) and is exclusively caused by anthropogenic activities[36]. Global forests are in a state of flux; reversal of deforestation is geographically uneven and continues to increase overall[37], underscoring the importance of validating forest carbon markets. Approximately 1 to 2 billion hectares of degraded and deforested land represent a unique opportunity for humanity to reclaim these areas for restoration and partial management of atmospheric CO_2[38–41]. Forests provide ecosystem services of soil carbon sequestration and water conservation[42], biodiversity safeguards[43], and the coupling of avoided forest carbon emissions with Indigenous Peoples habitation[44,45]. While reforestation and natural regeneration projects address climate change mitigation in the contemporary context[5], are readily implemented at low cost[40,46] and are of social and planetary value[35], they face the same accounting uncertainties and measures of carbon sequestration efficacy[41,47] as for carbon emission reduction approaches worldwide posing a barrier to market acceptance of forest carbon sequestration trading and improved rates of sustained reforestation[22,48]. The efficacy of protocols for determination of net forest carbon sequestration are of importance in catalyzing forest restoration and conservation efforts but have not been independently validated.

Here we review and assess the suitability and uncertainty of widely employed net forest carbon sequestration protocols[49], their scientific validity, impact on the value of carbon markets and efficacy in reducing the burden of atmospheric CO_2. Specifically, we analyze annual forest carbon offset results for the California Air Resources Board[50] (CARB) responsive to the Global Warming Solutions Act of 2006 (California Assembly Bill 32[51]). The CARB issues carbon offsets based on determination of net forest carbon sequestration according to CARB and Climate Action Reserve (CAR) protocols[52–55] (CARB-CAR); ~111 million metric tons of CO_2 equivalent (CO_2e)[i] have been issued since 2006[52]. The CARB-CAR protocols employ limited forest mensuration practice (e.g., forest survey every six years or longer; incomplete carbon pool accounting), vegetation proxies[56], estimated baselines and growth simulation models[57,58] that must quantify net carbon sequestration as real, additional, permanent, verifiable, and enforceable[54,55,57]. The CARB compliance rules stipulate invalidation criteria for offsets that exceed 5% of actual net forest carbon for a period of up to eight years[55,59]; CARB-CAR offsets have not been independently evaluated for this criteria. The CARB-CAR protocols share intrinsic numerical equations, carbon pool estimation terms, and model simulation parameters with the Clean Development Mechanism[60] (CDM), the American Carbon Registry[61,62] (ACR), the Verified Carbon Standard[63] (VCS) and the Gold Standard[64] (GS) (Supplement 2). The CARB-CAR and related forest carbon estimation protocols lack development of direct *in situ* measurement of gaseous project CO_2 programs and have not been validated by comparison with direct measurements.

To address validation of the CARB-CAR protocol, we compare a population of annual CARB-CAR values for net forest carbon sequestration, the basis for forest carbon offsets, with a population of annual values for projects that were monitored directly, *in situ*, for molecular CO_2 net flux, and characterized statistically[65] (referred to here as NEE1). The NEE1 data are based on globally applied eddy covariance methods[66,67] to quantify net carbon sequestration, or net ecosystem exchange (NEE) (also referred to as net ecosystem production (NEP)[68,69]) (Methods) as tCO_2e or gC $m^{-2}yr^{-1}$. NEE represents the meteorologically integrated net ecosystem carbon exchange of all carbon pools resulting from direct, high precision and high frequency measurement (continuous or semi-continuous) of the vertical gross CO_2 fluxes for photosynthesis (i.e., CO_2 assimilation) and ecosystem respiration (i.e., above ground respiration by plants and CO_2 efflux as soil respiration from autotrophic and heterotrophic soil microbes)[68]. While eddy covariance and CARB-CAR methods represent differing scales of observation[55,70,71], not controlled for in this study, we analyze population level differences for annual values across similar geographic regions. Eddy covariance is independent of CARB-CAR and related protocols that lack direct measurement of gaseous CO_2, however, the result of both methods is determination of annual net forest carbon sequestration[54,55,65] expressed in equivalent units of gC $m^{-2}yr^{-1}$ as reported (or as converted) for the projects. Both project methods are applied to forested environments over annual periods to determine NEE. The NEE1 and CARB-CAR projects, while representing different locations, with one exception (Howland, ME, USA) discussed below, share overlapping ecological (e.g., landcover) and forest characteristics of regions in the US common to both data sets including coastal and inland environments.

Statistical comparisons of the two project populations of annual forest carbon data were undertaken to reveal shared population characteristics, the accuracy and precision resulting from the CARB-CAR protocol methods relative to NEE1 annual values and by extension protocols that share CARB-CAR methods for determination of net forest carbon sequestration. We tested the null hypothesis that the CARB-CAR annual population mean for net forest carbon sequestration data fall within the statistical boundaries of the NEE1 project annual population mean[65]. Moreover, given the absence of direct CARB-CAR CO_2 measurement to test compliance thresholds, we incorporate this criterion in our analysis relying upon NEE1[65] as a reference population for annual net forest carbon values. In view of the statistical differences between the two populations, we assess and summarize the uncertainty, accuracy and precision of the CARB-CAR protocols, their effect on pricing of forest carbon products and their impacts on carbon market integrity. We also review implications of our findings for policy driven forest carbon programs including the REDD[72], the Paris Agreement[73] and the AB32 Legislation[51].

2. Results

Table I summarizes the CARB-CAR project sites (n = 63) and attributes considered in this study. Links to serial numbers for offsets issued and to summary pages of the CAR online documentation are provided. Features of the CARB-CAR process representing incomplete carbon accounting are identified: 1) exclusion of the soil carbon pool is confirmed for all CARB-CAR projects (Methods, CARB Protocols), 2) selected projects record single vintage year carbon sequestration but underlying data are arbitrarily assigned to partial years of carbon sequestration (63 instances). Protocol inconsistencies noted include: 1) model operations are arbitrarily executed as forward and backward runs relative to the start date of the project (33 instances), 2) anomalous initial year values are reported as a single vintage year but represent a different and arbitrary carbon accounting process compared to subsequent vintage years (31 instances).

Statistical analysis of CARB-CAR and NEE1 annual data were analyzed as two independent samples allowing comparison of the populations for similarities and differences. All annual values from the datasets are used in the analyses (i.e., gC $m^{-2}yr^{-1}$ annual carbon-to-carbon results comparison) and obtained from CARB-CAR and NEE1 sources (Table 1, Methods, Supplement 1). We first test the hypothesis that the results for

CARB-CAR population data, pooled across all annual intervals, for net forest sequestration fall within the NEE1 population median, mean and standard deviation (SD, ±) employing box plots (Figure 1 (a), (b)) and calculation of mean and SD. Selected segments of overlapping time intervals for the two populations, excluding outliers, are then used to test the null hypothesis that the large difference in mean values between CARB-CAR and NEE1 populations were drawn from the same underlying population (Figure 2). Overlapping time intervals are also employed to test that the CARB-CAR 5% threshold of invalidation is not violated (Figure 3) for annual average net forest sequestration values of CARB-CAR projects. The hypothesis that the CARB-CAR population data does not violate the 5% invalidation rule employing p-values for the difference in means for both populations (Table II) for all overlapping years is then tested. Comparison of specific CARB-CARB and NEE1 sites, with links to source data, can be explored with the interactive project map provided (Supplement 1). Differences in mean values for CARB-CAR and NEE1 data noted to emphasize the inconsistency between the methods are expressed as percentage errors where applicable[ii]. A review of the numerical equations employed in the CARB-CAR and related protocols is presented in Supplement 2 and referenced in the Discussion.

Figure 1 (a) presents a box plot of annual records from CARB-CAR (63 sites, 340 annual records) and NEE1[65] (59 sites, 540 annual records) projects (Table I, Supplement 3). The box plot shows the median (white line through each box), the 25th percentile (bottom of lower box), the 75th percentile (top of upper box), the upper and lower whiskers representing respective values that are not outliers, and outliers (individual open circles). The CARB-CAR data is left-skewed, meaning that it has an abnormally large number of small magnitude outliers, in this case representing extreme values for carbon sequestration. The skewness and kurtosis for the CARB-CAR dataset are -3.69 and 17.67 as compared to the NEE1 dataset of 0.25 and 2.31, respectively. Outliers are detected as points smaller than the 25th percentile by at least three times the interquartile range (the difference between the 75th and the 25th percentile). It is notable that both datasets contain outliers. NEE1 contains both small and large outliers, while all extreme values in the CARB-CAR data are of very small magnitude. Figure 1(a) shows the difference in distribution, central values and outliers between the populations. Due to the skewness of the CARB-CAR data, we present a selected interval of the box plot excluding the CARB-CAR outliers in Figure 1 (b) to further illustrate the differences between the populations. The box plot (Figure 1 (b)) shows the difference for the CARB-CAR median of -445.4 gC m^{-2}yr^{-1} as compared to the NEE1 median value of -172.5 gC m^{-2}yr^{-1} corresponding to the larger spread and left-skewness of CARB-CAR values. The population means and standard deviations (±), considering all annual values (Figure 1(a)) of the CARB-CAR and NEE1 datasets are, respectively, -948.8 ± 1,504.8 gC m^{-2}yr^{-1} and -198.0 ± 261.6 gC m^{-2}yr^{-1} representing an extreme range of 5x the value for CARB-CAR forest carbon sequestration

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relative to the NEE1 population data[65]. The difference in mean values between the two populations is significant at the 95% confidence level, rejecting the null hypothesis that the CARB-CAR population mean falls within the NEE1 population mean. The error of over-estimation is ~79% for the CARB-CAR protocol based on the populations sampled. The corresponding reduction in precision (standard deviation) for the CARB-CAR population is ~82% relative to the NEE1 population. Both populations exhibit positive emission values to the atmosphere; the CARB-CAR data are comprised of 3 positive values (maximum = 771.5 gC $m^{-2}yr^{-1}$, CAR676) compared to 116 NEE1 positive values (maximum = 1269.1 gC $m^{-2}yr^{-1}$, US-Miz).

Given the large difference in sample means for the CARB-CAR and NEE1 datasets it is conjectured that the true population means are also significantly different. The null hypothesis is set that the two sample populations were drawn from the same underlying population of annual values. In Figure 2 a plot of the 95% confidence interval for the difference in means between the CARB-CAR and NEE1[65] annual measurements for all years available and for the selected years of 2007 and 2008 is shown. The combined data set consists of 340 CARB-CAR and 540 NEE1 data points ("Total"), each reported as representing an annual cycle determined by each methodology. A formula for a large-sample confidence interval (Methods) is used for the bar labeled "Total"; no assumption on equal standard deviations between the two data sets has been made. Amongst the years with overlapping data (2001-2014), we choose 2007 and 2008, as they have the largest number of combined sample points, 65 in 2007 (23 for ARB and 42 for NEE1) and 65 in 2008 (24 for ARB and 41 for NEE1). The top and bottom of the open bars represent the range of the difference between the CARB-CAR and the NEE1 means with a 95% confidence level. The filled square symbol below each bar represents the 5% estimation error allowed by CARB-CAR. The null hypothesis that the two data sets come from the same population is rejected. The 5% estimation error does not overlap with the 95% confidence interval demonstrating that the CARB-CAR estimates are more than the allowed 5% from the NEE1 measurements. The standard deviation for the CARB-CAR data is very large compared to the NEE1 standard deviation, irrespective of the year. For example, in 2008, the standard deviations for CARB-CAR and NEE1 were respectively, 1,170 and 255 gC $m^{-2}yr^{-1}$, a 5x over-estimation difference. This leads to a very wide confidence interval that also establishes that the CARB-CAR project data are invalid based on the permitted 5% compliance margin of error. To our knowledge, no CARB-CAR compliance testing of project results has been reported.

Figure 3 shows a time interval plot of CARB-CAR annual data from 2002 to 2015 and NEE1 annual measurements[65] from 1992 to 2015 to further test the invalidation of CARB-CAR offsets according to the 5% invalidation compliance rule. The averages for the two data sets are shown by each vertical bar representing forest carbon sequestration

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calculated annually over all available locations. The selected intervals are absent first year data for the CARB-CAR population to present a conservative case for testing the null hypothesis. The year 2006 was selected, in which the largest average carbon offset by CARB-CAR sites (n = 12) has been recorded, namely -2,038 gC $m^{-2}yr^{-1}$, and apply the corresponding 5% admissible error of 101.9 gC $m^{-2}yr^{-1}$ to all CARB-CAR years, shown as error bars for each CARB-CAR year. No intersection between the admissible interval and the actual NEE1 measurements for any of the overlapping years (2001-2015) is observed. In addition, note the general consistency of the NEE1 averages through the interval versus the comparatively large year-to-year fluctuations observed for the CARB-CAR dataset that are not consistent with natural ecosystem carbon sequestration values. The null hypothesis is rejected indicating that the CARB-CAR data are invalid by exceeding the 5% validation compliance threshold for the years represented in this analysis.

Next, a detailed comparison between the population data sets, year by year, to further test the 5% invalidation threshold for the CARB-CAR data is presented . Table II shows the results of a hypothesis test with a null hypothesis that the difference between the CARB-CAR and the NEE1 annual means is under the allowed 5% threshold. The test is performed separately for all years between 2002 and 2015; p-values are recorded in the last two rows of Table II. The p-values range from 0.00 to 0.065. Typically, p-values smaller than 5 to 10% demonstrate a rejection of the null hypothesis. The results reject that the estimation error is within the allowed 5% value, with three exceptions. In the case of years 2004, 2013 and 2014, the p-values are higher than 5% (6.53%, 5.48% and 5.24%). In the case of years with p-values > 5% (2004; p = 0.065, 2013; p = 0.055, 2014; p = 0.052) the probability that the CARB-CAR data were not out of the norm is only 1.87 x 10^{-4} %, supporting the null hypothesis rejection.

3. Discussion

Results of the protocol review (Table I) and statistical tests (Figs. 1- 3) challenge the scientific basis of the CARB-CAR protocols for determination of NEE, the efficacy of compliance testing, and suitability for global carbon currency financial transactions. The analysis and assumptions were guided by the absence of CARB-CAR direct measurement of molecular CO_2 to validate, at the program level, widely employed estimation protocols and regulatory compliance testing. Irrespective of geographic location, project type and size of land area analyzed, results of the statistical analysis reject the null hypothesis that the population of annual means for CARB-CAR lies within the boundaries of the directly measured NEE1 population of annual means (e.g., CARB-CAR and NEE1 annual mean and SD are -948.8 ± 1,504.8 gC $m^{-2}yr^{-1}$ and -198.0 ± 261.6 gC $m^{-2}yr^{-1}$, respectively). The population mean and standard deviation for CARB-CAR data are linked to arbitrary and inconsistent features of the project protocols (e.g., exclusion of soil carbon pool, Table I) resulting in over-estimation errors for NEE of up to ~79 % and a reduction in precision of ~5x relative to the NEE1 population (e.g., difference in standard deviations), documenting irreconcilable differences between the respective methodologies. The CARB-CAR method, based on averages of spatial observations for representative forest plots across a project area, would be expected to exhibit less variance compared to NEE1 results (e.g., single or multiple NEE observation platforms), however, the opposite trend is observed. The exclusion of the soil carbon pool (Table 1) renders CARB-CAR net carbon balance incomplete and invalid, consistent with the statistical results. The soil carbon pool is critical to understanding carbon dynamics, a factor of importance to all stakeholders (e.g., landowners, carbon vendors, policymakers). For example, the ratio of night-time ecosystem respiration to gross primary production is rising across the FLUXNET2015 dataset population[74] suggesting that global soil respiration (e.g., heterotrophic) is responding to climate and environmental factors, a trend not observable with CARB-CAR protocols; these trends cannot be detected or quantified with traditional protocols. The consequences of forest carbon protocol invalidation (e.g., CARB, CAR, CDM, ACR, VCS, GS) cannot be underestimated as they are employed in response to legislation (e.g., AB32[51]) and are the foundation for monetization of carbon operations of the United Nations Reducing Emissions from Deforestation and Forest Degradation (UN-REDD, REDD+) program[75] and proposed carbon offset trading within the Paris Agreeement[16]. CARB-CAR transactions involving approximately 1.3M acres (~0.53M hectares) represent a minor fraction of < ~0.2% of available US forest area of ~766M acres (~310M hectares)[76]. Corresponding market share of offset volume for CARB-CAR forest carbon product in 2016 is estimated at ~3 % representing ~2 million tCO_2e compared to 63.4 million tCO_2e for voluntary forest carbon transactions[77]. The low CARB-CAR forest program adoption rate and offset volume reflect the cost, constraints and risk of invalidation intrinsic to the CARB-CAR forest carbon offset program[78,79]. Results of the statistical analysis, documentation of absence for direct CO_2 validation, and demonstration of exclusion for the soil carbon pool, converge on invalidation of net emission reduction claims and resulting financial products by CARB-CAR protocols.

Our results are supported by updated NEE analysis (1,163 site years, covering 155 global sites) reporting a mean and SD of -156 ± 284 gC $m^{-2}yr^{-1}$, respectively[41].; these annual data are inclusive of the NEE1[65] results reported herein but lack detailed statistical analysis and tabulated values for ecosystem photosynthesis and respiration. The expanded NEE comparative population of annual data[41,65] represent upper (e.g., net positive CO_2 to the atmosphere) and lower boundaries (e.g., extreme net carbon sequestration) of the natural range for net forest carbon flux across global, diverse forest ecosystems. The CARB-CAR population does not reflect negative or positive annual values of reported known natural ranges for NEE[41,65]. The multiple null hypothesis rejections employing all annual values (Figure 1 (a), (b)), annual values excluding initial-year values (Figure 3), and overlapping

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segments of the values (Figure 3, Table I) addressing the 5% invalidation rule, we argue that the ~111 million CARB-CAR forest carbon offset credits issued and pending[60], valued at ~ $1B USD (estimated using a 2015 average price of $9.70 USD per offset credit[80]), are invalid in the absence of observation and measurement of CO_2. Accordingly, buffer pools of CARB-CAR offsets to mitigate invalidated project outcomes are of limited value for compliance enforcement. We know of no alternative method to test CARB-CAR projects for compliance (e.g., 5% invalidation rule) other than by the statistical analysis presented. Examples of minimum forest mensuration methods to determine NEE, comparable to eddy covariance results[69,81,82], reveal the insuperable shortcomings of the CARB-CAR methods (Methods) relative to the complexity of annual and interannual forest carbon dynamics and the validation requirement for carbon financial products. Cost factors prohibit annual forest mensuration, including measurement of soil and ecosystem respiration, required to improve and validate CARB-CAR project reporting relative to eddy covariance results for NEE. Such costs would be in addition to the existing costs for landowners noted for carbon offsets[78,83,84]. Recognizing the urgency in utilizing and quantifying[41,85] all available strategies to manage atmospheric CO_2 and the availability of land for reforestation, improved, cost-effective, harmonized protocols for forest carbon sequestration are required to fulfill the objectives of climate change policy[5] and carbon financial markets[19].

Protocol Process. Annual NEE is typically calculated from 30″ observation intervals based on CO_2 measurement acquired at 10 Hz referenced against universal internal and external gas standards employed for CO_2 analyzers (Methods). The raw CO_2 data are checked for quality and archived for public access[86]. In contrast, the CARB-CAR (Table I, footnote 1) and related protocol reporting process is inconsistently applied across project reporting years and is not subject to quality checks against shared standards and references[49]. Selected CARB-CAR projects inconsistently apply carbon accounting methods across project years, for example, conflating timber inventory with annual net carbon determination (e.g., gC $m^{-2}yr^{-1}$) for initial years resulting in anomalous values (Figure 1 (a), Table I, 31 instances). Annual NEE1[65] data are devoid of similar outliers as only net flux of CO_2 is used in its determination for each year (Figure 1 (b)). Every year is treated in the same way; there is no "first year effect" upon initiation of NEE forest monitoring. In contrast selected CARB-CAR initial-year data derived by estimation[53 87] is treated differently than subsequent vintage years. Such initial year data may represent aggregate carbon sequestration that might have occurred prior to the project and that while reported as a single vintage year or less (Table I), cannot be verified as having occurred in any given annual interval(s). To avoid mis-representation as a single annual net carbon sequestration value, as it is currently defined[52], this value should be removed from calculated sequestered carbon accounting due to the uncertainty and arbitrary time value assigned to this component of the CARB-CAR protocol. CARB-CAR protocol reporting inconsistencies compound the issues of validation and reliability for stakeholders. For example, vintage year discrepancies appear to increase with newer projects (Table I) and are concentrated in California (Supplement 1), suggesting less stringent application of the CARB-CAR protocol process and a retraction of spatial and ecological representation across the US.

Soil Carbon Exclusion. CARB-CAR projects categorically exclude the soil CO_2 and related carbon pools[55] (e.g., RF-6, IFM-6, AC-6, Methods, Table I), the primary component of ecosystem respiration and determinant of NEE[65,87,88]. Soil carbon content represents up to three times the magnitude of above ground carbon composition and up to ~80% of ecosystem carbon exchange[41,87–89]; it cannot be excluded from a complete, scientifically valid, net material carbon balance[90–92] for a forest project. In the case of CARB-CAR avoided carbon (e.g., AC) projects, specific to wetlands, while sampling of bulk soil carbon is recommended[93], a corresponding term for soil carbon and CO_2 efflux (e.g., AC-6) is excluded from calculation of net GHG reduction (Table I). The NEE1 observations reported here are calculated using data for ecosystem respiration (R_{eco}) and Gross Primary Productivity (GPP) (e.g., NEE=GPP – R_{eco})[65]. The R_{eco} to GPP ratio (e.g., R_{eco}/ GPP) for the NEE1 sites yield a mean of 0.79 ± 0.29 gC $m^{-2}yr^{-1}$ ($n = 50$)[65], emphasizing the importance of soil and ecosystem respiration, accounting for up to ~79% of the NEE, in determination of accurate net forest carbon sequestration. The tight coupling between GPP and Reco is supported by an expanded NEE data set[41]. It follows that CARB-CAR results are in excess by at least the magnitude of soil carbon efflux or ecosystem respiration for each of the CARB-CAR sites, identifying a systemic bias of carbon excess and error in CARB-CAR and related protocols. The lack of direct observation of CO_2 fluxes inherent in the CARB-CAR and related protocols in which credit offsets are created by model forecast (e.g., *ex-ante*) impose systemic and insuperable invalidation risk for the CARB-CAR results. CARB-CAR carbon accounting errors result in loss of atmospheric benefit and carbon asset value, established through carbon market transactions to landowners, offset buyers and sponsoring entities (e.g., the State of California). Moreover, the CARB-CAR credit offsets do not satisfy the ARB Compliance Offset Protocol for U.S. Forest Projects requirement that net greenhouse gas reductions are accounted for in a complete, consistent, transparent, accurate and conservative manner[54,55,57]. Accordingly, the CARB-CAR forest offset credit products (e.g., offsets defined by serial number (Table I)), lacking soil CO_2 balance, are not suitable as the basis for commercial net carbon financial transactions posing a barrier to effective management of atmospheric CO_2, loss of credit issuance value, and program acceptance.

Exclusion of the soil carbon pool in CARB-CAR protocols impose additional methodological uncertainty by the requirement of a 100-year invariant project baseline to ensure forest carbon storage permanence[54,55,58]. In contradistinction to the CARB-CAR rationale of invariant soil carbon over a 100-year project interval, numerous studies suggest that loss of soil carbon due to surface warming cannot be ignored. Soil warming and related CO_2 efflux predictions, including feedbacks to the biosphere[94], vary over the coming decades[95–99] but they typically deny the assumption that the soil carbon pool will remain invariant over the 100-year required project interval[92,98]. The global soil-to-atmosphere (e.g., total soil respiration) CO_2 flux, driven by climate change, is increasing across diverse contemporaneous ecosystems[98], a trend supported by a series of NEE observation platforms[100,101]. Lack of direct observation of soil and ecosystem respiration over project lifetimes of 100 years, as defined by the CARB-CAR protocols and required of products[54,55,57], result in additional uncertainty for net forest carbon sequestration data over the coming decades, a dimension critical for verification of decadal forest carbon storage and management of atmospheric CO_2[5,41,85]. Moreover, direct measurement of the forest soil carbon pool is a critical ecosystem diagnostic for detection of transition from net carbon sequestration to net positive carbon emissions to the atmosphere due to anthropogenic encroachment and climate change. Six NEE1[65] locations (Supplement 3, Table 2; CA-Man, CA-Qfo, JP-Wat, JP-Tef, US-Uaf, US-Pfa) were observed as net positive CO_2 forests whereas no similar CARB-CAR project sites were identified suggesting insensitivity to or bias against CO_2 positive emission sites. Eddy covariance and additional methods for partitioning soil CO_2 efflux, relative to NEE, as a diagnostic for climate change impact are readily achievable by measurement of CO_2 isotopologues[iii] including $^{13}CO_2$[102,103] and $^{14}CO_2$[104–106]. Based on our analysis, CARB-CAR and related protocols cannot differentiate net-negative to net-positive CO_2 forest emissions, a critical test for forest carbon protocols.

Howland Forest Site Method Comparison. The Howland Research Forest Carbon Project (CAR681[107]), the only case in which CARB-CAR and NEE1 data are available for the same project location, approximate land area, and across shared annual time intervals (2003 – 2013) is described. The Howland Research Forest (Howland) is the second oldest AmeriFlux site in the US[82] with an established 20 year record of eddy covariance data and NEE[108] determination, process-based model development[109] as well as independent direct measurement of soil CO_2 efflux and ecosystem respiration[87], response to shelterwood harvest[110] and diverse ecological data[87]. The Howland Forest site for both NEE1 and CARB-CAR covers ~223 hectares (2.23 km^2) an area represented by eddy covariance[111] and forest survey. The Howland CARB-CAR project (CAR681, Table I) identifies vintage years for 2008 to 2013 as hindcasted and reported in 2014 (supporting CARB-CAR documents are available on the CAR project documents page[112] cited in Table I). CAR681 excludes soil carbon (Table 1) (FM-6)[55] (Project Design Document, pp. 10, 19[112]). The CARB-CAR model protocol involved growing and de-growing vegetation, slowing growth rates below that prescribed by the FVS proxy defaults and running the model forward and backward[112] (Table I). Average NEE1 seasonal data for the years 1996 to 2002[82], preceding the CARB-CAR Howland series by six years, were incorporated in the CARB-CAR vegetation model (Project Design Document[112]). CARB-CAR data reported for ~3 months of 2008, the initial-year of the Howland project, reports net carbon sequestration of -43,787.2 tCO_2e, or -5,338.7 gC $m^{-2}yr^{-1}$ [112], 25 times in excess of the reported population mean NEE1 data (e.g., -207.99 gC m^{-2} yr^{-2}). Subsequent years, 2009 to 2013, report CARB-CAR net forest carbon sequestration as invariant with exact values of -1,033.00 tCO_2e, or -127.50 gC $m^{-2}yr^{-1}$ [112]. The CAR681 project data were verified by independent audit confirming net sequestration of 48,852 tCO_2e over the reporting period[112]. In contrast, NEE1 initial-year data for Howland determined by eddy covariance for the year 2008[108] was -287.1 gC $m^{-2}yr^{-1}$, ~19 times smaller compared to the CARB-CAR result for that year, or an over-estimation error of ~95%, relative to the ARB initial-year value and invalid according to the 5% excess threshold criteria for that vintage year. The initial-year (i.e., 2008) CARB-CAR value represents 95% of the total Howland CARB-CAR sequestration, invalidating carbon offset issuance for the time interval. NEE1 values for the years 2009 to 2013 ranged from -191.9 to -330.9 gC $m^{-2}yr^{-1}$ with a mean and standard deviation of -255.02 ± 57.7 gC $m^{-2}yr^{-1}$, respectively [108]. The reported CARB-CAR subsequent year data are in error, on average by 50% less, compared to the NEE1 data, an exception for the CARB-CAR population. The CARB-CAR annual values were reduced by slowing the FVS growth rate to avoid the 5% invalidation threshold (Project Design Document[107]) excepting the initial-year. The Howland forest NEE1 data increased by ~ 6 gC m^{-2} yr^{-1} over the last 19 years, representing ~50% overall increase of forest carbon sequestration, a trend not evident in the CARB-CAR data and emphasizing the importance of trend detection for carbon sequestering ecosystems. Total ecosystem respiration for Howland accounted for ~87% of NEE for the years 1997 to 2002[108] and ~79% for the year 2008[89] implying that debits of similar magnitude should be applied to the CARB-CAR data summary by their exclusion.

Additional error for Howland CAR681 is noted for above ground carbon determination. For example, above ground standing biomass for Howland of 31 tC ha^{-1} (e.g., tons carbon) determined by the CARB-CAR common practice method for the project[112] is ~4 to 5 times smaller compared to the 119 – 150 tC ha^{-1} reported for above ground biomass determined by the Howland forest survey[108], potentially resulting in net excess carbon sequestration (e.g., less above ground photosynthetic uptake of CO_2) when corrected for soil CO_2 efflux or ecosystem respiration over the project area. The Howland forest offers detailed information on the impact of non-climate related land use history and forest recovery[113] emphasizing the limitation and potential error of baseline scenarios and initial-year carbon offset values derived from counterfactual arguments as applied to CAR681 and intrinsic to CARB-CAR and related protocols[49] (Table 1, Supplement 1, 2). Comparison of the CAR681 and Howland NEE1 results identify systemic uncertainties for the CARB-CAR method and protocol including: 1) absence of direct, high frequency molecular CO_2 measurement to determine annual NEE, 2) mis-representation of initial-year project vintage as annual net forest carbon sequestration and exceeding the 5% invalidation threshold, 3) arbitrary adjustment of model growth forecasts by forward and backward model run, 4) exclusion of terms for the soil carbon pool (e.g., soil carbon efflux and ecosystem respiration), 5) error in reporting of standing biomass incorporated in baseline counterfactual estimation, vegetation proxies and models, 6) verification and audit reporting that does not validate project results relative to independent direct measurement of net forest carbon, and, 7) project level data that cannot be verified as the basis for forest carbon financial products and related carbon market transactions. The anomalies noted for CARB-CAR sites (Table I) document non-standard, shifting protocol operations (e.g., arbitrary model operation to hindcast and forecast annual net forest carbon) and inconsistent reporting for the CARB-CAR and related protocols. Point three, above, is emphasized recognizing the lack of spatial and annual resolution provided by FVS analysis frameworks introducing errors of up to ~55% in calculation of annual changes in standing biomass for above ground carbon stock[90,114–116] such as observed for Howland681. Similar errors likely apply to the population of CARB-CAR projects reporting given that sequential, annual forest mensuration survey is not required or routinely practiced to determine corresponding annual vintage year carbon sequestration differences. Errors of exclusion for soil CO_2 as ecosystem respiration of up to ~80% and error in above ground carbon determination must be acknowledged in the model based approach common to the CARB-CAR[54,55,58] and related protocols. The combined error for the CARB-CAR protocol, considering the error terms to account for ecosystem respiration and above ground biomass determination, respectively, is estimated at up to ~135%.

CO_2 Forest Reduction Policies. The uncertainties described above apply to policy development, policy driven programs and associated carbon pricing trends involved in large-scale forest carbon projects, such as the UN-REDD and REDD+[75]. The UN-REDD and REDD+ approved projects rely on the Verified Carbon Standard[63] (VCS) sharing fundamental estimation equations and features with the CARB-CAR protocols discussed (Supplement 2). Additionally, methodologies developed under the United Nations CDM accepts projects and programs registered and approved by the VCS[75]. For example, the VCS method VM0007 REDD+ Methodology Framework (REDD-MF), v1.5[117], provides quantification of emission reductions from avoided conversion of forest. However, VM0007, and related VCS REDD and REDD+ protocols, rely upon similar underlying FVS and model simulation approaches as employed for the CARB-CAR population reported here. Technical reports for REDD VCS applications categorically exclude forest soil carbon and respiration (e.g., AC-6) from carbon pool accounting[118] (Table 1). In addition, REDD VCS applications cannot accommodate CH_4 and N_2O emissions expected from forest environments with lakes, wetland and peat features compounding the uncertainty in reported emission reductions for avoided conversion projects[119,120]. Results for REDD and REDD+ net forest carbon sequestration may not be verifiable or capable of identifying net annual ecosystem carbon change in response to reduced deforestation, climate and anthropogenic forcing, and may not be well suited for carbon pricing and trading of carbon financial instruments, based on CARB-CAR shared protocols. The implementation of REDD+ in Ghana, Africa, for example, is subject to impacts of invalidation for REDD+ projects now in operation and in the planning stages[121–123] including World Bank sponsored bond programs similar to that operating in Kenya[123] also based on VCS protocols. Current macroeconomic trends for voluntary carbon trading markets are reflected in REDD/REDD+ programs. For example, 2016 prices for forest carbon were the lowest for REDD/REDD+ projects, averaging \$4.60 tCO_2e on the largest volume of all project types[80]. Moreover, VCS protocol projects were characterized consistently by the lowest pricing of \$4.10 tCO_2e on the largest volume of all standards employed for forest projects[80]. Transaction volume (millions tons CO_2e) for forest carbon offsets fell ~40% from 2014 to 2016[80]. We suggest that the low prices for REDD+ and VCS are, in part, related to the uncertainty and risk of unverifiable net carbon sequestration results for these operations. In contrast, CARB-CAR pricing of ~\$9.70USD tCO_2e for 2015 compliance offsets[80], emphasize the asymmetry in carbon pricing; similar uncertainties apply to REDD+ (e.g., voluntary) and CARB-CAR (e.g., compliance) forest carbon offsets. REDD+ funding as a catalyst for expansion of forest carbon sequestration projects has been slow to materialize. As of mid-2017, ~\$218M out of \$2.9B in funding for REDD+ programs have been disbursed[80]. We argue here that reduced disbursement for REDD+ projects also reflect the uncertainty of project carbon asset values intrinsic to estimation protocols. In contrast, direct measurement of forest CO_2 flux (e.g., NEE) provides landowners with *in situ*, time resolved project data as a foundation for annual revenue of verified net sequestered forest carbon. While carbon pricing and carbon accounting methodologies are constrained by estimation based accounting frameworks, carbon trading platforms and pricing initiatives are rapidly expanding (e.g., 45 national, 25 subnational jurisdictions[124]) emphasizing the importance of shared methodology for forest carbon sequestration product offerings for expanding trading platforms. Although it is not clear how REDD+ will be integrated within the Paris Agreement (e.g., Article 6)[125] or into existing compliance markets[126], improved quantification of forest carbon sequestration links these entities and mechanisms together in a harmonized universal science-based transactional framework. For example, forest carbon offsets sourced in China are verified and traded as equivalent to those originating from Africa, the United States, Canada, Mexico and other national and sub-national platforms, potentially improving market liquidity and reducing costs of compliance[127].

Eddy Covariance Technology Innovation. The insuperable problems of existing estimation-based protocols for net forest carbon sequestration are achievable with existing technology and scientific methods. The eddy covariance method employed at the Howland Forest and NEE1 sites has been applied worldwide as standalone field installations for research purposes[128–130] in combination with remote sensing[131,132] and as research networks[133–136] not only for bulk CO_2, CH_4 and N_2O but, in select cases, for corresponding isotopologues. Carbon isotopologues offer additional criteria for ecosystem function and net forest greenhouse gas sequestration that cannot be addressed by CARB-CAR and related estimation protocols. In contrast to estimation-based protocols that cannot feasibly conduct interannual and annual comprehensive forest mensuration protocols due to prohibitive cost factors, NEE for CO_2 determined by eddy covariance integrates all vertical carbon fluxes (e.g., assimilation and respiration) in 30″ intervals, typically representing the average of 10 Hz CO_2 measurements[129], offering the key outcome of net forest carbon sequestration (e.g., NEE as gC $m^{-2}yr^{-1}$) over a given time interval and project landscape. The existing NEE flux towers and data base represents a significant achievement by the scientific community and available as a baseline for expansion of similar efforts to manage forest carbon projects. The eddy covariance method is identified by the IPCC[137] as a forest carbon sequestration methodology but has not been updated to account for instrumentation improvements and large scale innovative forest applications. Eddy covariance networks are not typically interconnected in real-time or applied across large project areas for creating universal commercial forest carbon financial products. Commercial development of low-cost eddy covariance networks with innovative features, including unmanned aerial vehicles[138,139], shared data networks[140] and automated reporting is achievable offering an alternative to estimation protocols currently in use. Advancements in blockchain accounting platforms[141], artificial intelligence[142] and the internet of things[143] can be readily integrated within eddy covariance networks but for the reasons we discuss here cannot be successful without direct measurement of CO_2. Key and confounding concepts of additionality and leakage[53] embedded in the CARB-CAR and related protocols could be improved with directly quantified forest carbon results for aggregated project areas. Eddy covariance as an instrumental method has characteristic limitations and uncertainties[144] and faces engineering challenges for large-scale deployment[145] and spatial replication essential for statistically robust fluxes of ecosystems[146]. Limitations of commercialization for eddy covariance technology and techniques can be resolved by improved engineering and development efforts (e.g., density and location of EC platforms, automated reporting, artificial intelligence) with cost reduction. NEE offers three-gas global warming potential budgets for CO_2, CH_4 and N_2O, essential for a realistic assessment of GHG management that while recognized is lacking[147] and unachievable with CARB-CAR protocols, as the next step in the evolution of forest carbon financial products.

Given the feasibility of employing eddy covariance networks, expanding carbon market exchanges[124] and the abundance of deforested landscapes, we suggest that standard methods and protocols be adopted for forest carbon financial products across project locations that: 1) are based on direct measurement of molecular CO_2 forest flux, 2) employ shared gas standards (e.g., World Meteorological Organization[148]) for CO_2 analyzers and for global reference frameworks[149], 3) employ standardized protocols, model parametrizations and criteria such as that established by the Integrated Carbon Observation System[150–152] (ICOS) and the Global Atmosphere Watch[153], and, 4) establish universal measurement-based criteria for the transformation of NEE forest carbon offset products to verified carbon financial transactions. Without direct measurement, standardization and harmonization of forest carbon offsets across international carbon trading platforms, efforts to restore forests and protect Indigenous Peoples land rights and stored carbon, will continue to decline, hinder economically viable markets and slow efforts to manage global warming. Furthermore, lacking direct observation of CO_2, CH_4 and N_2O, CARB-CAR protocols cannot contribute to the scientific community to improve carbon cycle models and related ecosystem and climate change science. Eddy covariance observation platforms, as suggested here, would provide new data where few such data exist (e.g., Africa[154]). We acknowledge the limitations of this study related to the small sample sizes and annual intervals presented, limited overlapping project sites, and differences in methodological spatial definition for CARB-CAR and NEE1. Despite study limitations, discrepancies between methods that rely on estimation (i.e., unobserved CO_2 flux, CARB-CAR) and direct measurement of forest CO_2 flux (NEE1) must be addressed for scientific, economic and policy validation and to offer achievable improvements to existing forest carbon protocols. The results presented here form a basis for ongoing comparison between CARB-CAR and NEE results. CARB-CAR sites can and should be tested employing NEE for validation and compliance reporting.

In conclusion, based on review and analysis of population differences with directly measured forest carbon sequestration as NEE (e.g., NEE1) we show that efforts by the CARB-CAR and related protocols have not verifiably measured, managed, tested for compliance or monetized net sequestered forest carbon. Results of the statistical analysis and demonstration of exclusion of the soil carbon pool by CARB-CAR protocols call into question the scientific validity of estimation-based protocols for net forest carbon. We do not make the case that forest carbon estimation methods should be eliminated, but that to employ them to claim verified reductions for net annual forest CO_2 sequestration, they must be validated by direct measurement. Without direct and verifiable measurement of forest CO_2 flux, as demonstrated by the extensive NEE sites across the world, we cannot expect or hope to manage local, regional and global forest growth for reforestation, sustainability and net carbon sequestration, an ~1-2 billion-hectare biospheric and economic opportunity (e.g., jobs, business revenue). Forest carbon protocols that do not directly observe and quantify CO_2 gross and net CO_2 flux cannot support verifiable data for financial markets or effective policy and legislative development. While an invalidation provision may be regarded as a conservative measure (e.g., 5% invalidation threshold[59]), routine tests of compliance and enforcement of the 5% invalidation value using independent measurement have not been applied within the AB32 legislation as implemented by the CARB-CAR and related protocols. The ACR, CDM, VCS and GS, impose no validation and compliance provisions with any form of directly measured forest CO_2, uncoupling results from the possibility of independent measurement verification. Measurement and standardized methods are hallmarks of the Montreal Protocol to monitor and enforce the reduction in emission of chlorofluorocarbons demonstrating the success of collective action within a common analytical framework[155–157]. Nothing less is required to advance forest carbon management, financial markets and their local-to-global benefits given the steady decline of intact forests, Indigenous Peoples land rights, and contemporary carbon market value. Moreover, the demise of the Chicago Climate Exchange[158], coincident with near zero-dollar value for forest carbon[159], offers a lesson learned that without measurement and accountability, institutional frameworks are vulnerable to economic and policy failure[160] and fraud[161]. Unnecessary carbon offset risk, supported largely by state and government subsidies and legislation, impose loss of opportunity for forest carbon storage and market capitalization, none of which can be regained[160]; the harm in time lost to manage surface warming is incalculable. The scientific basis for and application of forest carbon measurement (e.g., eddy covariance) are mature disciplines readily adapted to large-scale implementation through technology innovation and reduction in cost. Project specific climate finance and monetization mechanisms are a key but unspecified component of the Paris Agreement that if combined with direct measurement of forest CO_2 will benefit societies and economies in the coming decades and prove crucial to correcting the imbalance between nature and anthropogenic activity and resulting climate change.

4.0 Survey and Analysis Methods

Data Sources. The focus of this study was limited to characterizing differences between populations of individual annual values for net sequestered forest carbon; inter-annual values and annual time series carbon values are not considered. Use of annual data represent consistent application of both methods for each annual interval considered; units of gC $m^{-2}yr^{-1}$ are compared for both datasets as reported (or converted). All data are available in published records as noted. NEE populations consisting of single and multi-year values have been employed to characterize NEE[74,152,162]. The CARB-CAR dataset consists of 340 sample points spanning the years 2001-2014. The NEE1 dataset consists of 544 sample points spanning over the years 1992-2015. Pooled population values and population values segmented across the time domain of the annual records are employed to explore differences between the datasets. The results are based on two data sources: 1) Jointly published California Air Resources Board (ARB) and the Climate Action Reserve (CAR) (CARB-CAR) data[52], and, 2) a published analysis and synthesis of eddy covariance data[65] and annual data for each site reported as extracted from references therein[65] to determine annual net CO_2 for selected project sites (NEE1). Additional data for the Howland Forest (CARB-CAR671, NEE1-Ho1) covering the years 2008 to 2013 that were not included in the NEE1 dataset were obtained from an additional publication[108]; these values are not included in the summary statistics reported The study was restricted to results for CARB-CAR forest carbon data that have been identified by specific serial numbers assigned to CARB issued carbon offsets (Table I). Results for the American Carbon Registry[62] and the Verified Carbon Standard[63], both approved project registries by the ARB[52], were reviewed but were not included in this study. ACR project data was not available in summary format for carbon offsets presenting a challenge to independently compile and verify ACR results. A total of 55 ACR forest carbon projects are listed; 18 identify values for registered carbon credits but serial numbers for ARB issued offsets are not available[62]. The VCS identifies 12 proposed forest projects; one project is identified as in progress[163]. VCS offset credit summaries and serial numbers for ARB issued offsets are not available. Analysis of the ACR Part VII forest project listing applications, identical to those for CARB-CAR applications, verified that soil carbon was not included in the carbon pools employed in net forest carbon estimations. The ACR sites with confirmed exclusion of soil carbon include ACR projects (n=30): 189, 173, 192, 199, 202, 211, 298, 249, 200, 256, 265, 266, 267, 268, 262, 265,255, 276, 282, 282, 273, 274, 284, 288, 292, 303, 324, 360, 277, 278. Based on the information available, ACR and VCS results were not considered in this study. According to analysis of carbon pool accounting summarized in Supplement 2, the ACR and VCS share protocols, terms and equations with the CARB-CAR and are expected to show similar results as for the CARB-CAR data. All data were transformed from tons carbon dioxide equivalent into units of grams carbon per meter squared per year ($Cg\ m^{-2}yr^{-1}$) unless otherwise noted. Annual records are employed across all sites as reported in respective data sources. All sites are located on an interactive map included as Supplement 1 and described in detail below. Our premise in this analysis is that the indirect estimation method for forest carbon employed by CARB-CAR projects (i.e., no direct measurement of CO_2) can be compared to direct measurement methods for net CO_2 uptake or net ecosystem exchange (e.g., NEE) by forests considering each data set as independent populations. The two methods and their respective populations should show similar results (e.g., mean, SD) for net forest carbon sequestration across similar forest functional types defining the null hypothesis. The two populations are compared using statistical analysis methods as described below. The details of forest growth simulation models and related protocols employed by each of the CARB-CAR projects are described below. A summary of the underlying quantification equations employed by the CARB-CAR and related protocol is provided in Supplement 2.

CARB-CAR Data Sources. The CARB-CAR population data represent 63 sites covering 340 site years (Table 1, Supplement 1, 3), primarily located in the US. The CARB-CAR projects listed in Table 1 were extracted from the California Air Resources Board and the California Environmental Protection Agency website pages as noted for "Early Action Projects"[164] and as ARB Offset Credits Issued[52]. The 63 projects represent all available CAR projects as of 09-01-2018 as recorded by the CARB[52] and range in size from ~200 to 250,000 acres providing from 1 to 14 years of GHG reduction data. The CARB-CAR results for forest carbon represent underlying methodologies reported by the CARB[54,55] and CAR[50,165]. The CAR is authorized to provide its services under the CARB Cap-and-Trade Program's Compliance Offset Protocols. CAR services include listing projects and issuing Registry Offset Credits that may later be submitted to CARB for final evaluation and issuance of CARB Offset Credits. CAR forest carbon protocols were employed for the CARB Early Action Offset Program by issuing offset credits that qualified for transition to the CARB offset credit system under the CARB-approved voluntary offset protocols including the CAR Forest Project Protocol Versions 2.1 and 3.0 through 3.3[166]. The CARB-CAR underlying equations are identical with respect to carbon pool terms and calculation of net GHG emissions reduction (Supplement 2), however, terminology differs in some cases[167]. The project types with records from 1 to 15 years include avoided conversion (AC), conservation-based forest management (CFM) and improved forest management (IFM) projects (Table I). Descriptive reports and cumulative emissions data are derived from the CAR website homepage[168]. Forest project data were accessed through links to a Climate Action Reserve project identification number (CAR#) providing a project summary page, a document summary page and a cumulative performance report page listing nine columns as follows: 1) Vintage, 2) Reporting Period Start, 3) Reporting Period End, 4) Reporting Year, 5) Verified Gross GHG reductions and GHG removal enhancements for reporting period, 6) Verified cumulative GHG reductions and GHG removal enhancements for reporting period, 7) Negative Carryover from Prior Reporting Period, 8) Verified GHG reductions and GHG removal enhancements for reporting period, 9) Buffer Pool Contribution (%) and Total Quantity of Offset Credits to Buffer Pool[52]. These headings differed for early CARB-CAR projects including CAR 101 (Van Eck), CAR 102 (Garcia River), CAR 408 (Big River) and, CAR 429 (McCloud River) (Table I, Footnote 1). In these cases, Project Activity (Tons) and Baseline values for annual increments in the Cumulative Performance Reports page were provided for each project. The data used in this analysis was extracted from the Cumulative Performance Report page and from the column of Verified GHG Reductions for each year of each project or as otherwise reported on the project page when a Cumulative Performance Report was not available (Table I). Serial numbers for the CARB carbon credit offsets are provided in the documents cited (Table I). Project reporting is accompanied by the disclaimer: *NEITHER APX NOR THE CLIMATE ACTION RESERVE KNOWS OR ENDORSES THE CREDITWORTHINESS OR*

REPUTATION OF ANY CLIMATE ACTION RESERVE ACCOUNT HOLDER LISTED IN THIS DIRECTORY. Summary data for each of the projects reviewed are extracted from the CAR webpages as described above, however it is not possible to cite documents within the summary page; references to document titles are provided when cited in the text. Latitudes and longitudes for each project are also provided in Table I. Annual values for net sequestered carbon employed for the CARB-CAR data analysis are available in Supplement 4.

CARB Protocols. The CARB protocols cited are described in three related primary documents published in 2011[54], 2014[54] and 2015[55] entitled: "Compliance Offset Protocol U.S. Forest Projects." Each of cited protocols identify field methods employing forest mensuration surveys, model simulation requirements and primary sources, sinks and reservoirs in a series of tables for Reforestation Projects (RF), Improved Forest Management Projects (IFM) and Avoided Conversion Projects (AC). In summary, a project is initiated using CARB or CAR application forms, a biometric timber survey is undertaken, and subsequently the data combined with forest vegetation proxies and simulation models are used to derive the magnitude of net GHG reductions for the project in the future (e.g., 100-year requirement) and/or the past[50]. The CARB-CAR forest carbon protocols share common features of estimation for net GHG reductions and removals including forest growth simulation models. For example, the Forest Vegetation Simulator (FVS) and related vegetation proxies for forest project species are employed in the CARB-CAR protocols. FVS data are coupled with identical numerical equations and carbon pool terms for net forest carbon sequestration directly linking the CARB and CAR protocols[54,55,57,58] (Supplement 2). Within each project type soil carbon is identified as a reservoir/pool as item 6 listed as RF-6, IFM-6 and AC-6. The soil carbon information applicable to the protocols are listed in Tables 5.1 (RF-6), 5.2 (IFM-6) and 5.3 (AC-6) for the protocols published in 2011[54] and 2014[54], respectively. The same information is listed in Tables 4.1 (RF-6), 4.2 (IFM-6) and 4.3 (AC-6) in 2015[55]. Reference to inclusion or exclusion of the soil reservoir for each project listed in Table I is indicated and linked to one of the above protocols as cited in the summary documents provided for each project. Climate Action Reserve protocols[58,166] are considered equivalent to CARB protocols in this report as they are the basis for CARB registration of issued forest carbon offset credits. The underlying models and their specific application to the CARB project location are detailed in documents associated with each of the CARB projects as listed on each CAR project page. Table I provides features of the CARB-CAR data sets that appear to be anomalous or are applied inconsistently across the CARB-CAR project sites. CARB-CAR cites seven approved forest growth and yield models[169]; shared standards and references are lacking. Details of the ARB Compliance Offset Program and offset credits issued are provided by the CARB website[170]. All approved verification protocols must adhere to

CARB standards[171]. The CAR designation for carbon pools are synonymous with those for the ARB protocols; both exclude or otherwise exempt soil carbon as being static or not subject to significant soil disturbance[55,58]. The CARB-CAR methods assume spatial coverage across the full extent of the project area by placement of representative timber survey plots, in contrast to smaller forest areas represented by eddy covariance flux towers as discussed below (NEE Protocols).

Forest Mensuration. Forest mensuration, or biometric methodology, is intrinsic to the CARB-CAR protocol process and outcomes and are briefly reviewed here. Timber surveys, designed for timber operations, are required every six years or longer[54,55], however, simulation models estimate annual incremental change for CARB-CAR net forest carbon sequestration absent annual surveys. CARB-CAR Forest mensuration methods rely primarily on measurement of tree diameter at breast height (DBH)[172]. The limitation of the biometric approach is that biomass is not directly measured as it is not quantified by harvest and weight of the carbon pools; this approach is not practical or economically feasible resulting in destruction of the forest. Uncertainties of 50% – 80% for individual trees and 20+ % for plot level estimation persist for forest mensuration[172]. Timber survey errors include: 1) variation in the parameters of allometric equation(s) and natural variability of tree structures, 2) measurement errors (DBH, tree height) and differences in frequency of measurement (e.g., multiple measurements per year), and, 3) selection of tree-specific parameters within allometric equations such as wood density. The uncertainties are compounded when the forest areas have been or are subject to management including timber extraction, thinning and prescribed fire. In many cases diverse sources of uncertainty are not identified, or new sources of uncertainty are introduced due to bias in data collection, limited coverage of representative forest areas, exclusion of selected carbon pools and inconsistent application of standards and calibration of equipment between measurements. An example of a comprehensive forest mensuration protocol is found in Barford et al. (e.g., weekly measurement of DBH during the growing season, biomass calculation using density data from a study of northern hardwood forests similar in latitude and elevation, weekly collection of leaf litter during the fall months sorted by genus, dried and weighed)[173]. Direct measurement of CO_2 ecosystem and soil respiration cannot be estimated from forest mensuration methods. Examples of forest mensuration including soil CO_2 efflux in relation to eddy covariance approaches are well represented [69,174,175].

NEE Data Source. The NEE population data, referred to as NEE1, represent 59 sites covering 540 site years ranging from 5 to 18 years of annual data; gross primary production and ecosystem respiration are also reported[65]. NEE1[65] data have been checked for quality, analyzed statistically, and referenced, presenting the best available source of annual data for comparison with the CARB-CAR data. We did not consider aspects of NEE time series in this report. The NEE1 study reported a mean and standard deviation of approximately -200.00 ± 162 gCm^{-2} yr^{-1} [65], compared to a mean of -198.0 and standard deviation of 261.6 gCm^{-2} yr^{-1} calculated in this study. The difference in mean and standard deviation result from different approaches to calculation. We calculated the sample mean and sample standard deviation of the pooled annual data of 544 points (Supplement 4). The authors of the NEE1 data calculate the mean by first obtaining the 59 means corresponding to the 59 different locations, and then calculating the mean of means[65]. The NEE1 standard deviation is also based on the deviations of each data point from the corresponding location mean (as opposed to the global mean). The difference in mean and standard deviation noted do not change the conclusions of the summary study[65] or our use that data. The NEE1 population includes 19 countries and forest projects, in part, overlapping with the CARB-CAR US dataset including temperate evergreen and deciduous forests, boreal forests and mixed forests. The NEE1 project data as reported in each of the NEE1 site references[65], was utilized for this comparison based on independent data analysis and statistical results for the population of sites reported including data for annual net ecosystem exchange (NEE), ecosystem respiration (Reco) and gross primary productivity (GPP). Additional data for the Howland Forest (CARB-CAR671, NEE1-Ho1) covering the years 2008 to 2013 that were not included in the NEE1 dataset were obtained from an additional publication[108]; these values were not included in summary statistics reported. We note that although 544 site years was reported[65], four of those site years were absent data; we use the available 540 site year values and identify the four years of missing data in Supplement 4; references for extracted annual data are presented in NEE1[65]. Individual annual data were not extracted from available flux data due to restrictions on public release[86].

NEE Protocols. Measurement of net ecosystem exchange (NEE) is based on well-developed methods employing eddy covariance (EC). The EC method measures gas fluxes in and out of an ecosystem integrating all carbon pools in the above and below ground ecosystem compartments[129,174]. The EC method is the most accurate and direct approach available for determining the dynamic net ecosystem exchange (NEE) for a project area. NEE as used here is most simply described as the annual difference between CO_2 assimilation by photosynthesis (Gross Primary Productivity or GPP) and ecosystem respiration (soil and above ground respiration or Reco) where NEE = GPP + Reco[69]. In this report, separation of autotrophic and heterotrophic soil respiration and above ground plant respiration is not required for comparative analysis using NEE1 data. We emphasize soil CO_2 efflux as the dominant component of ecosystem respiration[87,88,176] and a key term in determination of net forest carbon balance. A negative NEE corresponds to a positive (net) sink of CO_2 or a positive (net) uptake of CO_2 by the biosphere, unless otherwise noted. The method is based on direct and fast measurements (e.g., 10 Hz) of actual gas transport characterized by a three-dimensional wind field in real time. In this study, we did not control for tower height or upscaling results across the diverse site locations. The concentration of the gas of interest (e.g., CO_2, $^{13}CO_2$ and $^{14}CO_2$) is measured concomitantly resulting in flux of the gas. Flux data are first converted to half-hourly mean grams of carbon per square meter (gC $m^{-2}s^{-1}$) and then summed for each year as the cumulative annual net carbon exchange (gC $m^{-2}yr^{-1}$). Tower based estimates of net ecosystem exchange are reported in negative units reflecting a micrometeorological sign convention where flux from the atmosphere is negative, unless otherwise noted. The EC method has been applied worldwide under remote and harsh conditions employing solar power often for months without maintenance [129]. Open or closed path gas analyzers (e.g., CO_2, CH_4, N_2O) coupled with automated flux calculation, telemetry and integrated micrometeorological sensors, for example, are typical and deployed across numerous field platforms readily delivered to the project site. EC data are analyzed by a variety of models across small and large scales to calculate NEE[129]. The spatial footprint of the NEE observation scales with height of sampling inlet above the canopy, representing from ~0.1 km^2 to ~10 km^2 [41] for typical single EC platforms. Upscaling of EC data provides up 100 km^2 of carbon sequestration data[23,178–180]. Annual errors in NEE typically range between 30 and 100 gC m^{-2} yr^{-1} [100,181,182]. Commercially available bulk and isotopic analyzers for EC measurements are available from a variety of vendors (e.g., Los Gatos Research, San Jose, CA, USA).

Acknowledgements. The references cited in this study used eddy covariance data acquired and shared by the FLUXNET community, including potentially these networks: AmeriFlux, AfriFlux, AsiaFlux, CarboAfrica, CarboEurope-IP, CarboItaly, CarboMont, ChinaFlux, FLUXNET Canada, Green- Grass, ICOS, KoFlux, LBA, NECC, TERN OzFlux, TCOS-Siberia, and USCCC. Detailed data (e.g., annual records) cannot be shared publicly because of Fluxnet2015 (https:// fluxnet.fluxdata.org/data/data-policy/) and Lathuile (https://fluxnet.fluxdata.org/data/la-thuile-dataset/) data policies. Annual values used in this study were acquired from individual references cited in NEE1[183].

Statistical Methods. Individual annual records were used in this analysis; trends in time series are not considered. Figure 1. The CARB-CAR dataset consists of 340 sample points spanning the years 2001-2014. The NEE1 dataset consists of 540 sample points spanning over the years 1992-2015.

The skewness and kurtosis of the CARB-ARB and NEE1 datasets are -3.69 and 17.67, respectively. As a comparison, the skewness and kurtosis for the NEE1 dataset are 0.25 and 2.31.

The skewness is calculated in the following way:

$$\frac{n\sum_{i=1}^{n}(x_i-\overline{x})^3}{(n-1)(n-2)s^3}$$

where $\overline{x}$ and s are the sample mean and sample standard deviation of the CARB-CAR data, and n=340.

The skewness is negative, which means that the distribution is skewed to the left.

The kurtosis is calculated in the following way:

$$\frac{n(n+1)\sum_{i=1}^{n}(x_i-\overline{x})^4}{(n-1)(n-2)(n-3)s^4}-\frac{3(n-1)^2}{(n-2)(n-3)}$$

where $\overline{x}$ and s are the sample mean and sample standard deviation of the CARB-CAR data, and n=340. It provides a measurement of the extremities of the data. A kurtosis value of 17.67 demonstrates the presence of very large outliers.

Figure 3. We calculate the 95% confidence interval for the difference in means of the two data sets CARB-CAR and NEE1.

The first bar is based on the complete data sets over all available years. We use the following formula for large sample size:

$$(\overline{x_1}-\overline{x_2}) \pm 1.96\sqrt{\frac{s_1^2}{n_1}+\frac{s_2^2}{n_2}}$$

where $\overline{x_1}$ and $\overline{x_2}$ are the sample means, and s_1 and s_2 are the sample standard deviations of the two samples.

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For the year 2007, we have 23 CARB-CAR and 42 NEE1 data points. For the year 2008, we have 24 CARB-CAR and 41 NEE1 data points. In order to calculate the confidence interval, we use the following formula for a small sample size:

$$(\bar{x}_1 - \bar{x}_2) \pm t\sqrt{s_p^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}$$

where

$$s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}$$

and t is based on $(n_1 + n_2 - 2)$ degrees of freedom.

Table II. Table 1 shows the results of multiple one-sided hypothesis tests, ranging from 2002 to 2014. For each year, we test the following hypotheses:

$$H_0\colon\ \mu_1 - \mu_2 \leq D$$

$$H_a\colon\ \mu_1 - \mu_2 > D$$

where μ_1 and μ_2 are the true population means and D is the allowed 5% threshold.

Since the CARB-CAR sample sizes vary from 2 to 32 per year, we use a small-sample one-sided hypothesis test. The test statistic is the following:

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - D}{\sqrt{s_p^2}\sqrt{\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

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where s_p^2 was already defined in the description of figure 3 methodology, and t is based on $(n_1 + n_2 - 2)$ degrees of freedom.

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Author Contribution Statements

B.D.V.M. conceived the research, developed and wrote the manuscript; M.M. performed the statistical analysis; A.D. constructed the interactive map.

Additional Information

Supplementary information accompanies this paper.

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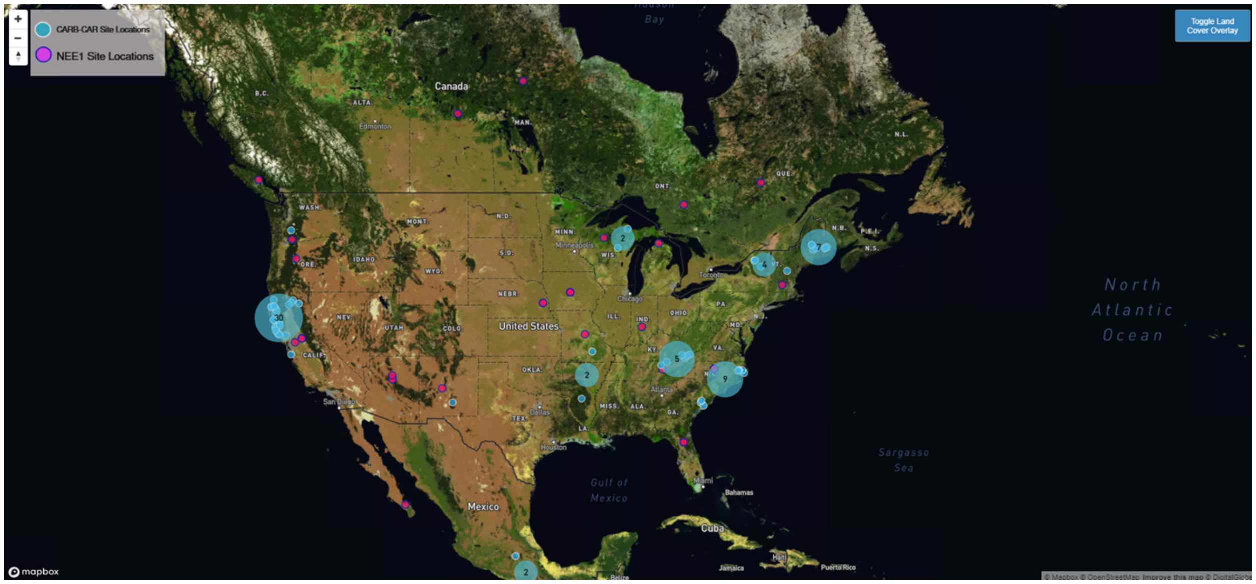
Supplementary Information

Supplement 1: Project Locations. The interactive map can be accessed here: http://geocambridge.com/PEMfluxmap/



The project location map, Figure 1, is an interactive map displaying the locations of 59 NEE1 sites[65] and 63 CARB-CAR project sites (see Methods section for details). Information for each site, including the underlying biome and land cover classification is provided, allowing users to compare the underlying ecological properties for a given project site with other sites. Each project site point was geocoded or otherwise plotted in WGS84 coordinate system using the best available latitude and longitude information for each location. Blue circles represent NEE1 sites while pink circles represent CARB-CAR projects. All sites on the map feature a unique site identifier code (e.g., CAR697) which is linked to project data in Table 1 and summarized in Table I, Supplement 3. A link to the project web page for each site is included in the pop-up display. CARB-CAR and NEE1 sites were classified for functional type based on the 2015 CCI-LC dataset. This Land Cover product was developed by the European Space Agency Climate Change Initiative (ESA CCI Land Cover project). The land cover overlay represents a 300-meter resolution global land cover classification and is compatible with the plant functional types used in many global land cover models. Land cover data source and additional information: https://www.esa-landcover-cci.org. The base map provided is Satellite Streets by Mapbox (https://www.mapbox.com).

Supplement 2: The CARB and CAR Quantification Methodology. The equations for carbon material balance as defined by the CARB protocols[54,55] are analyzed considering the simple case for a one-year project. The equations identify the exclusion of soil carbon pools in the CARB-CAR and related forest carbon protocols. The net GHG reductions and GHG removal enhancements are provided by the common quantification equation provided by CARB-CAR (CARB 2011, p. 37, Equation 6.1[54]; CARB 2014, p. 39, Equation 6.1[54]; CARB 2015, p. 47, Equation 5.1; CAR, Equation 61., p. 46[55]). In summary,

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$$\boldsymbol{QR_y = [(\Delta C_{onsite} - \Delta BC_{onsite}) + (AC_{wp,\,y} - BC_{wp,y}) \times 80\% + SE_y] \times (1 - ACD) + N_{y-1}} \quad (1)$$

Equation *(1)* can be rewritten for clarity with each grouped expression or factor given a subscript for discussion purposes written as (for the definition of each term above see[55]),

$$QR_y = [(actual\ onsite\ carbon - baseline\ onsite\ carbon)_1 + (actual\ onsite\ wood\ products - baseline\ onsite\ wood\ products)_2 \times (80\%)_3 + (secondary\ emissions)_4] \times (avoided\ conversion\ factor)_5 + (negative\ carry\ over)_6$$

(2)

Expression *(2)* can be simplified considering the case of a single year as,

$$\boldsymbol{QR_y = [(\Delta C_{onsite} - \Delta BC_{onsite})_1 + (0_{wp,\,y} - 0_{wp,y})_2 \times 0\%_3 + 0_{y4}] \times (1 - 0)_5 + 0_6,}$$

(3)

and by considering term 2, “wood products”, as zero product in this case. Zero wood product eliminates terms 3 and 4. Term 5 is set at zero reflecting no project conversion in this case. Expression *6*, carryover of GHG reductions from a previous year, is set at zero considering this year as a one-year project for the purposes of illustration. The simplifications noted can be expressed as,

$$\boldsymbol{QR_y = (actual\ onsite\ carbon - actual\ baseline\ carbon).} \quad (4)$$

The terms for actual onsite carbon and actual baseline carbon are defined as follows:

$AC_{onsite,\,y}$ = Actual onsite carbon (CO_2e) as inventoried for year y, and,
(5)

$BC_{onsite,y}$ = Baseline onsite carbon (CO_2e) as estimated for year y.
(6)

Both “actual onsite” and “baseline onsite” carbon terms require an inventory of required carbon pools as identified in tables for reforestation (Table 4.1[55]), improved forest management (Table 4.2[55]) and for avoided conversion (Table 4.3[55]) and counterfactual arguments to establish baselines. The carbon inventory tables identify the following carbon pools: 1) standing live tree carbon, 2) shrubs and herbaceous

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understory carbon, 3) standing dead tree carbon, 4) lying dead tree carbon, 5) litter and duff carbon, 6) soil carbon, 7) carbon in in-use forest products, 8) forest product carbon in landfills, 9) biological emissions from site preparation activities, 10) mobile combustion emissions from site preparation activities, 11) mobile combustion activities from ongoing project operation and maintenance, 12) stationary combustion emissions from ongoing project operation and maintenance, and, 13) biological emissions from clearing of forestland outside of the project area. Each of the above pools is labeled as RF for reforestation, IFM for improved forest management and AC for avoided conversion within each table. Specifically, the soil carbon pool for each project type is labeled as RF-6, IFM-6 and AC-6. In the case for each project type, the pools for RF-6, IFM-6 and AC-6 are noted as "included/excluded" according to project activities such as deep ripping or furrowing and mechanical site preparation not conducted on contours[55]. Additionally, no crediting is allowed for increased soil carbon[55]. Thus, in cases where soil carbon is excluded, such as for the projects analyzed in this report and listed in Table I, we can rewrite (4) for clarity as,

$$QR_y = \left(\textbf{actual onsite carbon}_{\textit{excluding soil carbon}} - \textbf{actual baseline carbon}_{\textit{excluding soil carbon}}\right). \quad (7)$$

Equation (7) can be rewritten as,

$$QR_y = \left(\textbf{actual onsite above ground carbon} - \textbf{actual above ground baseline carbon}\right). \quad (8)$$

In summary, the CARB equations, in practice as reported here, exclude terms for soil carbon in carbon pool accounting. Identical equations are employed for the CAR projects[167].

Next, we consider similarities between the CARB-CAR equations and the ACR, CDM and VCS protocols. The American Carbon Registry identifies an analogous equation for net anthropogenic GHG removals by equation 44 of the ACR methodology[61]:

$$C_{AR-AC} = \Delta C_{Actual} - \Delta C_{BSL} - LK, \quad (9)$$

Where:

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C_{AR-AC} = Net anthropogenic GHG removals by sinks; MT CO_2e,

(10)

ΔC_{Actual} = Actual net GHG removals by sinks; MT CO_2e,

(11)

ΔC_{BSL} = Baseline net GHG removals by sinks; MT CO_2e, and,

(12)

LK = Total GHG emissions dues to leakage: MT CO_2e.

(13)

No terms for direct measurement of CO_2 are identified. Soil carbon is identified as an optional carbon pool.

The Clean Development Mechanism, AR-ACM0003 A/R, for large-scale consolidated methodology for afforestation and reforestation of lands except wetlands, Version 02.0 Sectoral scope(s)[184]: 14, states:

$$\Delta C_{AR-CDN,t} = \Delta C_{ACTUAL,t} - \Delta C_{BSL,t} - LK_{t},$$

(14)

Where,

$C_{AR-CDM,t}$ = Net anthropogenic GHG removals by sinks, in year t; t CO_2-e,

(15)

$\Delta C_{ACTUAL,t}$ = Actual net GHG removals by sinks, in year t; t CO_2-e,

(16)

$\Delta C_{BSL,t}$ = Baseline net GHG removals by sinks, in year t, t CO_2-e, and,

(17)

LK_t = GHG emissions due to leakage, in year t, t CO_2-e.

(18)

No terms for direct measurement of CO_2 are identified. Soil carbon is identified as an optional carbon pool.

The Verified Carbon Standard describes the Methodology for Carbon Accounting for Mosaic and Landscape-scale REDD Projects, VM0006[117], for quantifying emission reductions and/or removals from activities to reduce unplanned deforestation and forest degradation of the mosaic configuration. The methodology is chosen for comparison to the CAR, ACR and CDM protocols as it can be combined with Improved Forest Management (IFM) and Afforestation, Reforestation and Revegetation (ARR) methodologies to implement a landscape scale Reduced Emissions from Deforestation and Forest Degradation (REDD+) projects. The net anthropogenic GHG removal is summarized as follows:

$$\boldsymbol{C_{ANR}(t)} = \Delta \boldsymbol{C_{ANR}(t)} - \Delta \boldsymbol{C_{ANR,BSL}}\,(\boldsymbol{t}), \quad \textbf{(19)}$$

Where:

$C_{ANR}(t)$ = Net anthropogenic greenhouse gas removals due to biomass increase in assisted natural regeneration during year t [tCO_2e],

(20)

$\Delta C_{ANR}(t)$ = Annual change in carbon stocks in all selected carbon pools due to ANR during year t [tCO_2e],

(21)

$\Delta C_{ANR,BSL}\,(t)$ = Baseline GHG gas emissions or sources during year t [tCO_2e].

(22)

No terms for direct measurement of CO_2 are identified. Soil carbon is identified as an optional carbon pool.

In each case for the ACR, CDM and VCS, similar above ground and baseline terms are employed reflecting the simplified equation (7) noted above for the CARB-CAR protocols. No terms for direct measurement of CO_2, soil carbon or soil CO_2 efflux are employed in the protocol equations cited.

Supplement 3: Table 1, CARB-CAR Project and Location Data (File Attached)

Supplement 3: Table 2, NEE1 Project and Location Data (File Attached)

Supplement 4: Table 1. Annual Data records CARB-CAR (File Attached)

Supplement 4: Table 2. Annual data records NEE1 (File Attached)

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1649 **Supplement 5: Summary data CARB-CAR, NEE1 (File Attached)**

[i] The concentration of CO_2 that would cause the same amount of radiative forcing as a given mixture of CO_2 and other greenhouse gases.

[ii] $percentaage\ error = \frac{|\ CARB\ CAR\ value - NEE1\ value|}{CARB\ CAR\ value}\ x\ 100$

[iii] The term isotopologue refers to chemical species that differ only in the isotopic composition of their molecules or ions.

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Table 1(on next page)

CARB-CAR site locations, links to online data source and anomalous features

CARB-CAR site locations, links to online data source and anomalous features

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	Climate Action Reserve #	Successor Climate Action Reserve #	ARB Project ID #	Project Name & Location	Longitude	Latitude	Functional Type	Type of Protocol	Acres**	Hectares	Project Interval (Vintage Years)	Project Management	Offsets Issued with Serial Numbers	Cumulative Performance Report	Anomalous Features*	Soil Carbon Status
1	CAR101	NA	CAFR0049	The Van Eck Forest (Humboldt County, CA)	-124.08	40.87	Northern California Coast (Coast Redwood/Douglas Fir Mixed Conifer) & Southern Cascades (Southern Cascade Mixed Conifer)	Early Action	2,104	851	2001-2014	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=101&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20101	^^ (2008) to 2001; ## (2008) to 2014	%%Reporting Year 2006, Soil Carbon Pool tCO2e = 0
2	CAR102	CAR1098	CAFR0040	Garcia River Forest (Mendocino, CA)	-123.51	38.91	Temperate coniferous	Early Action	23,780	9,623	2005-2017	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=102&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20102	^^(2007)2007-2004; ##(2007) 2008-2014	%%Reporting Year 2010, Soil Carbon Pool Excluded from carbon pool calculations
3	CAR408	CAR1100	CAFR0041	Big River / Salmon Creek Forests (Mendocino, CA)	-123.67	39.301	Temperate coniferous	Early Action	15,911	6,439	2007-2017	IFM	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20408	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20408	##(2007) 2007-2014; $2012	%%2007 Project Submittal Form, Soil Carbon Excluded
4	CAR429	NA	CAFR0073	McCloud River (McCloud, CA)	-122	41.2	Temperate broadleaf and mixed	Early Action	9,200	3,723	2006-2014	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=429&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20429	## (2006) 2006 to 2014	%%2009 Project Submittal Form, Soil Carbon N/A
5	CAR430	NA	NA	RPH Ranch (Comptche, Mendocino County, CA)	-123.59	39.26	Temperate coniferous	Early Action	106	43	2010	IFM	https://thereserve2.apx.com/mymodule/reg/TabDocuments.asp?r=111&ad=Prpt&act=update&type=PRO&aProj=pub&tablename=doc&id1=430	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20430	##(2002) 2002 to 2010; $$(00.00) 2002 to 2009	%%2008 Project Submittal Form, Soil Carbon N/A
6	CAR497	NA	CAFR0029	Blue Source – Alligator River (Hyde County, NC)	-76.031	35.631	Northern Atlantic Coastal Swamp Hardwoods, Cypress	Early Action	2,272	919	2010-2017	AC	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=497&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20497	$(2011)	%%Project Design Document, Section 15. Carbon Stock Inventory, Soil Carbon Excluded
7	CAR5	NA	NA	Arcata Sunnybrae	-12	40.8	Northern California Coast	Not	17	69	2006-	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=575&ad	https://thereserve2.apx.com/myModule/rpt/myrpt.	^^(2012) 2012 to	%%Project Design Document, 4. Onsite Carbon

	75			Tract (Humbodlt County, CA)	4.05	64	(Coast Redwood/Douglas Fir Mixed Conifer) & Southern Cascades (Southern Cascade Mixed Conifer)	Eligible	1		2015		=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	asp?r=802&md=Prpt&id1=%20575	2006; $(2006) one month	Inventory Methodology
8	CAR582	CAR1130	CAFR0103	Finite Carbon – MWF Brimstone IFM Project I (Scott County, TN)	-84.455	36.272	Mixed Oak	Early Action	4861	1,967	2007-2015	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=582&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20582	^^(2013) 2013 to 2007; $(2007) ~3 months; $(2013) ~ 8 months; $(2015); %(2015)	%%Project Design Document, Item 23. Soil Carbon Pool Absent; Table 23, soil carbon absent, Table 10, soil carbon absent
9	CAR590	NA	NA	Lompico Forest Carbon Project (Santa Cruz County, CA)	-122.04	37.13	Temperate coniferous Temperate broadleaf, mixed Coastal Redwood forest	Not Eligible	425	172	2010-2014	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=590&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20590	$$(1074.00) 2010 to 2012	%%Project Design Document, Section 3. Onsite Carbon Inventory Methodology, soil carbon excluded as an optional carbon pool.
10	CAR645	CAR1088	CAFR0080	Finite Carbon – The Forestland Group Champion Property (Franklin, St. Lawrence & Lewis Counties, NY)	-75	44.3	Spruce-fir; Pine and hemlock; Northern hardwoods	Early Action	100,000	40,469	2009-2016	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=645&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20645	^^(2012) 2012 to 2009; $(2009) ~7 months; $ (2014, 2015, 2016); %(2014, 2015, 2016); %(2016) 2015, 2016	%%Project Design Document, Table 5. Sources, Sinks, and Reservoirs, IFM-6, Soil Carbon excluded
11	CAR646	NA	NA	Katahdin Iron Works Ecological Reserve (Piscataquis County, ME)	-69.17	45.45	Evergreen Needleleaf Forest	Not Eligible	10,000	4,047	2007-2012	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?r=111&ad=Prpt&act=update&type=PRO&aProj=pub&tablename=cr&id1=646	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20646	$(2007) ~8 months; ^^(2013) 2013 to 2007	%%Project Design Document, Section 3. Inventory Methodology, IFM-4, Soil Carbon excluded
12	CAR648	CAR1086	CAFR0047	Finite Carbon – Potlatch Moro Big Pine CE (Calhoun	-92.54	33.5	Evergreen Needleleaf Forest	Early Action	16,000	6,475	2006-2014	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=648&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20648	$(2006) ~1 month; ^^(2013) 2013 to 2006; $(2013) ~7	%%Project t Design Document, Table 7. Sources, Sinks, and Reservoirs, IFM-6, soil carbon excluded.

				County, AR)											months; % (2014) 2012, 2013, 2014; $(2014) ~7 months	
13	CAR655	NA	CAFR0105	Alder Stream Preserve (Piscataquis County, ME)	-69.015	45.114	Evergreen Needleleaf Forest	Early Action	1,460	591	2006-2013	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=655&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20655	$ initial year 1 month, 2006; ## 2012, 2014; ##2006 to 2013	%%Project Design Document, Section 3, Inventory Methodology, IFM-6, soil carbon excluded
14	CAR657	CAR1063	CAFR0002	Finite Carbon Farm Cove Community Forest Project (Near Grand Lake Stream, Maine)	-67.851	45.187	Evergreen Needleleaf Forest	Early Action	19,769	8,000	2010-2015	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=657&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20657	$(2003) < 1 month; ^^(2012) 2011 to 2003	%%Project Design Document, Section A13. Carbon Pools,. IFM-6, soil carbon excluded
15	CAR658	CAR1134	CAFR0087	Finite Carbon – Brosnan Forest (Near Charleston, SC)	-80.45	33.167	Evergreen Needleleaf Forest	Early Action	10,209	4,131	2010-2011; 2015-2016	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=658&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20658	#(2010) $(2013) ~8 months; ^^(2013) 2011 to 2010	%%Project Design Document, Section A13. Carbon Pools,. IFM-6, soil carbon excluded
16	CAR659	NA	CAFR0026	Blue Source – Pungo River Forest Conservation Project (Washington County, NC)	-76.64	35.804	Atlantic Coastal Plain -- Swamp Hardwood and Cypress	Early Action	704	285	2003-2016	AC	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=659&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20659	$(2003) < 1 month; ^^(2012) 2011 to 2003	%%Project Design Document, 11.2.3.4.1 Soil carbon was sampled to establish starting carbon stocks that would be degraded if the baseline scenario was followed, e.g. full conversion to agricultural use. The soil carbon was excluded as source of CO2 over the lifetime of the project (e.g., AC-6).
17	CAR660	CAR1099	CAFR0042	Gualala River Forest (Southern Mendocino	-123.402	38.796	Coastal Redwood and Douglas Fir	Early Action	13,913	5,630	2004-2017	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=660&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20660	^^(2011) 2010 to 2004; %(2015) 2015,	%%Project Design Document, Section 7. Summary of the carbon stock inventory for the Forest Project by

				County, Near Gualala, CA)											2016; %(2017) 2016, 2017	each pool, soil carbon pool excluded
18	CAR661	CAR1140	CAFR0001	Willits Woods (Near Willitis, CA)	-123.357	39.411	Coastal Redwood and Douglas Fir	Early Action	18,008	7,288	2004-2016	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=661&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20661	^^(2011) 2010 to 2004	%%Project Design Document, Section 5. Calculation methodologies for determining metric tones per acre for each of the included carbon pools, soil carbon excluded
19	CAR672	NA	CAFR0116	Hershey Mountain (North of Concord, NH)	-71.667	43.567	Adirondacks & Green Mountains Northern Hardwood	Early Action	2,141	866	2007-2013	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=672&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20672	#(2007); $(2007) ~6 months; ^^(2014) 2013 to 2007	%%Project Design Document, Section A13. Carbon Pools, soil carbon FM-6 excluded
20	CAR676	NA	CAFR0031	Pocosin Lakes Forest Conservation Project (Tyrrell County, NC)	-76.209	35.862	Atlantic Coastal Plain, Swamp Hardwood and Cypress	Early Action	1,349	546	2003-2012	AC	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=676&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20676	^^(2012) 2011 to 2003; $(2003) ~2 months;	%%Project Design Document, 11.2.3.4.1 Soil carbon was sampled to establish starting carbon stocks that would be degraded if the baseline scenario was followed, e.g. full conversion to agricultural use. The soil carbon was excluded as source of CO2 over the lifetime of the project (e.g., AC-6
21	CAR681	NA	CAFR0106	Howland Research Forest (Howland, ME)	-68.627	45.246	Red Spruce and Eastern Hemlock	Early Action	552	223	2008-2013	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=681&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20681	#(2008); $(2008); ^^(2014) 2013 to 2008; %(2008) 2008, 2008	%%Project Design Document, Section 3 Inventory Methodology, IFM-6, soil carbon excluded
22	CAR683	NA	CAFR0030	Francis Beidler Project (Berkeley, Dorchester and Orangeburg Counties, SC)	-80.358	33.321	Native Hardwoods, Softwoods, Mixed Forest	Early Action	5,548	2,245	2007-2017	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=683&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20683	#(2007) ~5 months; $(2012); ^^(2012) 2012 to 2007; ^^(2015) 2015 to 2012; $(2015); $(2016); $(2017)	%%Project Design Document, Section 3, Inventory Methodology, soil carbon excluded

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23	CAR686	CAR1160	CAFR0058	Virginia Conservation Forestry Program – Clifton Farm (Near Rosedale, VA)	-81.86	37.022	Mixed Pine Hardwood, Cove Forests, Oak - Hickory	Early Action	4,069	1,647	2004-2016	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=686&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20686	^^(2012) 2011 to 20014; ^^(2014) 2013 to 2012); $(2016) 2015,2016	%%Project Submittal Form, Item 10, soil carbon excluded
24	CAR688	NA	CAFR0028	Blue Source – Noles North Forest Project (Washington and Hyde Counties, NC)	-76.548	35.881	Atlantic Coastal Plain, Swamp Hardwood and Cypress	Early Action	281	114	2002-2016	AC	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=688&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20688	$(2002) ~7 months; ^^(2012) 2011 to 2002; $$(6,099.00) 2003 to 2009; $$(5,830.00) 2013 to 2014	%%Project Design Document, 11.2.3.4.1 Soil carbon was sampled to establish starting carbon stocks that would be degraded if the baseline scenario was followed, e.g. full conversion to agricultural use. The soil carbon was excluded as source of CO2 over the lifetime of the project (e.g., AC-6)
25	CAR694	NA	NA	Lucchesi Tract (Humboldt County, CA)	-124.064	40.875	Temperate coniferous, Temperate rainforest;	Not Eligible	322	130	2010-2016	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=694&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20694	^^(2012) 2011 to 2001; $$(00.00)2001 to 2009; $$(2,182.00) 2012 to 2016	%%Project Design Document, Section D. Step 4. Determine the baseline carbon stocks over 100 years for all required and optional carbon pools in the Project Area, soil carbon excluded
26	CAR696	CAR1159	CAFR0057	Rich Mountain (Russell & Washington Counties, NW of Saltville, VA)	-82.03	36.831	Allegheny & North Cumberland Mountains - Mixed Pine Hardwood, Cove Forests, Northern Hardwoods, Oak - Hickory	Early Action	5,750	2,327	2002-2016	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=696&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20696	$(2002) ~6 months; ^^(2012) 2011 to 2002; ^^(2015) 2014 to 2013; %(2016) 2015, 2016	%%Project Submittal Form, item 10. IFM-6, soil carbon excluded
27	CAR697	CAR1147	CAFR0102	Tazewell – Elk Garden (Russell, Washington, and Tazewell Co. near Tazewell, VA)	-81.559	37.124	Allegheny & North Cumberland Mountains - Mixed Pine Hardwood, Cove Forests, Northern Hardwoods, Oak - Hickory	Early Action	11,697	4,734	2007-2016	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=697&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20697	^^(2014)2013 to 2005; %(2014) 2015, 2016; %(2016) 2015, 2016	%%Project Submittal Form, item 10. IFM-6, soil carbon excluded

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28	CAR730	CAR1139	CAFR0123	Usal Redwood Forest (Mendocino County, CA)	-123.847	39.876	Coast Redwood/Douglas-fir Mixed Conifer	Early Action	49,000	19,830	2007-2017	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=730&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20730	#(2007); $(2207) ~6 months; ^^(2015) 2015 to 2007	%%Project Submittal Form, item 10. IFM-6, soil carbon excluded
29	CAR749	CAR1109	CAFR0063	Green Assets – Middleton (Charleston, SC)	-80.141	32.9	SE Middle Mixed Forest Piedmont Atlantic Coastal Plain & Flatwoods	Early Action	3,732	1,510	2007-2017	AC	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=749&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20749	$(2007) < 1 month; ^^(2013) 2011 to2007; $(2011)2013, 2014; ^^(2014) 2013 to 2011; %(2015) 2014, 2015; %(2016) 2015, 2016; %(2017) 2016, 2017	%%Project Design Document, Section 11.2.3 Data gathering procedures and parameters, AC-6, soil carbon excluded, Table 5, soil carbon emissions excluded
30	CAR777	NA	CAFR0064	Yurok Tribe Sustainable Forest Project (Northwest Humboldt County, CA)	-123.8	41.406	Northern California Coast (Coast Redwood/Douglas Fir Mixed Conifer) & Southern Cascades (Southern Cascade Mixed Conifer)	Early Action	21,240	8,596	2011-2014	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=777&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20777	#(2011) $(2011) ~8 months; ^^(2014) 2013 to 2012	%%Project Desing Document, Section 3. Inventory Methodology, IFM-6, soil carbon excluded
31	CAR780	CAR1062	CAFR0088	Shannondale Tree Farm (Washington County, NC)	-91.45	37.367	Atlantic Coastal Plain - Atlantic Coastal Plain Swamp Hardwood and Cypress	Early Action	4037	1,634	2010-2013	AC	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=780&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20780	#(2013); $(2013) ~4 months; ^^(2013) 2011 to 2010; ^^(2015) 2013 to 2012	%%Project Design Document, Section A13. Carbon Pools, IFM-6, soil carbon excluded
32	CAR802	NA	CAFR0027	Noles South Forest Project (Washington County, NC)	-76.548	35.865	Atlantic Coastal Plain - Atlantic Coastal Plain Swamp Hardwood and Cypress	Early Action	324	131	2003-2016	AC	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=802&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20802	$(2003) ~1 month; ^^(2012) 2011 to 2003; $$(5,180.00) 2005 to 2009; $$(5,830.0	%%Project Design Document, 11.2.3.4.1 Soil carbon was sampled to establish starting carbon stocks that would be degraded if the baseline scenario was followed, e.g. full conversion to

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															0) 2011, 2012	agricultural use. The soil carbon was excluded as source of CO2 over the lifetime of the project (e.g., AC-6)
33	CAR935	NA	NA	Arcata City Barnum Tract (Arcata, CA)	-124.049	40.876	Northern California Coast Redwood/Douglas-fir Mixed Conifer	Not Eligible	280	113	2003-2016	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=935&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%20935	$(2003) ~11 months; ^^(2012) 2011 to 2003; $$(2,904.00) 2005 to 2011; $$(2,527.00) 2012 to 2016	%%Project Design Document, Section Step 4. Determine the baseline carbon stocks over 100 years for all required and optional carbon pools in the Project Area, IFM-6. soil carbon excluded
34	CAR1013	NA	CAFR5055	Buckeye Forest Project (Sonoma County, CA)	-123.31	38.74	Coast Redwood / Douglas-fir Mixed Conifer and Northern California Coast Mixed Oak Woodland	Compliance	19,525	7,901	2014-2017	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1013&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	NA	#(2014); $%(2014); $%(2015); $%(2016); $%(2017);	%%Application for Listing, Part VII, Carbon Stock Inventory, IMF-6, Not applicable
35	CAR1015	NA	CAFR0100	Rips Redwoods (Sonoma County, CA)	-123.212	38.711	Coast Redwood / Douglas-fir Mixed Conifer and Northern California Coast Mixed Oak Woodland	Early Action	1426	577	2013-2014	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1015&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%201015	#(2013); $(2013) ~7 months	%%Project Design Document, Section 2.B.B. Carbon Sinks, Sources and Reservoirs, IFM-6, absent
36	CAR1032	NA	CAFR5037	Virginia Highlands I (Russell, Buchanan and Dickenson Counties, VA)	-82.347	37.085	oak-hickory, loblolly-shortleaf pine, and mixed oak-pine	Compliance	9,753	3,947	2013	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1032&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	NA	#(2013); $(2013) ~ 7 months	%%Application for Listing, Part VII, Carbon Stock Inventory, IMF-6, Not applicable
37	CAR1041	NA	CAFR5038	Sacramento Canyon ARB001 (Shasta County, CA)	-122.29	41.05	Southern Cascade, Mixed Conifer	Compliance	16,941	6,856	2015-2017	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1041&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	NA	#(2015); %(2015) 2013, 2014, 2015; $(2016) 2015, 2016; $(2017) 2016, 2017	%%Application for Listing, Part VII, Carbon Stock Inventory, IMF-6, Not applicable
3	CAR1	NA	CAFR5	Trinity Timberlan	-12	40.5	"Northern California Coast	Comp	11,9	4,8	2014	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1046&a	NA	#(2014); $(2013)	%%Application for Listing, Part VII, Carbon Stock

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8	046		076	ds University Hill Project (Trinity County, CA)	3.5	8	(Coast Redwood/Douglas Fir Mixed Conifer) & Southern Cascades (Southern Cascade Mixed Conifer)"	liance	00	16			d=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub		~10 months; %(2013) 2013, 2014	Inventory, IMF-6, Not applicable (Attachment E)
39	CAR1066	NA	CAFR5058	Buck Mountain ARB002 (Siskiyou County, CA)	-121.85	41.38	Southern Cascade, Mixed Conifer	Compliance	12,486	5,053	2015-2017	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1066&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	NA	#(2015); $(2015) ~9 months; %(2015) 2014, 2015; $(2016)2015, 2016; $(2017) 2016, 2017	%%Application for Listing, Part VII, Carbon Stock Inventory, IMF-6, Not applicable
40	CAR1067	NA	CAFR5063	Sustainable Mountain (Humboldt County, CA (near Willow Creek)	-123.76	40.91	Douglas Fir Mixed Conifer	Compliance	2,112	855	2015	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1067&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	NA	$(2014) ~ 6 months; %(2014) 2013, 2014	%%Application for Listing, Part VII, Carbon Stock Inventory, IMF-6, excluded
41	CAR1092	NA	CAFR5087	Big Valley (Near Aiden, CA)	-121.24	41.13	Douglas Fir Mixed Conifer	Active	14,622	5,917	2016	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1092&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	NA	#(2016); %(2016) 2014, 2015, 2016	%%Application for Listing, Part VII, Carbon Stock Inventory, IMF-6, Not applicable
42	CAR1094	NA	CAFR5095	Ashford III (Ashford, WA)	-122.04	46.46	Northwest Cascade Mixed Conifer	Compliance	5290	2,141	2014	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1094&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	NA	#(2014); %(2014) 2012, 2013, 2014	%%Application for Listing, Part VII, Carbon Stock Inventory, IMF-6, Not applicable
43	CAR1095	NA	CAFR5096	Brushy Mountain (Mendocino County, CA)	-123.26	39.63	Southern Cascade Mixed Conifer	Compliance	16,392	6,634	2014-2017	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1095&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	NA	#(2014); $(2014) ~ 8 months; $(2016) 2015, 2016; %(2015) 2014, 2015; %(2016) 2015, 2016; %(2017) 2016, 2017;	%%Application for Listing, Part VII, Carbon Stock Inventory, IMF-6, excluded (Addendum to Listing Application)
4	CAR1	NA	CAFR5	Montesol Forest	-12	38.6	Southern Cascade Mixed	Comp	3,10	1,2	2016	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1102&a	NA	#(2016); $(2016) ~	%%Application for Listing, Part VII, Carbon Stock

4	102		148	Carbon (Napa and Lake County, CA)	2.564	71	Conifer	liance	2	55			d=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub		7 months	Inventory, IMF-6, Not applicable
45	CAR1103	NA	CAFR5149	Forest Carbon Partners – Glass Ranch Improved Forest Management Project (Humboldt County, CA)	-123.644	40.346	Southern Cascade Mixed Conifer	Compliance	22,676	9,177	2015	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1103&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	NA	#(2015); %(2015) 2014, 2015	%%Application for Listing, Part VII, Carbon Stock Inventory, IMF-6, Not applicable
46	CAR1104	NA	CAFR5150	Forest Carbon Partners – Gabrych Ranch Project (Humboldt County and Trinity County, CA)	-123.606	40.713	Southern Cascade Mixed Conifer	Compliance	4,039	1,635	2015	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1104&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	NA	#(2015); %(2015) 2014, 2015	%%Application for Listing, Part VII, Carbon Stock Inventory, IMF-6, Not applicable
47	CAR1114	NA	CAFR5114	Crane Valley	-123.606	40.713	Southern Cascade Mixed Oak Woodland and Sierra Mixed Oak Woodland	Compliance	19,384	7,844	2016	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?r=111&ad=Prpt&act=update&type=PRO&aProj=pub&tablename=cr&id1=1114	NA	#(2016); %(2016) 2014, 2015, 2016	%%PART VII. CARBON STOCK INVENTORY IFM-6 Soil (if applicable): N/A
48	CAR1175	NA	CAFR5195	Finite Carbon – Passamaquoddy Tribe (Frankin, Somerset, Penobscot, Hancock, and Washington Counties, ME)	-67.63	45.288	New Brunswick Foothills & Lowlands, White Mountains Mixed Hardwoods	Compliance	98,492	39,858	2015-2016	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1175&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	NA	#(2015); %(2015) 2014, 2015; %(2016) 2015, 2016; %(2016) 2015, 2016	%%PART VII. CARBON STOCK INVENTORY IFM-6 Soil (if applicable): Excluded
49	CAR1180	NA	CAFR5280	Maillard Ranch (Mendocino County, CA)	-123.36	39.92	Temperate coniferous	Compliance	12,360	5,002	2016	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1180&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	NA	#(2016); %(2016) 2015, 2016	%%PART VII. CARBON STOCK INVENTORY IFM-6 Soil (if applicable): Excluded"

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50	CAR1183	NA	CAFR5283	Forest Carbon Partners-Mescalero Apache Tribe (Otero & Lincoln County, NM)	-105.65	33.17	Red Spruce and Eastern Hemlock	Compliance	221,822	89,768	2016	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?r=111&ad=Prpt&act=update&type=PRO&aProj=pub&tablename=cr&id1=1183	NA	#(2016); $(2016) ~10 months; %(2016) 2015, 2016	%%PART VII. CARBON STOCK INVENTORY IFM-6 Soil (if applicable): Not Applicable
51	CAR1191	NA	CAFR5291	Hollow Tree (Mendocino County, CA)	-123.782	39.85	Coast Redwood/Douglas-fir Mixed Conifer	Compliance	20,295	8,213	2016	IFM	https://thereserve2.apx.com/mymodule/reg/TabDocuments.asp?r=111&ad=Prpt&act=update&type=PRO&aProj=pub&tablename=doc&id1=1191	NA	#(2016); %(2016) 2015, 2016	%%PART VII. CARBON STOCK INVENTORY IFM-6 Soil (if applicable): Not Applicable
52	CAR1197	NA	CAFR5297	Upper Hudson Woodlands ATP, LP (Warren, Hamilton, Essex, Washington, Saratoga and Fulton, NY)	-74.33	43.88	Mixed conifer/mixed hardwood forest	Compliance	86,825	35,137	2017	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1197&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	NA	#(2017); %(2017) 2015, 2016, 2017	%%PART VII. CARBON STOCK INVENTORY IFM-6 Soil (if applicable): Excluded
53	CAR1204	NA	CAFR5304	AMC Silver Lake (Piscataquis & Aroostook Counties, ME)	-69.15	45.44	Spruce-Fir and Mixed Hardwood forests	Compliance	89,315	36,145	2017	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1204&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	NA	#(2017); %(2017) 2015, 2016, 2017	%%PART VII. CARBON STOCK INVENTORY IFM-6 Soil (if applicable): Excluded
54	CAR1209	NA	CAFR5309	Wolf River (Antigo, WI)	-88.86	45.23	Northern hardwood/mixed conifer forestland	Compliance	17,722	7,172	2017	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?r=111&ad=Prpt&act=update&type=PRO&aProj=pub&tablename=cr&id1=1209	NA	#(2017); %(2017) 2015, 2016, 2017	%%PART VII. CARBON STOCK INVENTORY IFM-6 Soil (if applicable): Excluded
55	CAR1213	NA	CAFR5313	MWF Adirondacks (Franklin, St. Lawrence & Lewis Counties, NY)	-74.91	44.35	Adirondacks & Green Mountains Northern Hardwood	Compliance	100,094	40,507	2017	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?r=111&ad=Prpt&act=update&type=PRO&aProj=pub&tablename=cr&id1=1213	NA	#(2017); %(2017) 2015, 2016, 2017	%%PART VII. CARBON STOCK INVENTORY IFM-6 Soil (if applicable): Excluded"
56	CAR1215	NA	CAFR5315	Molpus Ataya (Campbell &	-83.89	36.54	Allegheny & North Cumberland Mountains -	Complia	26,261	10,627	2017	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?r=111&ad=Prpt&act=update&type=PRO&aProj=pub&	NA	#(2017); %(2017) 2015,	%%PART VII. CARBON STOCK INVENTORY IFM-6 Soil (if applicable):

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				Claiborne Counties, TN)			Mixed Pine Hardwood, Cove Forests, Northern Hardwoods, Oak - Hickory	nce					tablename=cr&id1=1215		2016, 2017	Excluded
57	CAR1217	NA	CAFR5317	West Grand Lake (Washington County, ME)	-67.75	45.23	New Brunswick Foothills & Lowlands, White Mountains Mixed Hardwoods	Compliance	19,552	7,912	2015	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?r=111&ad=Prpt&act=update&type=PRO&aProj=pub&tablename=cr&id1=1217	NA	#(2015); %(2015) 2013, 2014, 2015	%%PART VII. CARBON STOCK INVENTORY IFM-6 Soil (if applicable): Excluded"
58	CAR973	NA	CAFR5003	Bishop Project (Near Bessemer, MI, and other locations)	-87.852	46.5620	Tree cover, broadleaved, deciduous, closed to open (>15%)	NA	2,112.86	855.044862	2013-2016	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=973&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=802&md=Prpt&id1=%201004	$2013	%% Blue Source - Bishop Improved Forest Management Project ARB Project Listing Form Attachments February 4, 2013, Part V.B, Soil carbon excluded.
59	CAR1004	NA	NA	Berry Summit (Near Eureka, CA	-123.758	40.905	Tree cover, needle leaved, evergreen, closed to open (>15%)	NA	2,112.86		2013	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1004&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	NA	$2013	%% Project Description Document, Table 5, IFM-6 not included
60	CAR1174	NA	CAFR5224	Eddie Ranch (Mendocino County, CA)	-123.17	39.456	Tree cover, needle leaved, evergreen, closed to open (>15%)	NA	2,286		2017	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1174&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	NA	$2017, %2017	%% Application for Listing, Part VII-A, IFM-6, Soil Carbon, not applicable
61	CAR1190	NA	CAFR5220	Greenwood Creek (Mendocino County, CA)	-123.631	39.073	Tree cover, needle leaved, evergreen, closed to open (>15%)	NA	8,659	3,594.17	2015-2017	IFM	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1190&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	NA	$2015-2016-2017; %2015, 2016, 2017	%% Application for Listing, Part II-C, IFM-6, Soil Carbon, not applicable
62	CAR1262	NA	NA	San Juan Lachao Pueblo Nuevo, Oaxaca, Mexico	-97.125	16.158	Tree Cover, broadleaved, deciduous, closed	NA	32,840.31	13,290	2014-2016	Forestry	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1262&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	NA	$2014, 2015, 2016; %2014, 2015	%% Carbono en el suelo: No se incluye, REPORTE DE PROYECTO Captura de Carbono en San Juan Lachao, Oaxaca San Juan Lachao Pueblo Nuevo, Oaxaca 11 de octubre de 2017 CAR1262
63	CAR1306	NA	NA	Ejido San Nicolás Totolapan, CDMX, Mexico	-99.2544	19.2994	Tree cover, broadleaved, deciduous, closed to open (>15%)	NA	5,302.83	2,145.98	2017-2018	Forestry	https://thereserve2.apx.com/mymodule/reg/TabProjectEmissions.asp?id1=1306&ad=Prpt&act=update&sBtn=&r=111&Type=PRO&tablename=cr&aProj=pub	NA	$2017, 2018	%% https://thereserve2.apx.com/mymodule/reg/TabDocuments.asp?r=111&ad=Prpt&act=update&type=PRO&aProj=pub&tablename=doc&id1=1

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*Anomalous Features

Vintage year is an outlier defined in Figure 1 (a). Issue date may vary.

^^Backward model reporting year run (in parenthesis) for the interval noted. Issue date may vary.

Forward model reporting year run (in parenthesis) for the interval noted. Issue date may vary.

$ A single vintage year (in parenthesis) is reported as a partial year or a single vintage year is split representing two or more reported carbon sequestration intervals as indicated. Issue date may vary.

$$ Exact values (in parenthesis) for carbon sequestration are repeated over interval as indicated. Issue date may vary.

% A single vintage year (in parenthesis) represents two or more reported years and or multiple net carbon sequestration years as indicated. Issue date may vary.

**Project size ranged from 221,822 to 106 acres with a mean size of 21,256 acres, standard deviation of 37,451 acres. Issue date may vary.

%% Soil carbon pool excluded and not directly measured as specified in project documentation.

IFM: Improved Forest Management. This protocol applies to forest offset projects that involve management activities that maintain or increase carbon stocks on forested land relative to baseline levels of carbon stocks.

AC: Avoided Conversion. This protocol applies to forest offset projects that involve preventing the conversion of forestland to a non-forest land use by dedicating the land to continuous forest cover through a qualified conservation easement or transfer to public ownership, excluding transfer to federal ownership.

Footnote 1: For example, CAR 101 (Van Eck), CAR 102 (Garcia River), CAR 408 (Big River) and, CAR 429 (McCloud River) provide Project Activity (Tons), Confidence Deduction, Adjusted Project Activity and Baseline values for annual increments in the Cumulative Performance Reports page for each project (Table I). Values for "Project Activity (tons)", if interpreted as annual gross primary productivity, suggested by CARB-CAR equations (Supplement 2; "actual onsite carbon" as above ground carbon pools), yield a mean of 16,941.4 ± 4,694.2 gC $m^{-2}yr^{-1}$ (n=39 annual, CAR101,102,408,429) compared to GPP reported for NEE1 (n = 50 sites, 487 annual values) of 1,269.8 ± 636[65]. The CARB-CAR values are in excess ~13x and ~7x of NEE1 mean and standard deviation, respectively, demonstrating the extreme and irreconcilable characteristics of the CARB-CAR methods. Initial-year data for the aforementioned sites (CAR101,102,408,429) were zero or small relative to the magnitude of project activity and baseline (e.g., CAR408, 1.4%) (Table I).

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Table 2 (on next page)

Results of hypothesis test for all annual data

Results of a hypothesis test with a null hypothesis that the difference between the CARB-CAR and the NEE1 means is under the allowed 5% threshold. The test is performed separately for all years between 2002 and 2014, the p-values are recorded in the last two rows.

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Table II. Results of a hypothesis test with a null hypothesis that the difference between the CARB-CAR and the NEE1 means is under the allowed 5% threshold. The test is performed separately for all years between 2002 and 2014, the p-values are recorded in the last two rows.

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
CARB-CAR mean	-742.31	-719.94	-539.51	-1021.7	-2038	-992.42	-950.47	-593.86	-983.74	-725.04	-682.77	-865.27	-999.38	-1432.7
CARCAR SD	928.79	585.94	1049.3	683.21	3433.1	1418.7	1170.2	644.84	1460.8	1190.5	1049.7	1541.1	1590.6	1835.7
CARB-CAR (n)	2	5	9	9	12	23	24	25	32	32	31	32	30	23
NEE1 mean	-190.55	-189.15	-243.45	-267.26	-225.08	-241.51	-217.16	-206.75	-184.51	-92.287	-93.452	-53.874	-2.375	-9.2857
NEE1 SD	249.06	266.8	268.25	250.02	243.39	237.56	254.86	275.89	244.93	231.71	161.39	199.85	214.46	207.25
NEE1 (n)	40	48	45	42	44	42	41	31	24	17	12	11	8	7
p-value	0.009	0.001	0.065	0.000	0.001	0.001	0.000	0.004	0.008	0.024	0.039	0.055	0.052	0.032
p-value in %	0.87	0.05	6.53	0.00	0.07	0.13	0.03	0.36	0.81	2.37	3.88	5.48	5.24	3.25

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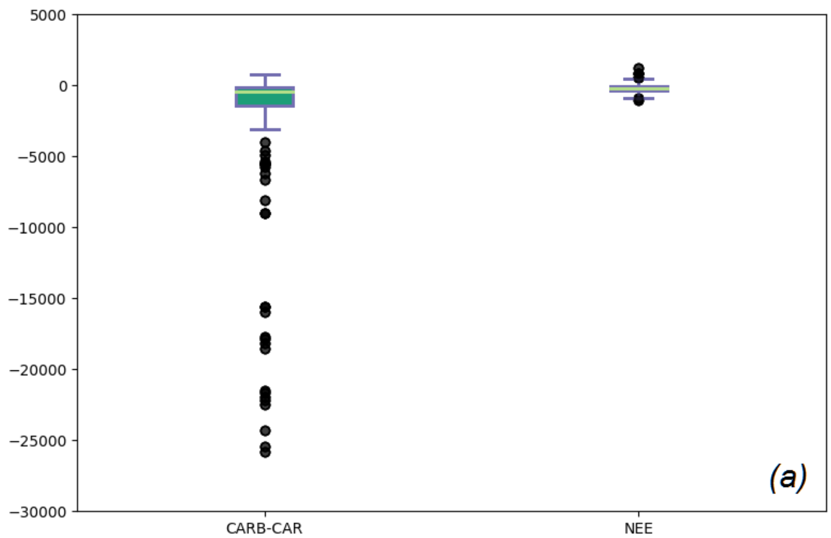
Table 3(on next page)

Box plots for CARB-CAR and NEE1 data analyzed in this study

Figure 1 (a). Figure 1 presents a box plot of annual records from CARB-CAR (340 years, 63 sites) and NEE1 (540 years, 59 sites) projects. The box plots show the median (white line through each box), the 25th percentile (bottom of lower box), the 75th percentile (top of upper box), the upper and lower whiskers represent the upper and lower values that are not outliers, and outliers (individual closed circles). The CARB-CAR data show outliers exceeding -12,000 gC $m^{-2}yr^{-1}$. CARB-CAR median is -445.1 gC m^{-2} yr^{-1} compared to the NEE1 median value of -172.5 gC m^{-2} yr^{-1}. The means and standard deviations (±) are, -948.8 ± 1504.8 and -198.2 ± 261.6, for CARB-CAR and NEE1, respectively.

Figure 1 (b). Box plots, described as above, for CARB-CAR and NEE1 populations with CARB-CAR outliers removed.



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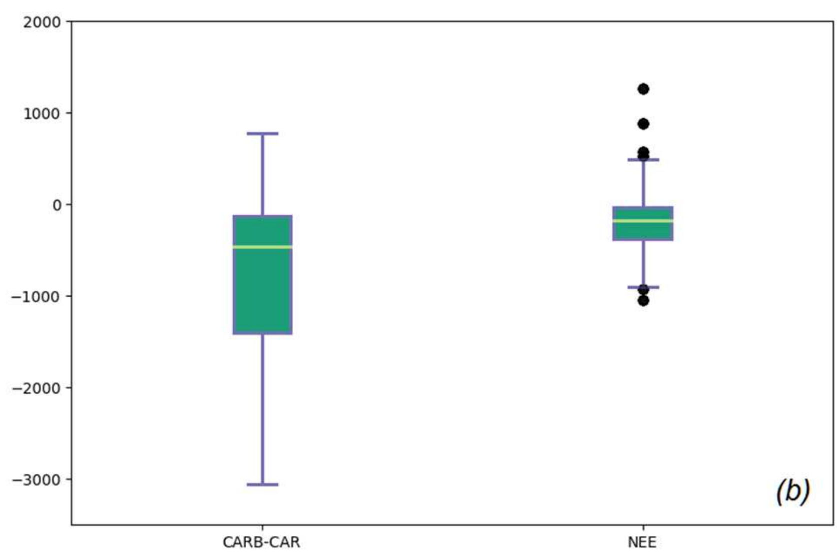

Figure 1 (b). Box plots, described as above, for CARB-CAR and NEE1 populations with CARB-CAR outliers removed.

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Figure 1 (on next page)

Plot of 95% confidence interval for the difference in means between CARB-CAR and NEE1 annual data

Figure 2. Plot of the 95% confidence interval for the difference in means between the CARB-CAR and NEE1 measurements. The combined data set (All Years) consists of 340 CARB-CAR and 540 NEE1 data points. A formula for a large-sample confidence interval (described in Methods) is used for the unfilled bars and no assumption on equal standard deviations between the two data sets has been made

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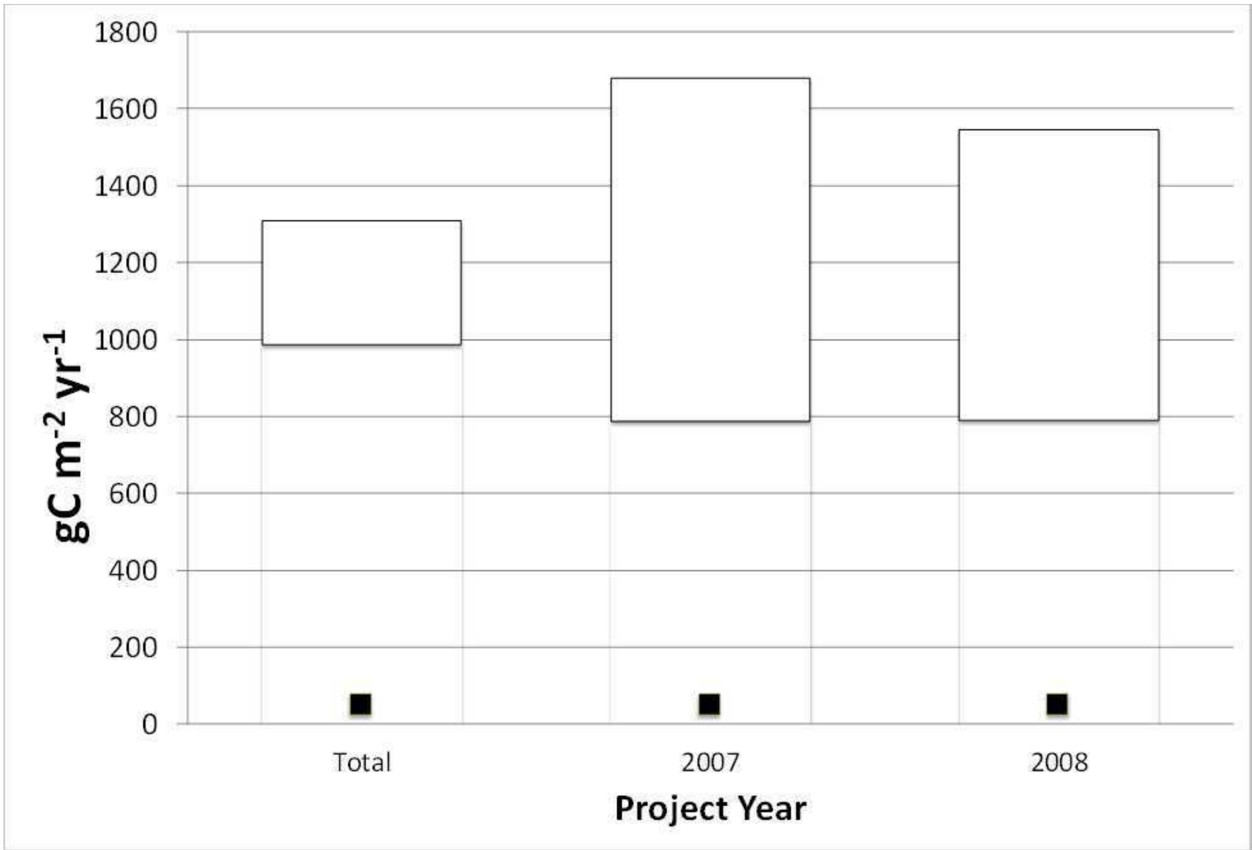

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Figure 2(on next page)

Time interval plot of CARB-CAR and NEE1 annual data.

Figure 3. Time interval plot of CARB-CAR data (open bars) from 2002 to 2015 and NEE1 measurements [65] (filled bars) from 1992 to 2015. Values are plotted as positive numbers representing net sequestration of carbon. The averages for the two data sets are shown by each bar representing forest carbon sequestration calculated annually over all available locations. The error bars represent 5% of the CARB-CAR year for 2006 and applied to all CARB-CAR project annual averages.

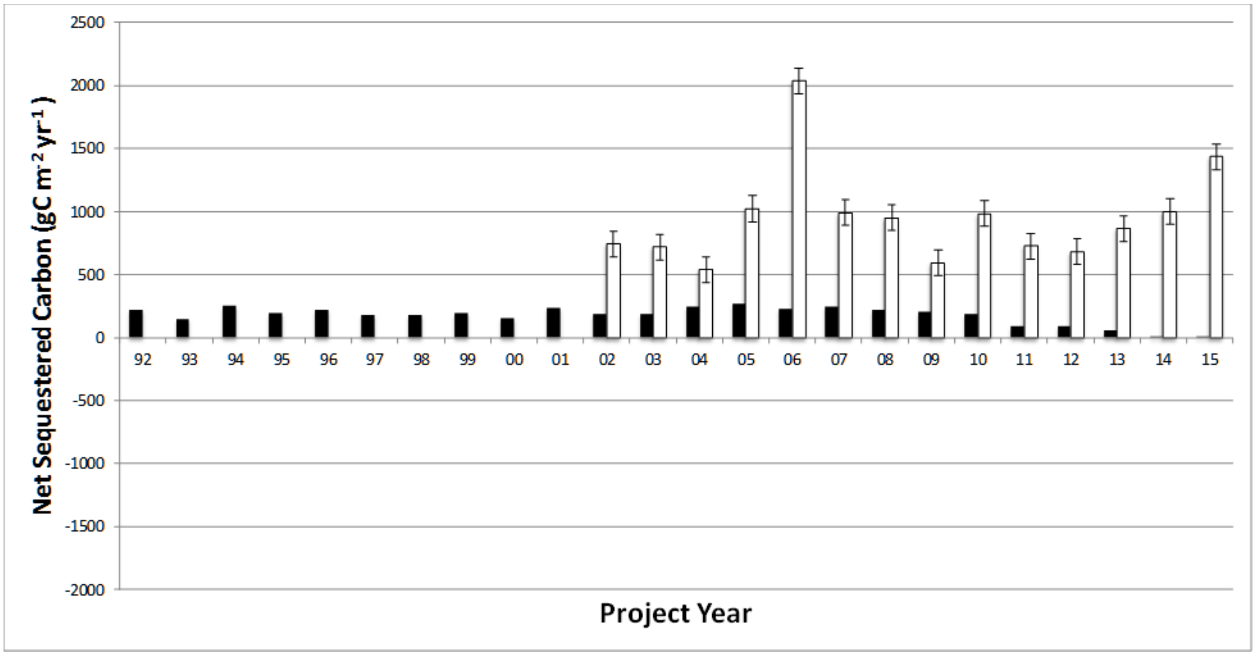

Figure 3. Time series plot of CARB-CAR data (open bars) from 2002 to 2015 and NEE1 measurements[65] (filled bars) from 1992 to 2015. Values are plotted as positive numbers representing net sequestration of carbon. The averages for the two data sets are shown by each bar representing forest carbon sequestration calculated annually over all available locations. The error bars represent 5% of the CARB-CAR year for 2006 and applied to all CARB-CAR project annual averages.

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