Emissions reductions from harvested wood products and management residuals

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Contents

1 California forest management emissions profile

1.1 Introduction

Utilization of wood biomass produced from forest management has potential to reduce greenhouse gas (GHG) emissions and other climate pollutants. Currently the majority of biomass produced from forest management activities is either left in the woods to decompose or aggregated at a landing where it is piled and eventually burned. Woody material resulting from a history of fire suppression, and residual material from management activities has lead to accumulation of dead woody material in excess of historic reference conditions and has resulted in elevated risk of damaging wildfire in much of California's forestland. Prescribed natural fire and sanitation pile burning have evolved as common practice for fuel load management in California's forests. However, air quality impacts of these common forestry practices as well as the opportunity cost of not using residual biomass in bioenergy energy and/or other applications weigh in favor of alternative utilization strategies. As demonstrated by previous studies, prescribed natural fire is often only an effective tool for reducing fuel loading and maintaining fire-resilient landscapes when coupled with mechanical treatment to remove biomass (Stephens et al 2009), and open burning can be a substantial source of strong radiative forcing agents (black carbon) and criteria air pollutants (PM, NOX) when compared to use in controlled combustion biomass power plants with modern emissions control technology.

Forest management activities in California produce logs for lumber markets and as well as maintain and enhance forest health. In adition to merchantable logs, management activities produce logging residuals and slash that are either left in the stand to decompose or piled and burned as directed by forest practice rules (California Forest Practice Rules, Article 7 § 917.2). Combustion or decomposition of this residual material results in emissions of greenhouse gases (GHG), criteria air pollutants (CAP) and short-lived climate pollutants (SLCP).

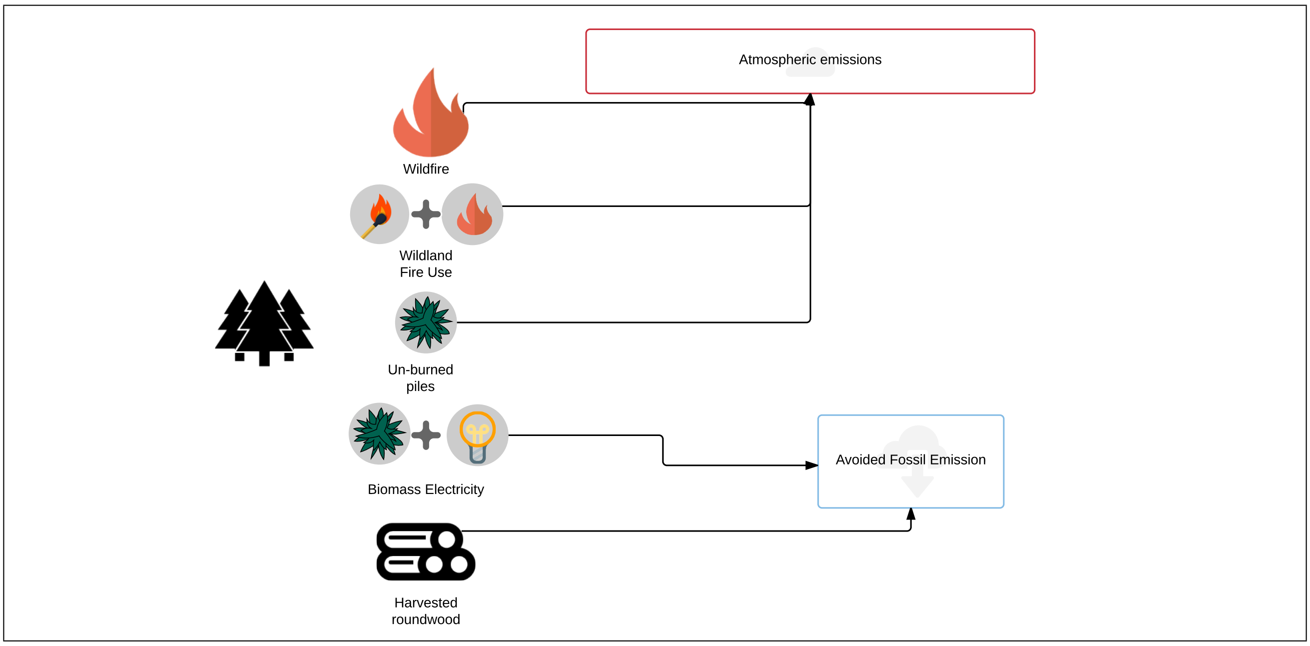

Figure 1: Overview of the system.

Quantifying the climate effects of wood products and forest management residuals is important to the development of the Forest Climate Plan (FCP)[1] as well as efforts underway by the California Board of Forestry and CalFire to meet the intent of AB 1504 (2010)[2]. To inform these efforts, this report provides estimates of the following :

1. GHG and SLCP emissions produced from the combustion or decomposition of logging residuals.

2. GHG emissions reductions from the use of wood products harvested in the state.

Estimates are based on empirical data and reflect past forest management activities. It is **critical** to note that the empirical data used in this analysis reflect point-in-time measures that are affected by a dynamic system

[1]The Forest Climate Action Team (FCAT) was assembled in August of 2014 with the primary purpose of developing a Forest Carbon Plan by the end of 2016. FCAT is comprised of Executive level members from many of the State's natural resources agencies, state and federal forest land managers, and other key partners directly or indirectly involved in California forestry. FCAT is under the leadership of CAL FIRE, Cal-EPA, and The Natural Resources Agency.

[2]AB-1504 Forest resources: carbon sequestration.(2009-2010)

of climate, growth, and mortality in forests as well as macroeconomic and policy forces. To effective manage forests for climate (and/or other) benefits, a process modeling approach is necessary. This analysis may provide insight into opportunities to more effectively utilize woody biomass residuals from current forest management activities based on available historical data.

Several steps are necessary to address the objective stated:

1. Estimate CO2 equivalent emissions from burning forest management residuals using criteria pollutant and GHG emissions inventory published by the California Air Resources Board (CARB)
2. Estimate the volume and fate of wood removed, left in the forest, and burned as a result of direct anthropogenic management activities.
3. Establish life-cycle displacement factors (DF) for all utilized wood and apply DF to harvested wood to obtain an aggregate estimate.

1.1.1 Key Findings

- Baseline emissions of GHG and SLCP emissions from burning of forest management residuals can be estimated and should be considered in any forest management emissions baseline.
- Total emissions from pile burning of foreat management resulals includine SLCP and GHG components extrapolated from CARB emissions inventory is XXX MTCO2e
- Harvested wood in California in 2012 resulted in avoided emissions of 4 MMTCO2e
- Logging residuals not used in bioenergy production contributed emissions of:
  - XXX MMTCO2e resulting from anthropogenic burning of logging residuals
  - XXX MMTCO2e resulting from decomposition of loggin residuals left unburned
- Un-utilized slash from non-commercial management activities on National Forest System lands contributed emissions of XXX MMTCO2e
- Forest Inventory and Analysis re-sample data has been used in the southeast to quantify removals resulting from non-commercial management activity and could be used for this purpose in California
- The Prescribed Fire Information Reporting System (PFIRS) may be a usefull tool in quantifying emissions from pile burns and prescribed fire. However, at this time it is not a requirement for California Air Quality Management Districts to report emissions through this system, and thus it is not comprehensive. It is a requirment that prescribed fires and pile burns on National Forest System Lands are reported through PFIRS. It is not possible at this point to associate burns in PFIRS with commercial harvest activities.

1.2 Estimating CO2 equivalent emissions from forest biomass burning

1.2.1 Estimating black carbon emissions from biomass burning

The California Air Resources Board (CARB) reports emissions from forest biomass burning in the most current statewide emissions inventory. The Criteria Air Pollutant (CAP) emissions inventory and the Greenhouse Gas (GHG) emissions inventory are both necessary sources for establishing aggregate annual climate-forcing emissions. The GHG inventory captures gasses with radiative forcing properties but does not capture elemental carbon or black carbon (BC) emissions which have strong radiative forcing properties. The California Air Resources Board (2015, 2016) reports aggregate SLCP emissions from wildfire (80.52 MMTCO2e), and from prescribed fire (3.66 MMTCO2e). However, no reference in the SLCP Strategy is made to the source of these estimates.

The California Air Resources Board has published criteria air pollutant emissions estimates for 2015. Particulate matter as reported in the criteria air pollutant emissions inventory contains black carbon which is a strong short lived climate pollutant.

GWP_{20}	$GWP\sigma_{20}$	GWP_{100}	$GWP\sigma_{100}$	GWP_{500}	$GWP\sigma_{500}$	Source
2200.0	888.82	633.33	255.41	193.33	77.67	Fuglestvedt2010
3200.0		900.0				CaliforniaAirResourcesBoard2015

Table 1: Range of GWP values for Black Carbon.

CARB reports PM 2.5 emissions in tons/day. Annual emissions as reported by CARB are shown in

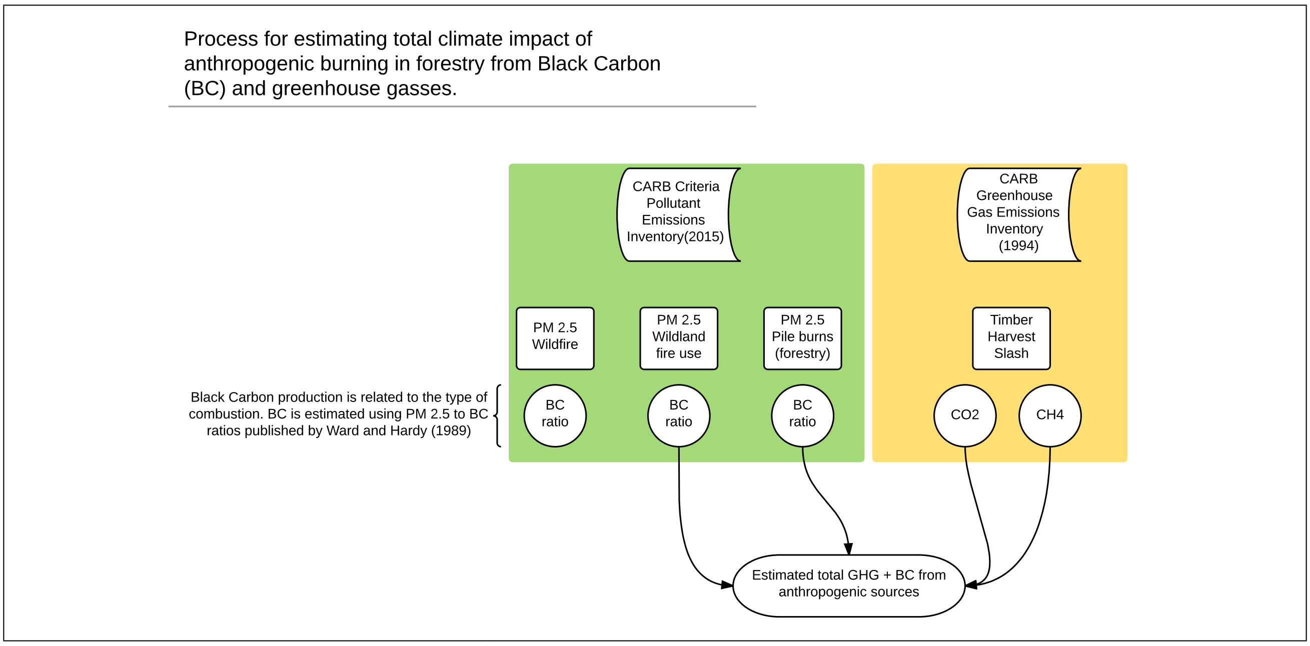

Figure 2: Data sources available from CARB for estimating GHG and SLCP emissions from forest management.

Source	PM 2.5 (t y^{-1})
ALL VEGETATION	137630.15
FOREST MANAGEMENT	5480.51
WILDLAND FIRE USE (WFU)	6802.43

Black Carbon emissions can be estimated from PM 2.5 emissions if the ratio of smoldering to flaming combustion is known. Ward and Hardy (1989) provide estimates of the ratio of smoldering to flaming combustion for a hand/machine piled burns, prescribed natural fire and wildfire. BC is a fraction of the Total Carbon (TC) component of PM 2.5. Thus BC is related to PM 2.5 by Eq. (1) :

$$BC = (PM_{2.5} \times F \times TC_f \times BC_f) + (PM_{2.5} \times S \times TC_s \times BC_s) \quad (1)$$

where:

BC = Black Carbon (mass units)

$PM_{2.5}$ = $PM_{2.5}$ (mass units)

F = Percent of combustion in flaming phase

TC_f = Total Carbon fraction of $PM_{2.5}$ for flaming phase

BC_f = Black Carbon fraction of Total Carbon for flaming phase

S = Percent of combustion in smoldering phase

TC_s = Total Carbon fraction of $PM_{2.5}$ for smoldering phase

BC_s = Black Carbon fraction of Total Carbon for smoldering phase

Based on Ward and Hardy (1989) and Jenkins et al. (1996) the following ratios are used herein.

Source	BC_f t^{-1} PM	TC_f^{Cv} t^{-1} PM	BC_f^{Cv} t^{-1} TC	BC_s t^{-1} PM 2.5	TC_s^{Cv} t^{-1} PM	BC_s^{Cv} t^{-1} TC
Pile Burn	0.046904	0.09	0.45	0.01624	0.01	0.49
Prescribed	0.08016309	0.0733	0.5833	0.020944	0.08	0.29
Wildfire	0.05870124	0.0867	0.4467	0.0228641	0.06	0.338

Table 2: Factors used for calculating Black Carbon (BC) emissions from three primary combustion sources. BC is a fraction of Total Carbon (TC) which is a fraction of total PM 2.5. Coefficients of variation (C_v) are reported here as well.

To arrive at a rough estimate of BC emissions based on PM2.5 the following steps are taken

1. Determine the amount of PM2.5 produced in the flaming and smoldering phases of combustion for each type (piles, prescribed, wildfire). Ratios from Ward and Hardy (1989), table 5 are used.

2. Define 1000 normal probability distributions using the coefficient of variation from Table ?? the percent of PM2.5 comprised of carbonaceous material (TC) and percent of TC comprised of black carbon (BC) give estimates and coefficient of variation estimates provided by Ward and Hardy (1989), tables 2 and 3.

3. Estimate annual BC emissions based on probability distributions defined in 2.

The following plot represents estimates of total BC emissions resulting from combustion of biomass in the CARB CPE emissions categories reflecting woody biomass combustion in wildfire, pile burning and prescribed natural fire.

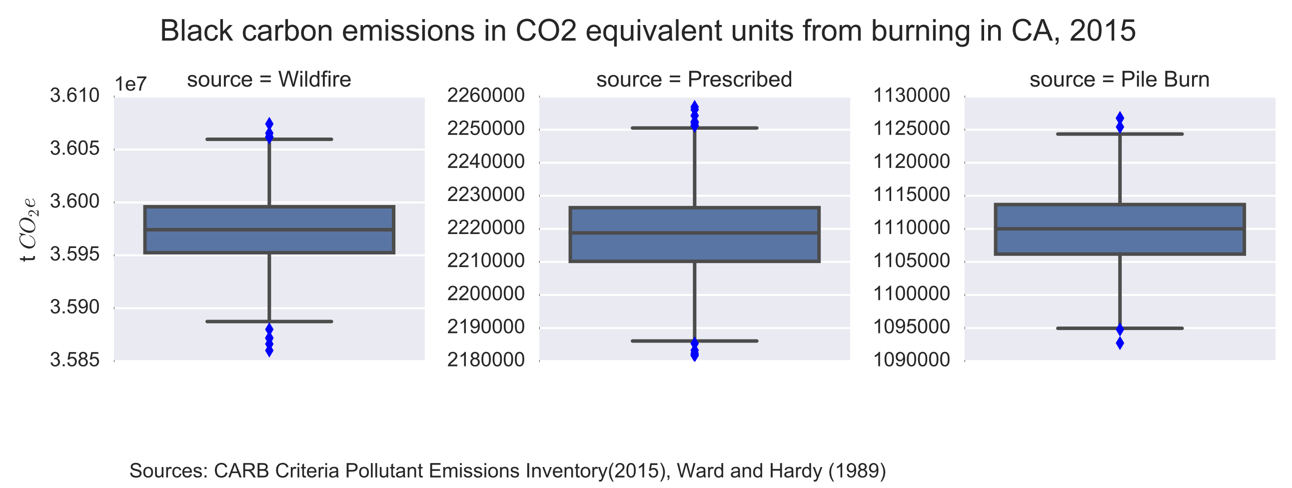

Figure 3: Short-lived climate pollution from open burning of biomass as reported by CARB criteria pollutant emissions inventory.

In addition the `http://www.arb.ca.gov/cc/inventory/archive/tables/net_co2_flux_2007-11-19.pdf` CARB 1994 greenhouse gas emissions inventory estimates emissions from wildfire and slash burning through 2004 (Table ??).

Source Category	Average annual emissions 1994-2004 $MMTCO_{2e}$
Forest and rangeland fires	2.0194
Timber harvest slash	0.155266666666667

To arrive at an estimate of total emissions in 2015 from burning forest management residuals in CO2 equivalent terms from published CARB estimates we can combine the CO2 emissions reported for 2004 in the LULUC Biodegradable Carbon Emissions and Sinks with black carbon emissions extrapolated from the CARB Criteria Air Pollutant Emissions inventory estimates. The time discrepancy between the 2004 and 2015 is acknowledged as an irreconcilable source of uncertainty in this estimation. Further model based estimation could be used to derive a ratio of GHG to PM using the CONSUME model. This does however show that a baseline of substantial emissions from forest management residuals has been reported in CARB emissions inventories and should be recognized as a baseline condition. We find that a rough estimate of CO2e emissions from pile burning annual approaches 1 Mt CO2e.

	Mt CO2e	Source
0	0.17	CO2 pile burning
1	0.99	CO2e BC pile burning
2	1.16	Total Mt CO2e

BC emissions in terms of CO2e has not been included in any GHG emissions inventory published by CARB.

1.3 Fate of harvested wood

Wood harvested from California's forests is used in construction, landscaping and consumer products. Residual streams from the production of these wood products are used to generate elctricity and heat and a protion if the residual goes to landfills or is left in the woods as slash.

1.3.1 Wood Displacement Factors

In all of its applications, a range of other products can be used in place of wood. For example, in residential construction, precast concrete and structural steel framing are competitive alternatives to wood. The choice of materials used in construction has a profound impact on GHG emissions from the construction sector. This impact can be expressed as a displacement factor (DF). A displacement factor quantifies the amount of emissions reduction achieved per unit of wood used. A meta analysis conducted by (Sathre and O'Connor, 2010) compared empirical analysis from 21 international studies and found an average emissions reduction of 2.1 tons of carbon (3.9 t CO2e) per ton of dry wood used. Studies ranged substantially around the average, the authors found that the majority of published displacement factors ranged between 1 and 3 tC/t dry wood. The displacement factors published in (Sathre and O'Connor, 2010) and used in this analysis include the following sources emissions reduction:

1. **Reduced emissions from manufacturing:** Wood products require total energy than than manufacturing most alternative materials.
2. **Avoided process emissions:** Wood-alternatives such as cement have substantial CO2 emissions associated with production.
3. **Carbon storage in products:** Carbon in harvest wood was drawn from the atmosphere through photosynthesis and will remain fixed through the useful life of the wood product.
4. **Carbon storage in forests:** Forests producing wood continue to grow. It is assumed that forests producing wood in California are managed to sustain forest growth (not converted to non-forest land uses).
5. **Avoided fossil fuel emissions due to bioenergy substitution:** Logging and milling residuals used to produce energy avoid emissions from fossil energy sources in the energy sector.
6. **Carbon dynamics in landfills:** A fraction of carbon in wood deposited in landfills post use remains in semi-permanent storage. The remainder is converted to methane through biological decomposition in the landfill. Capture and use of the methane as an energy source, in turn reduces emissions from fossil energy sources.

1.3.2 Displacement Factors Applied to Timber Products Output

To evaluate the climate impact of harvested wood in California I use harvested roundwood estimates from the Timber Products Output (TPO) database[3]. I use two estimates of the DF applied to the harvested wood reported in the TPO based on weather logging residuals are used in bioenergy or left in the woods to decompse or burn.

Figure 4 reflects the flow of wood from Californias forest to its fate in-use and is the frame of reference for the following analysis.

I use displacement factors reported by Sathre and O'Connor (2010) applied to the reported volumes from the TPO. The following references are used to arrive at a displacement factor for harvested roundwood without logging residue utilization.

reference	displacement factor
Eriksson et al. (2007)	1.7
Eriksson et al. (2007)	2.2
Salazar and Meil (2009)	4.9
Werner et al. (2005)	1.7

I use an average of the DF reported here of **2.625** tCO2e/t finished wood product. For harvested roundwood with logging residue utilization the following studies are used.

reference	displacement factor
Eriksson et al. (2007)	1.9
Eriksson et al. (2007)	2.5
Gustavsson et al. (2006)	4
Gustavsson et al. (2006)	5.6
Gustavsson et al. (2006)	2.2
Gustavsson et al. (2006)	3.3
Pingoud et al. (2001)	3.2

[3] Timber Products Output Reporting Tool `http://srsfia2.fs.fed.us/php/tpo_2009/tpo_rpa_int1.php`

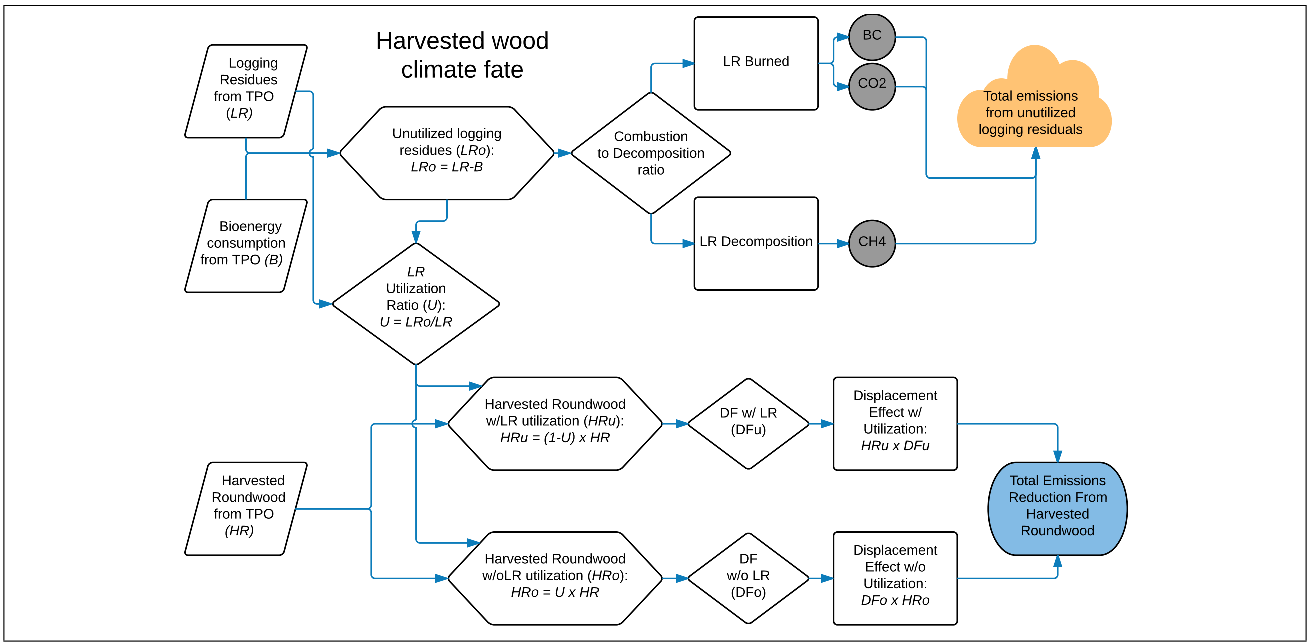

Figure 4: Wood flows from commercial timber harvest in California

I use an average of the DF reported here of **3.243** tCO2e/t finished wood product.

TPO is reported in terms of roundwood harvested for products. The displacement factors presented in Sathre and O'Connonr are in terms of tons of carbon in wood products. Therefore we must assume a milling efficiency to convert TPO estimates to finished wood products. I assume a milling efficiency of 0.5.

Further, TPO is reported in in cubic feet and the DF implies a mass unit. To convert cubic meters to a mass unit we use the average wood density of harvested volume in California weighted by species. Harvest volume by species is reported in Mciver et al. (2012). The resulting weighted average wood density used here is **27.94 lbs/cuft**.

McIver and Morgan report the percent of harvest used as bioenergy feedstock. From personal communications with Chelsea McIver, all bioenergy feedstock reported is sourced in-woods (ie, not mill residues).

	year	bioenergy % of harvest
0	2000	0.024
1	2006	0.036
2	2012	0.082

The TPO reports the total logging residues produced from the states harvest.

	Ownership	Roundwood Products	Logging Residues	Year
0	National Forest	72.4	20.7	2012
1	Other Public	16.2	3.4	2012
2	Forest Industry	328.9	72.4	2012
3	Other Private	53	11.2	2012
4	National Forest	52.8	16.3	2006
5	Other Public	1.1	0.3	2006
6	Forest Industry	274.3	59.6	2006
7	Other Private	139.2	33.2	2006
8	National Forest	90.8	22.6	2000
9	Other Public	5.2	1.6	2000
10	Forest Industry	372.5	70.6	2000
11	Other Private	159.4	49.1	2000
12	National Forest	132.1	11.2	1994
13	Other Public	24.7	4.3	1994
14	Forest Industry	396.1	63.1	1994
15	Other Private	174.7	22.3	1994

In addition to the TPO, the California Board of Equalization (BOE reports historical timber harvest. Averaged over the years where both repositories report data, the BOE is 8% less than TPO (Table **??**). This is reasonable considering that there is not financial incentive to under-report under the TPO data collection protocol.

year	McIver, et. al. (2012) MMBF	BOE MMBF	BOE/M&M
1978	4606.0	4491	0.98
1979	4044.0	3991	0.99
1980	3478.0	3164	0.91
1981	2832.0	2672	0.94
1982	2488.0	2318	0.93
1983	3638.0	3358	0.92
1984	3701.0	3546	0.96
1985	4093.0	3818	0.93
1986	4416.0	4265	0.97
1987	4667.0	4500	0.96
1988	4847.0	4670	0.96
1989	4699.0	4424	0.94
1990	4264.0	4021	0.94
1991	3439.0	3195	0.93
1992	3192.0	2973	0.93
1993	3041.0	2871	0.94
1994	2814.0	2316	0.82
1995	2520.0	2306	0.92
1996	2515.0	2273	0.9
1997	2640.0	2400	0.91
1998	2420.0	2091	0.86
1999	2429.0	2144	0.88
2000	2244.0	1966	0.88
2001	1801.0	1603	0.89
2002	1691.73	1690	1.0
2003	1667.95	1663	1.0
2004	1704.0305	1706	1.0
2005	1738.5	1725	0.99
2006	1960.35	1631	0.83
2007	1759.6	1626	0.92
2008	1476.0745	1372	0.93
2009	911.19	805	0.88
2010	1302.38	1161	0.89
2011	1432.5	1288	0.9
2012	1421.3	1307	0.92

Table 3: Total annual harvest reported by Mciver et al. (2012) and California Board of Equalization.

The BOE does not report harvest from tribal lands but the TPO does. By TPO data, harvest from tribal lands averages 0.74% of the total annual harvest in the state for the 37 years of parallel data. For this analysis we use TPO data and include tribal lands.

year	State	Federal	Private	Tribal
1947	0.0	0.0	569.85	0.0
1948	0.0	0.0	735.29	0.0
1949	0.0	0.0	698.53	0.0
1950	0.0	0.0	808.82	0.0
1951	0.0	0.0	900.74	0.0
1952	2.57	113.79	808.82	4.78
1953	3.31	117.65	977.94	2.76
1954	2.94	141.54	880.51	4.6
1955	2.57	191.73	906.25	6.07
1956	4.41	206.99	862.13	5.33
1957	4.96	170.59	801.47	6.62
1958	5.51	208.27	821.69	6.99
1959	4.96	279.6	788.6	9.19
1960	5.15	250.37	680.15	8.82
1961	5.33	259.74	707.72	10.11

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year	State	Federal	Private	Tribal
1962	6.25	259.01	744.49	8.64
1963	4.04	311.76	678.31	9.93
1964	4.6	348.16	643.38	9.01
1965	5.7	363.05	591.91	9.74
1966	5.88	360.85	545.96	8.27
1967	6.43	355.51	562.5	7.54
1968	8.82	440.44	542.28	14.52
1969	7.35	372.61	529.41	9.93
1970	6.25	345.4	481.62	5.15
1971	7.17	383.09	476.1	12.87
1972	6.8	411.58	591.91	12.13
1973	6.07	371.69	516.54	9.38
1974	7.35	322.79	525.74	9.38
1975	6.43	287.87	498.16	3.31
1976	7.35	348.53	507.35	6.99
1977	5.15	323.35	544.12	6.99
1978	5.15	332.35	509.19	8.64
1979	4.78	321.32	417.28	8.82
1980	3.68	279.04	356.62	7.72
1981	2.76	201.65	316.18	4.04
1982	7.72	173.9	275.74	1.47
1983	7.9	313.42	347.43	2.57
1984	6.25	288.05	386.03	3.86
1985	6.62	339.52	406.25	0.92
1986	5.33	365.26	441.18	4.96
1987	7.72	364.89	485.29	7.54
1988	5.7	403.68	481.62	2.57
1989	6.8	373.53	483.46	2.02
1990	4.41	283.09	496.32	2.57
1991	6.99	248.35	376.84	4.41
1992	4.23	190.99	391.54	5.88
1993	6.25	137.32	415.44	2.39
1994	3.12	152.02	362.13	2.76
1995	7.35	101.1	354.78	2.94
1996	10.11	86.4	365.81	2.39
1997	8.64	101.65	375.0	2.76
1998	4.78	83.46	356.62	2.94
1999	0.0	97.24	349.26	0.0
2000	3.49	63.42	345.59	1.84
2001	2.94	56.07	272.06	1.84
2002	0.18	31.38	279.41	2.5
2003	0.18	28.85	277.57	3.29
2004	0.18	20.78	292.28	3.05
2005	0.18	43.66	275.74	1.95
2006	0.74	41.61	318.01	2.37
2007	0.18	58.57	264.71	3.55
2008	0.18	37.7	233.46	2.48
2009	0.18	30.37	136.95	0.72
2010	0.18	49.89	189.34	1.79
2011	0.18	55.42	207.72	2.1
2012	5.13	37.39	218.75	1.49

Table 4: Annual harvest by ownership from Mciver et al. (2012) (MCF)

To use the TPO data to estimate emissions reductions using the DF we apply a conversion factor of **5.44** MCF/MMBF. This is an approximation as the actual sawlog conversion factor varies with the log size which, on average on average over time has changed.

The ratio of harvested volume to which we can apply a displacement factor reflecting bioenergy use of logging residuals can be calculated based on the ratio of reported consumption of logging residuals in bioenergy by Mciver et al. to the total logging residuals reported in the TPO. McIver and Morgan report bioenergy consumption from 2000 forward. For years previous, we use the average bioenergy consumption from 2000 – 2012. These results assume bioenergy application throughout the reporting years. Bioenergy use of residuals did not begin until the late 1970. Further analysis is necessary to modify these results to reflect the development of the bioenergy industry.

To calculate the total emissions reduction resulting from California's timber harvest, we apply the appropriate displacement factor (with or without logging residual utilization) to the commensurate fraction of harvested roundwood. The results are shown in the following chart.

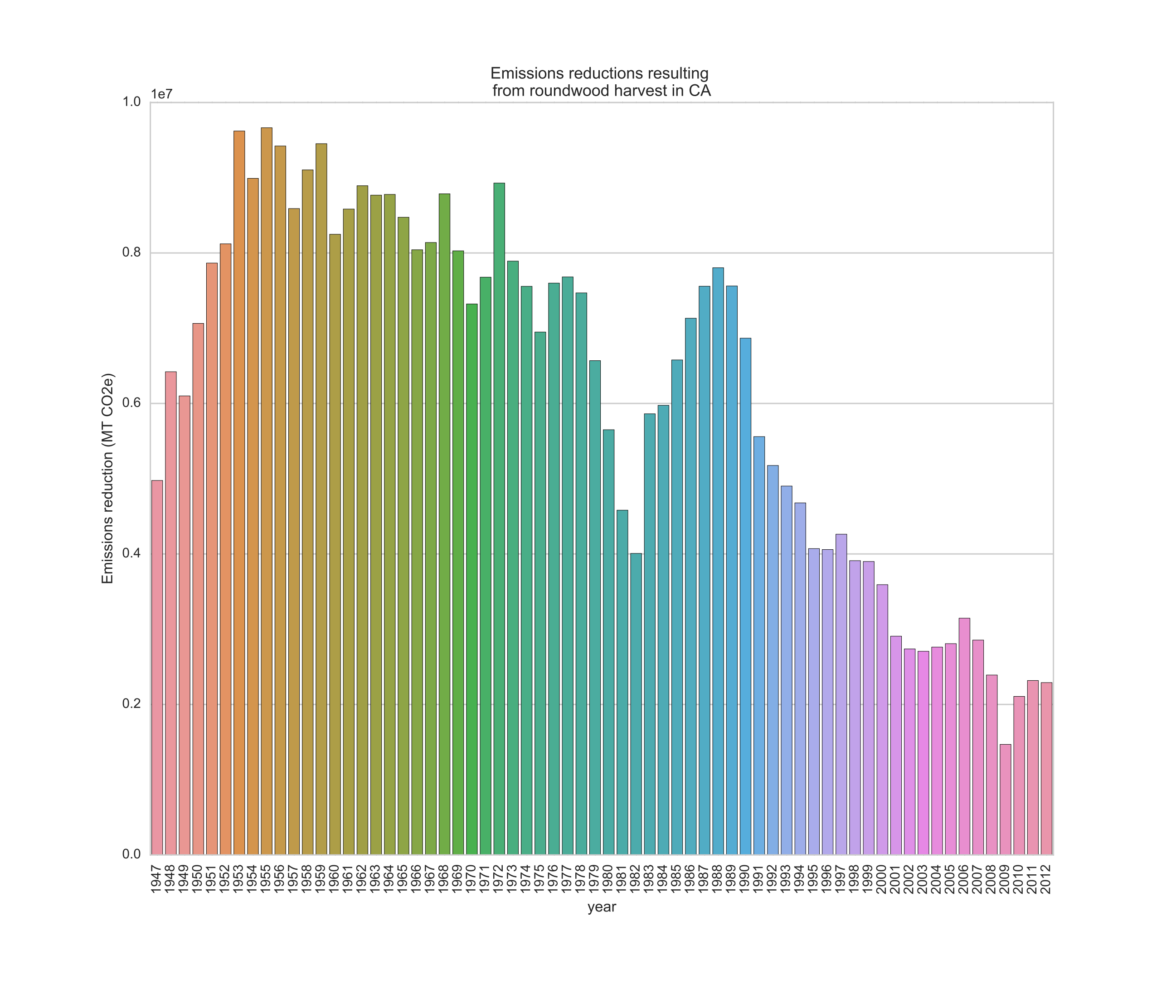

Figure 5: Historical emissions reductions resulting from harvested roundwood using displacement factors from (Sathre and O'Connor, 2010) applied to TPO data.

Contribution of the varios ownership categories to the aggregate is shown in figure

1.3.3 Emissions from un-utilized logging residues

From logging residuals not used in bioenergy, emmisions are produced from combustion of the residual material or from decomposition of the material over time. To calculate the ratio of burned to decompsed logging residues I begin with the CARB estimate of PM2.5 produced from forest management. #### Estimate biomass from PM2.5 To estimate total biomass from PM2.5 I assume 90% consumption of biomass in piles and use the relationship of pile tonnage to PM emissions calculated using the Piled Fuels Biomass and Emissions Calculator provided by the Washington State Department of Natural Resources. This calculator is based on the Consume fire behavior model published by the US Forest Service.

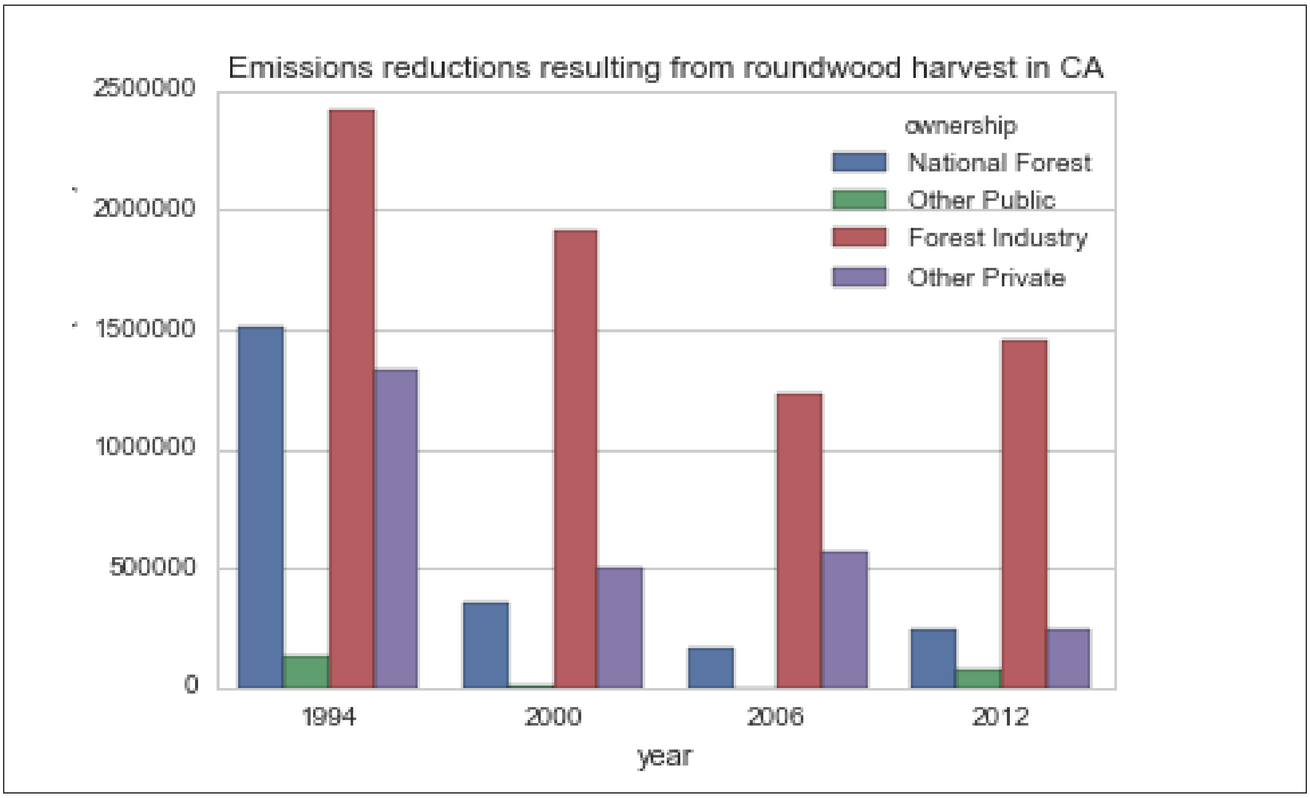

Figure 6: Historical emissions reductions by ownership for selected years resulting from harvested roundwood using displacement factors from (Sathre and O'Connor, 2010) applied to TPO data.

	YEAR	EICSOUN	Annual PM 2.5(t)	Biomass (BDT)
0	2000	FOREST MANAGEMENT	5474.31	901120
1	2005	FOREST MANAGEMENT	5474.31	901120
2	2010	FOREST MANAGEMENT	5474.31	901120
3	2012	FOREST MANAGEMENT	5477.3	901613
4	2015	FOREST MANAGEMENT	5480.51	902142

Total emissions resulting from pile burned forest management residuals can then be derived for the two greenhouse gasses produced from pile burning (CO2, CH4) and from BC:

	Year	Emissions source	CO2 (t)	CH4 (tCO2e)	BC (tCO2e)	Pile Burn (tCO2e)
0	2000	FOREST MANAGEMENT	1.34928 (+06)	127280	248255	1.72481 (+06)
1	2005	FOREST MANAGEMENT	1.34928 (+06)	127280	248255	1.72481 (+06)
2	2010	FOREST MANAGEMENT	1.34928 (+06)	127280	248255	1.72481 (+06)
3	2012	FOREST MANAGEMENT	1.35002 (+06)	127349	248391	1.72576 (+06)
4	2015	FOREST MANAGEMENT	1.35081 (+06)	127424	248536	1.72677 (+06)

1. Emissions from decomposition of un-utilized forest management residuals

   Un-utilized residual biomass not consumed in pile burns decomposes over time resulting in emission of methane and carbon dioxide. To provide a full picture of the emissions from residual material produced from commercial timber harvesting in California, decomposition of unutilized logging residuals left on-site that are not burned must be accounted for. To establish the fraction of logging residue that is left to decompose, residues burned and used in bioenergy are subtracted from the total reported by the TPO:

$$LR_d = LR - LR_{piles} - LR_{bio}$$

where:

$$\begin{aligned} LR_d &= \text{Logging residuals subject to anerobic decomposition} \\ LR &= \text{Total logging rsiduals reported by TPO} \\ LR_{piles} &= \text{Logging residues combusted in anthropogenic pile burns} \\ LR_{bio} &= \text{Logging residues used to produce bioenergy} \end{aligned}$$

To calculate the GHG emissions from decomposition of piles we use the following equation.

$$CO_2e_{decomp} = (LR_d \times C_{LR} \times CO2_{ratio}) + (LR_d \times C_{LR} \times CH_{4ratio} \times GWP_{CH_4})$$

where:

CO_2e_{decomp} = Carbon dioxide equivalent emissions from decomposition of logging slash

C_{LR} = Carbon fraction of biomass: 0.5

$CO2_{ratio}$ = Fraction of carbon released as CO_2: 0.61

CH_{4ratio} = Fraction of carbon released as CH_4: 0.09

GWP_{CH_4} = Global warming potential of methane: 56

1.3.4 Emissions from non-commercial management residuals

/Note: Residues from non-commercial management activities are assumed to be small in comparison with logging residues. In addition, there is presently no empirical data available. As such, estimating these volumes has not been prioritied. I have attempted to provide an estimate for public lands in the National Forest System./

The TPO in California does not report wood volume produced from non-commercial management activities. This includes management activities such as pre-commercial thinning, sanitation thinning, and fuels reduction thinning. To estimate the volume of material produced from these activities we use the following sources:

1. **Public lands:** The USFS Forest Service Activity Tracking System (FACTS) reports management activities conducted on National Forest System Lands. To ensure estimates of biomass volume using FACTS are not duplicative of reported volume in the TPO a series of filters are applied to the FACTS attributes to identify only non-commercial management activities.

2. **Private industrial timber lands:** CalFIRE's Forest Practice Geographical Information System. **TODO**

1. Forest Service Activity Tracking System (FACTS)

   Data from TPO does not account for forest management activities that do not result in commercial products (timber sales, biomass sales). The USFS reports Hazardous Fuels Treatment (HFT) activities as well as Timber Sales (TS) derived from the FACTS database. I use these two data sets to estimate the number of acres treated that did not produce commercial material (sawlogs or biomass) and where burning was not used. The first step is to eliminate all treatments in the HFT data set that included timber sales. I accomplish this by eliminating all rows in the HFT data set that have identical `FACTS_ID` fields in the TS dataset. I further filter the HFT dataset by removing any planned but not executed treatments (`nbr_units1 >0` below – `nbr_units1` references `NBR_UNITS_ACCOMPLISHED` in the USFS dataset, see metadata for HFT here), and use text matching in the 'ACTIVITY' and 'METHOD' fields to remove any rows that contain reference to 'burning' or 'fire'. Finally, we remove all rows that that reference 'Biomass' in the method category as it is assumed that this means material was removed for bioenergy.I use a range of 10-35 BDT/acre to convert acres reported in FACTS to volume. The following table presents descriptive statistics for estimates of residual unutilized wood biomass on an annual basis in million cubic feet.

	nf\n	nf\lr	opriv\lr	fi\lr	opub\lr
count	11	4	4	4	4
mean	12.0194	17.7	28.95	66.425	2.4
std	4.68948	5.07346	16.1593	6.07639	1.79444
min	2.37421	11.2	11.2	59.6	0.3
25%	8.92407	15.025	19.525	62.225	1.275
50%	13.3557	18.5	27.75	66.85	2.5
75%	14.5349	21.175	37.175	71.05	3.625
max	17.8532	22.6	49.1	72.4	4.3

1.4 Further questions

This analysis is a first step towards a broader analysis of the climate impacts of harvested wood in California. The following are key questions which follow from this analysis.

1.5 References

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