



# Evaluation of environmental impacts of harvest residue based bio-energy using radiative forcing analysis

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## Abstract

The 'carbon neutrality' assumption plays an important role in the evaluation of the global warming potential (GWP) of bio-energy relative to fossil fuels. In the case of woody bio-energy, this assumption implies that the carbon dioxide emitted during the combustion of the biomass is equal to the carbon dioxide sequestered from the atmosphere within that biomass.

This carbon neutrality assumption associated with woody biomass and the environmental impacts associated with wood based bio-energy are hotly debated both in national and international arenas. This study presents a comprehensive evaluation of the environmental impacts of woody biomass based bio-energy and proposes a GWP impact assessment methodology using radiative forcing for incorporating the dynamics of carbon sequestration, decomposition of residues and biomass processing in the Life Cycle Assessment of bio-energy.

## Objectives

The specific objectives of this study are to:

1. Perform a 'Cradle-to-Grave' life-cycle assessment of woody biomass based bio-energy;
2. Evaluate the temporal dynamics of carbon sequestration and decomposition of residues in a particular forest type in the Pacific Northwest region west of the Cascade mountains (West-PNW);
3. Apply a radiative forcing analysis that incorporates the temporal aspect of carbon sequestration within an LCA framework.

## System Boundaries

**Functional unit:** 1 BDmT of residues

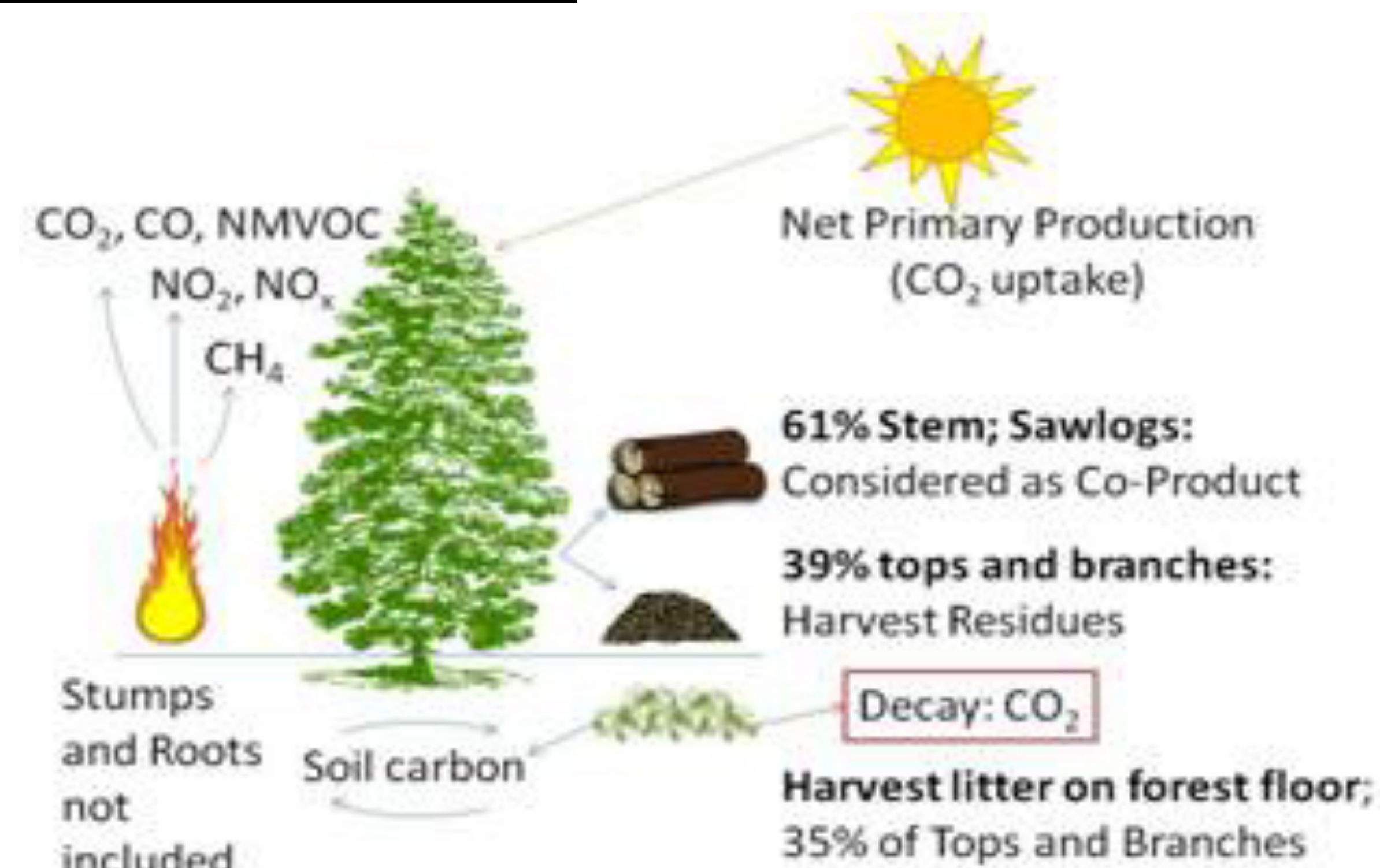


Figure 1. Representation of the carbon balance in the forest.

### Assumptions:

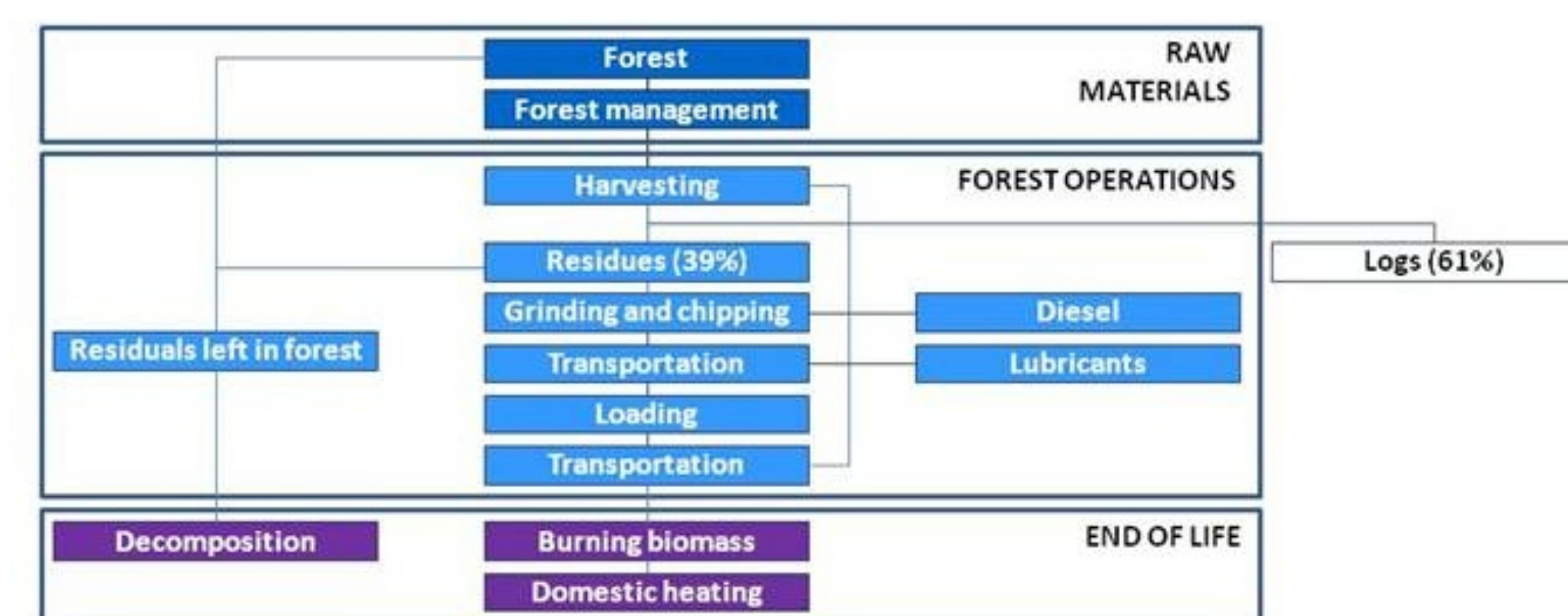
1. Forest stand:
  - 1 acre of forest situated in Western Washington in the Grays Harbor county;
  - Type of forest management: clear-cutting;
  - Rotation period: 45 years (2014-2059);
  - Foliage, stumps and roots not considered;
  - Residual decay in forest = 90% decay, aerobic conditions (EIA, 2006).
2. Harvest operations:
  - Cutting: Feller Buncher;
  - Skidder operation: gentle slope skidder;
  - Chipping at primary landing: Chipper.
3. Biomass transportation: 50 miles;
4. Biomass combustion in furnace for domestic heating.

## Methodology

### 1. Evaluation of carbon stocks through the Forest Vegetation Simulator (FVS)

FVS evaluates the standing and harvested carbon for different tree components: stem, top, foliage, branches, bark, stump and roots.

### 2. System boundary for the LCA and allocations



### 3. Normalization

Scale all carbon stocks to the amount of carbon that needs to be harvested per functional unit :

**1.7 BDmT of biomass** is harvested to produce 1 BDmT of residues  
(0.7 BDmT of biomass is left in forest to decompose)

### 4. Evaluation of carbon sinks and carbon sequestration

$$C_{sink}(t) = \frac{dC_{stock}(t)}{dt} \quad C_{seq}(t) = C_{sink}(t) \cdot \frac{MW_{CO_2}}{MW_C}$$

$C_{sink}$  = carbon sink,  $C_{stock}$  = carbon stock,  $C_{seq}$  = carbon sequestered,  $MW_{CO_2}$  = Molecular weight of  $CO_2$ ;  $MW_C$  = Molecular weight of carbon (IPCC, 2006)

### 5. Evaluation of the effect on global warming through the cumulative Radiative Forcing

$$RF_{cum} = \int_0^{TH} a_i \cdot [C_i(t)] dt \approx \sum_{i=0}^{TH} a_i \cdot [C_i(t)] \quad y_i(t) = a_0 + \sum_{i=1}^n a_i \cdot e^{-\frac{t}{\tau_i}}$$
$$[C_i(t)] = C_{sink}(t) \cdot y_i(t)$$

$RF_{cum}$  = cumulative Radiative Forcing;  $[C_i(t)]$  = time-dependent abundance of  $i$ ;  $y_i(t)$  = decay function (Cherubini, 2011)  
 $a_i$  = radiative efficiency,  $a_0 = 0.217$ ,  $a_1 = 0.259$ ,  $a_2 = 0.338$ ,  $a_3 = 0.186$ ,  $\tau_1 = 172.9$ ,  $\tau_2 = 18.51$ ,  $\tau_3 = 1.186$  (IPCC, 2007).

Figure 2. Methodology for incorporating the carbon sequestration in the LCA.

## Results

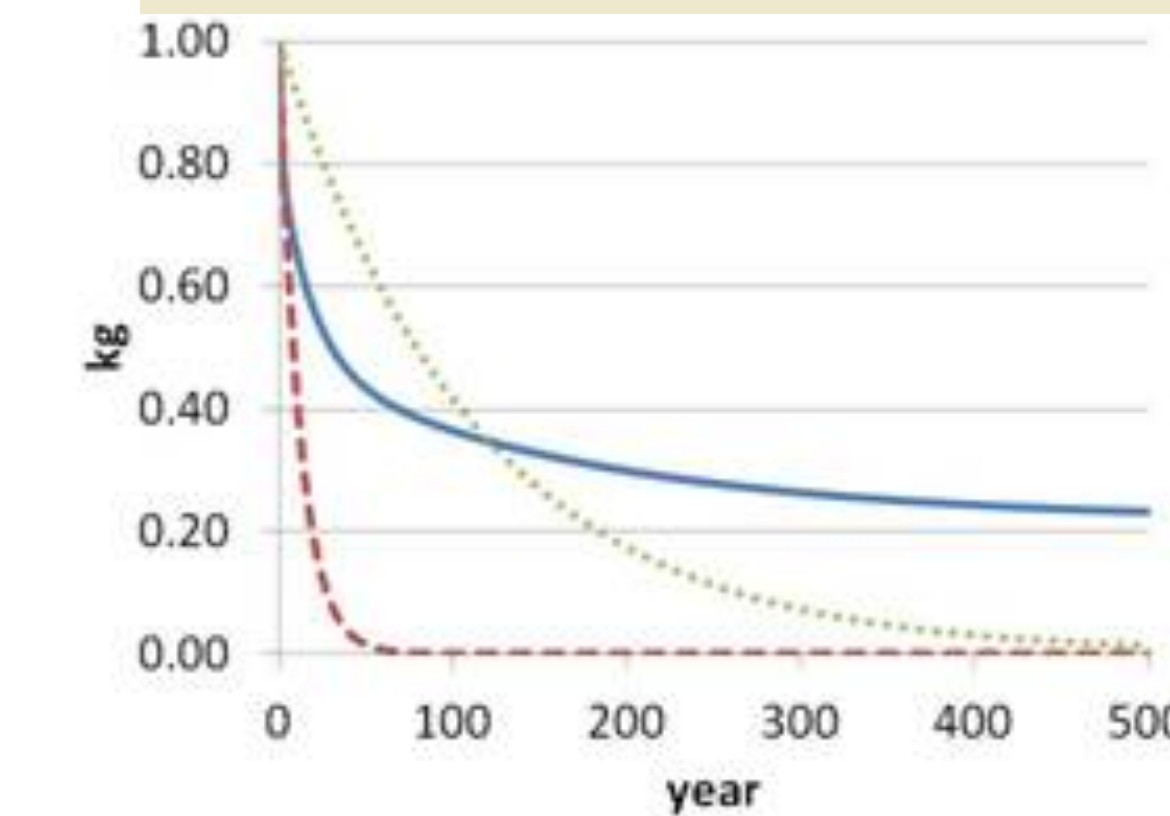


Figure 3. Decay function of GHGs (in the atmosphere).

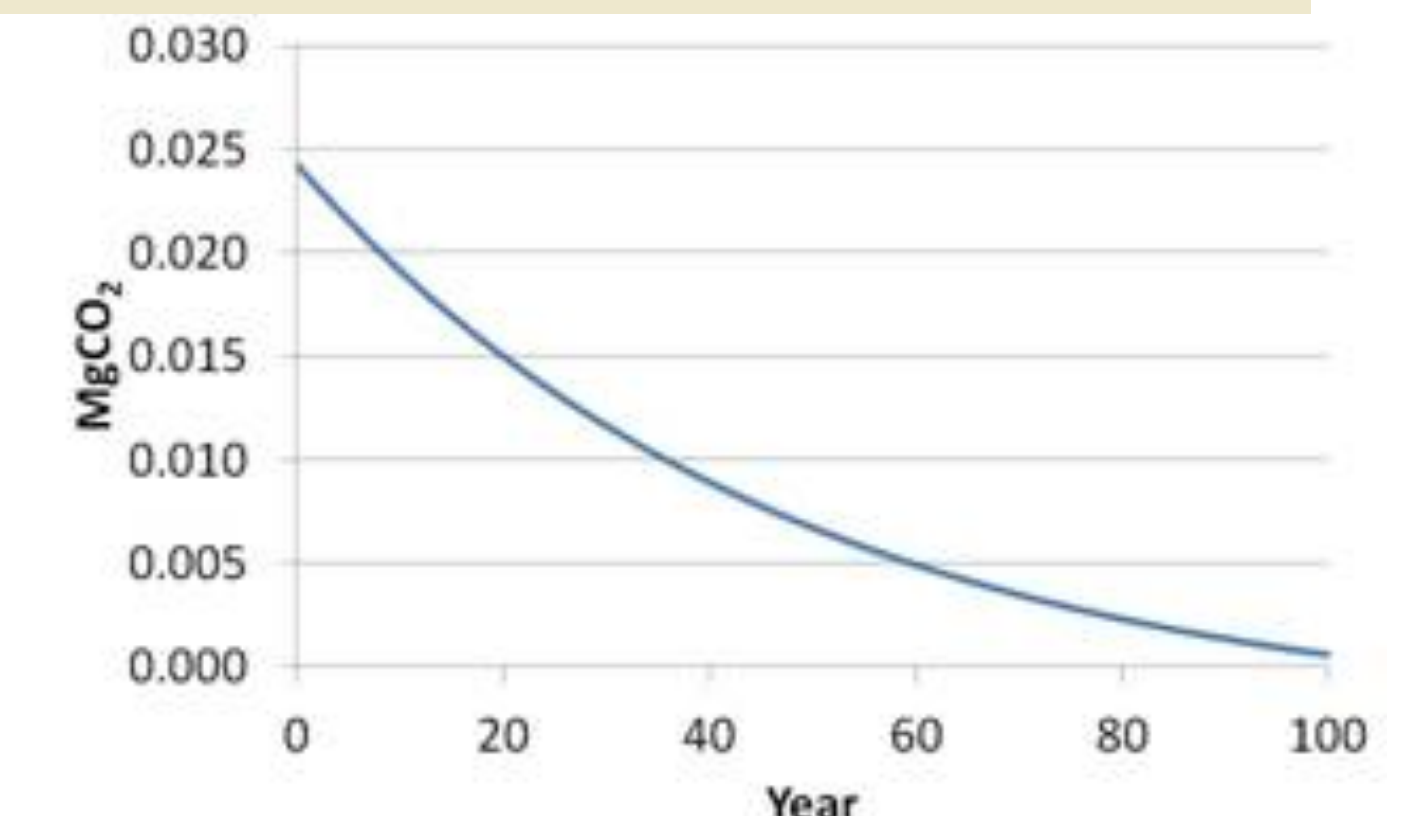


Figure 4. Decomposition of residues left in forest.

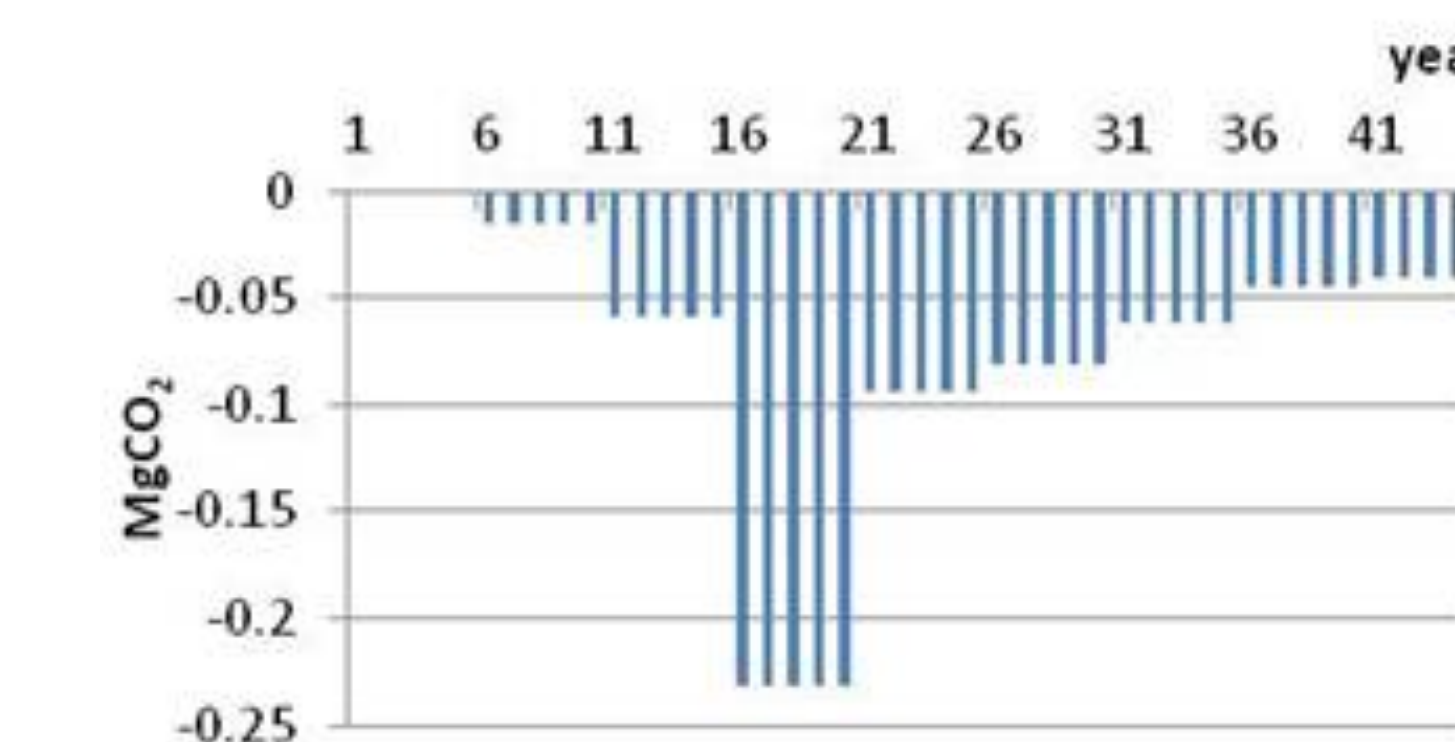


Table 5. Difference of biomass growth between subsequent years (carbon sink) and carbon biomass (carbon stock) over time normalized to the functional unit (1 BDmT) expressed in terms of carbon dioxide absorbed.

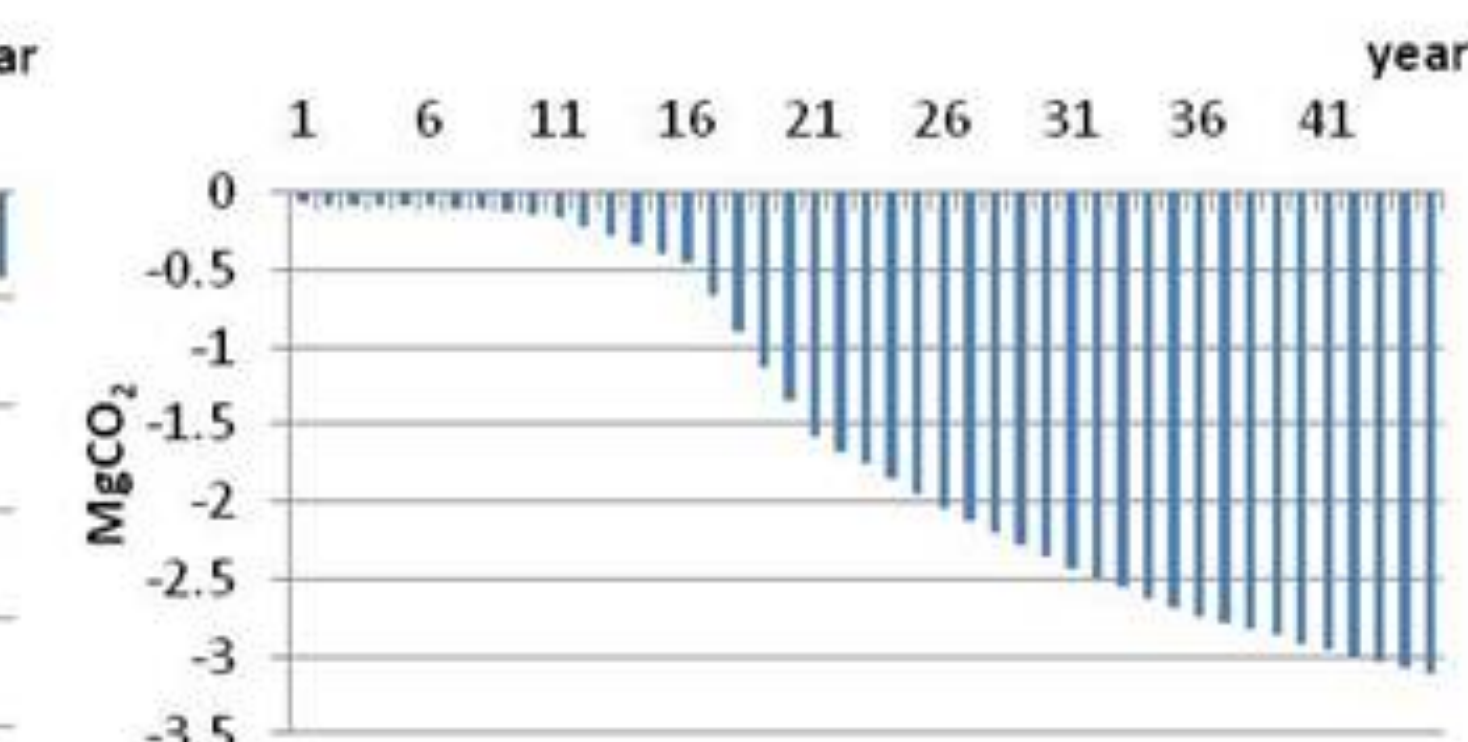


Figure 6: Result of the evaluation of the impact on global warming through the Radiative Forcing.

## Conclusions

- The adverse global warming potential impact associated with biomass collection and burning from industrial forests in the western/coastal PNW region is fully offset by the carbon sequestered during forest growth within a period of approximately 18 years.
- Given, the harvest rotation cycle is assumed to be 45 years, biomass based energy has a net negative global warming potential (beneficial for environment).
- Conservatively, for the given region, forest management and harvest practices, the carbon neutrality of woody biomass can be generally assumed.

### References

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