DOI: 10.5152/forestist.2020.20025
Forestist 2021: 71(2): 110-117

ISTANBUL UNIVERSITY
CERRAHPAŞA

Original Article

Evaluation of renewable hybrid barriers in terms of carbon emission with concrete and steel barriers

Emre Birinci[1], Hüseyin Yörür[2], H. İbrahim Yumrutaş[3], Ahmet Duyar[4]

[1]Forestry and Forest Products Programme, Kastamonu University, Arac Rafet Vergili Vocational School, Kastamonu, Turkey
[2]Department of Forest Industry Engineering, Karabük University, Faculty of Forestry, Karabük, Turkey
[3]Department of Transportation Engineering, Karabük University, Faculty of Engineering, Karabük, Turkey
[4]Department of Forest Engineering, Karabük University, Faculty of Forestry, Karabük, Turkey

ABSTRACT

Roadside barriers called as passive safety systems are presently produced from various materials such as steel, concrete, wood, and plastic. Existing roadside barriers have prioritized safety over aesthetics and environmental concerns. To this end, a new environmental barrier-the renewable hybrid barrier (RHB)-has been designed that can fulfill safety requirements as well as add value in terms of aesthetics. Sand is placed inside the barrier, and the barrier's outer shell is covered by fir timber. A life cycle analysis was completed to ensure the sustainable production of RHBsand to better understand their environmental impacts. The amount of greenhouse gas emitted into nature during the production of RHB and steel and concrete barriers was calculated and compared. Our results showed that concrete and steel barrier production releases approximately 4.5 times more greenhouse gases than RHB production. The live biomass equivalent of the wood materials used in RHB production was also calculated. We found that RHBs sequestrated 45.94 kg-CO_2eq. It is thought that more widespread use of RHBs can contribute positively to the environment and nature.

Keywords: Carbon emission, renewable hybrid barrier, wood

Introduction

The trend toward renewable materials has increased in recent years, in an effort to reduce the conflict between economic development and environmental problems, including global warming. Global warming is defined as the rise of the Earth's surface temperature over time as a result of anthropogenic greenhouse gas accumulation, including carbon dioxide (CO_2), methane (CH_4), and nitrogen oxide (NO) (NASA, 2020; Selin & Mann, 2020).The CO_2 concentration in the atmosphere rose from 280–290 ppm prior to the industrial revolution, to approximately 350 ppm afterwards, as a result of increased fossil fuel use (Draper & Weissburg, 2019; IPCC, 2014). Atmospheric CO_2 has increased by 9% since 1958, with the current yearly increase calculated at 1 ppm (Saraçoğlu, 2010). These findings support the argument that global warming is occurring faster than projected (Xu et al., 2018).

Forests are the most important carbon sink among terrestrial ecosystems (Lal, 2004). In these ecosystems, carbon is primarily stored in live biomass (Eggleston et al., 2006), but is also stored in dead organic matter, and in soil carbon pools. These carbon sequestration services significantly contribute to the reduction of global climate change (Settele et al., 2015); however, deforestation and some aspects of the natural succession of forests can cause carbon to transfer from live biomass to the atmosphere (IPCC, 2014). Silvicultural is a forest management strategy that can be used to manage forests and obtain various wood-based forest products, which can be used to sequester carbon long-term (Pingoud et al., 2010). Wood, and wood-based materials are therefore important to reduce the effects of global warming (Zhang et al., 2020).

Wood and wood-based products naturally contain various amounts of carbon, due to the properties of their carbon compounds (Kalaycioglu et al., 2005; Lee et al., 2018). The amount of round timber in the harvested wood, the amount of industrial raw materials used, and material loss during production can all cause significant changes to the final product's carbon stock. The return period of this carbon stock to the atmosphere depends on various factors, such as the product's use pattern, and disposal method (i.e., fuel, recycling, decomposition) (Pingoud et al., 2010).

Cite this paper as:
Birinci, E., Yörür, H., Yumrutaş, H. İ., & Duyar, A. (2021). Evaluation of renewable hybrid barriers in terms of carbon emission with concrete and steel barriers. *Forestist, 71*(2), 110-117.

Corresponding author:
Emre Birinci
e-mail:
ebirinci@kastamonu.edu.tr

Received Date:
05.06.2020
Accepted Date:
17.08.2020
Available Online Date:
23.10.2020

Not only can wood potentially sequester high amounts of carbon, but the wood production process requires less energy and causes less CO_2 emissions than the production of steel, aluminum, or other materials (Noda et al., 2016). Wood production requires 5 kWh/ML of energy, while concrete requires 45 kWh/ML of energy, and steel requires 550 kWh/ML of energy. In fact, the indirect effect of reduced production energy, and reduced CO_2 emissions during production may be more effective than storing carbon directly in forest products (Saraçoğlu, 2010). For these reasons, various studies have emphasized that wood products should replace such higher energy materials (Kayo et al., 2014; Noda et al., 2016).

A life cycle assessment (LCA) can be used to examine the mitigation effect of replacing non-wood materials with wood-based products on global warming. An LCA accounts for the environmental impact of a material throughout its entire life cycle, through the procurement of raw materials, production, and disposal (Noda et al., 2016). An LCA provides information which can be calculated and measured, in order to evaluate a product's effect on the environment, its resource efficiency, and its potential waste amounts (Demirer, 2011).

Passive safety structures (also called barriers) are used at the edges and medians of highways to protect errant vehicles from leaving the road. The main purpose of these barriers is to reduce the severity of an accident, not to prevent it (KGM, 2005; Pilia et al., 2012). Barriers are classified as flexible, semi-rigid, or rigid, depending on their deflection characteristics at the moment of impact; (Tunç, 2004). Many different types of barriers are currently on the market, including barriers made from concrete, steel, plastic, or wood. Although different barriers are able to withstand the high impact loads typical with collisions, aesthetic concerns have been ignored due to prioritized safety and structural requirements. Safety engineers have often been unable to realize the impact that these barriers have on the landscape, especially in historical, touristic, and natural areas, while architects and designers have often focused on aesthetically pleasing barriers that have structural deficiencies. These deficiencies could be overcome by designing a barrier that is aesthetically pleasing and structurally capable.

In this study, we designed renewable hybrid barriers (RHB) that are economical, light, aesthetic, environmentally friendly, and capable of absorbing impact energy and sound. Our barriers have been designed from wooden materials and sand. We evaluated the use of our RHBs by comparing the amount of CO_2 emitted during the production of RHB, concrete, and steel barriers. We also evaluated the carbon storage capacity of our RHBs by calculating the biomass equivalent of the fir wood used in RHB production, and used the LCA method to examine the carbon content of the RHBs during their entire life cycle. Finally, we examined how wood protection techniques, such as impregnation and heat treatment, affected carbon sequestration in fir wood.

Method

Roadside Barriers

Five materials were used in RHB production: wood, sand, vegetable soil, metal (steel), and concrete. The RHB were produced in the New Jersey barrier style (Figure 1). The produced barriers were 1250 mm long, 800 mm wide, and 1000 mm tall, with a concrete base that was 100 mm thick. The total volume of the concrete base was .1 m^3. The steel profiles used in the metal grids were 20×40 mm in size, and 2 mm thick. The total metal profile length was 6.75 m, with a weight of 10.23 kg, and a density of 7.80 g/cm^3. Five-millimeter-thick, crushed stone sand was used, with a total sand volume of .46 m^3. At the top of the barrier, 30 cm deep vegetable soil was used to plant evergreen plants. The total volume of this soil was .1 m^3. The total volume of the fir timber (*Abies nordmanniana* subsp. Equi-trojani) used in the production of one barrier was .06 m^3.

The RHBs were compared to New Jersey concrete barriers with the same dimensions, that were produced from C25 concrete (Figure 2). The total volume of each concrete barrier was .721 m^3, with a weight of 1683 kg. For the production of one concrete barrier, a total of 8 m of 8 mm diameter rebar was used.

W-beam steel guardrails produced from S235JR quality steel were also compared with RHBs, as they are widely used (Figure 3). These barriers consisted of five parts: W-rail, post, spacer, connection plate, hexagonal screws, and nuts. Within the scope of this study, all parts and dimensions of a double-sided, W-beam steel barrier with the same length as the RHBs have been determined, in order to compare this type of steel barrier with RHBs. For the production of a W-beam steel barrier of 1.25 m in length, the following items were used: 2 pieces of 3×316×1250 mm W-rail; 2 pieces of 5×62.5×1500 mm steel post; 4 pieces of 5×70×350 mm spacer; 2 pieces of 5×40×115 mm connection

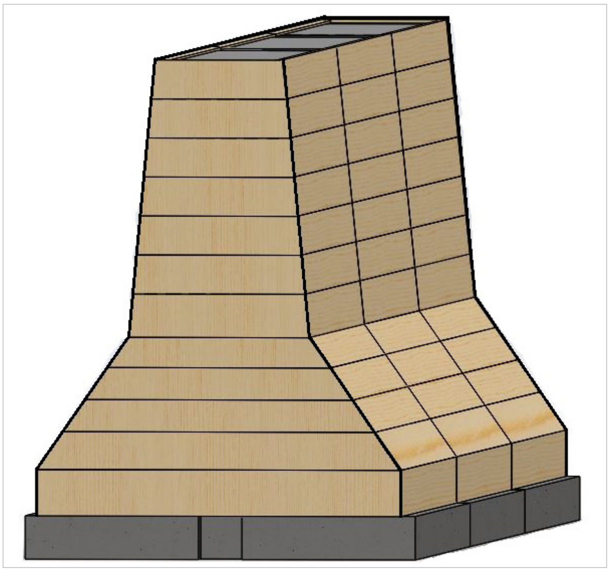

Figure 1
An Renewable Hybrid Barrier in New Jersey Barrier Type

plate; and 28 pieces of M10×45 mm hexagon screws, and nuts. The total weight of the W-beam steel barrier was 47.53 kg.

Preparation of Wood Samples

Wood from fir trees (*Abies nordmanniana* subsp. Equi-trojani) with a density of .43 gr/cm^3 was used in this study. As shown in Figure 4, 30 fir samples of 75×10×150 mm (radial×tangent×longitudinal) dimensions were prepared. Three samples were not subjected to any treatment (control), nine samples were subjected to only impregnation, nine samples were heat treated at 150°C, and another nine samples were heat treated at 210°C.

Impregnation of Wood Samples

Impregnation of the fir wood was carried out in the impregnation laboratory of Kastamonu University, Faculty of Forestry (Kastamonu/Turkey). Tanalith-E was chosen as the impregnation material since it is widely used, and has a lower toxicity profile compared to older wood preservatives. The density of Tanalith-E was 1.3 gr/cm^3, at a concentration of 3%. During the impregnation process, 400 mm/Hg pre-vacuum was applied to the samples for 30 minutes. After transferring the impregnating material to the boiler, 4 bars of pressure were applied to the samples for 60 minutes. After impregnation, excess impregnation material on the samples was cleaned and removed. The impregnated samples were stored at 22°C±3°C, and 65% relative humidity for 10 days to allow fixation to occur.

Figure 2
New Jersey Type Concrete Barrier

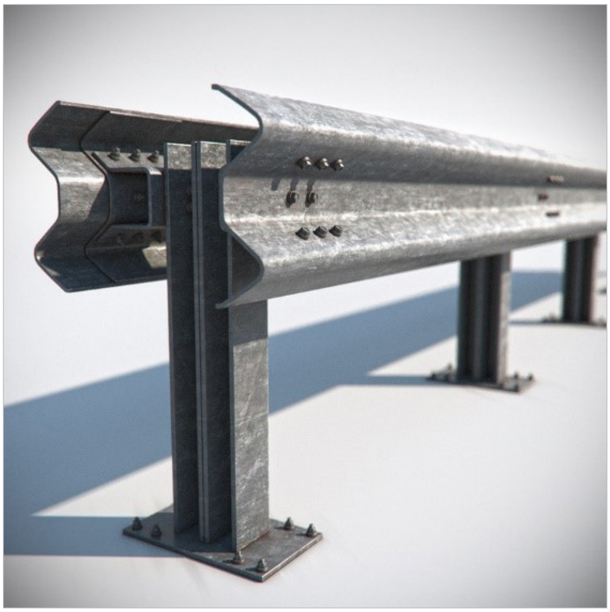

Figure 3
W-Beam Steel Barrier

Retention amounts were calculated as kg/m^3 according to Equation 1.

$$R\ (\text{kg/m}^3) = \frac{(Ma - Mb) \times C}{V} \times 10 \quad (1)$$

Where;
Mb : oven dry weight of the wood sample before impregnation (g);
Ma : wet weight of the wood sample after impregnation (g);
C : the concentration of the impregnation material (%);
V : the volume of the wood sample (m^3).

Heat Treatment Process of Wood Samples

Fir samples were subjected to heat treatments in a laboratory oven at 150°C or 210°C for 2 hours under normal outdoor atmospheric pressure. After heat treatment, all samples were subjected to conditioning for 7 days in 65%±5% relative humidity, and 20°C±2°C in an incubator.

Accelerated Weathering Process of Wood Samples

A total of 24 samples were subjected to the aging process at the Bartın University, Faculty of Forestry (Bartın/Turkey), Forest Industry Engineering Department laboratories. The aging process was carried out using an QUV-Lab Product® accelerated aging device with an UVA-340 lamp, that operated at 365–295 nm wavelength for 300 or 600 hours. During this process, the test samples were subjected to three cycles of the following program: 4 hours .75 W/m^2 UV light, 2 hours conditioning at 50°C, and 15 minutes water spray.

Elemental Carbon Analysis of Wood Samples

Elemental carbon analysis was carried out using an Eurovector EA3000-Single device at the Central Laboratory of Kastamonu University, based on the ASTM D 5373 standard.

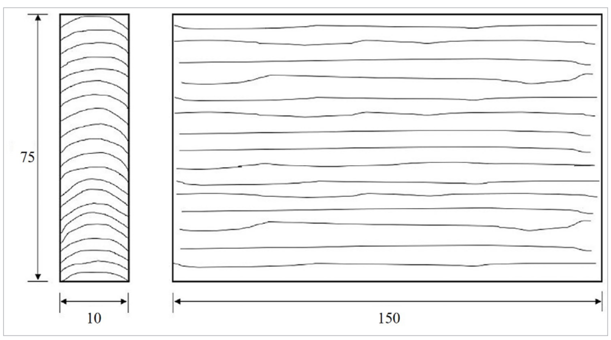

Figure 4
The Sizes of Impregnated, Weathered and Heat Treated Samples (mm)

Life Cycle Analysis

The life cycle of RHB consists of the raw material procurement, production, installation, on-site maintenance/repair, and disposal stages. We determined to what extent greenhouse gas emissions (CO_2, CH_4, N_2O) caused by fossil fuel consumption are reduced for each of these production stages for all three barrier types. CO_2 equivalents (kg-CO_2eq) were determined from the 100-year global warming potentials (GWP100) of each greenhouse gas (CO_2: 1, CH_4: 34, N_2O: 298).

Biomass Equivalent of the Wood Used in Production of RHB

Fir timber used in RHB production was supplied from shelled fir logs with 50% losses (Sofuoğlu & Kurtoğlu, 2012). The loss of live biomass caused by the forest harvesting of these logs was calculated based on the rules stated in the "Land Use, Land Use-Change and Forestry" guide.

The formula used for estimating the carbon loss due to commercial roundwood felling is presented in Equation 2. Aboveground biomass (AGB), which is the forest biomass equivalent to the timber required for the production of RHBs, and carbon loss from aboveground biomass carbon stocks in living biomass were estimated using Equations 3 and 4, respectively.

$$L_{fellings} = H\ x\ D\ x\ BEF_2\ x\ (1 - f_{BL})\ x\ CF \quad (2)$$

$$AGB = H\ x\ (1 + BEF_2) \quad (3)$$

$$L_{ACS} = AGB\ x\ D\ x\ CF \quad (4)$$

Where

$L_{fellings}$: carbon loss due to commercial fellings, kgC;
H : extracted volume, roundwood, m^3;
D : basic wood density, $kg.m^{-3}$;
BEF_2 : biomass expansion factor for converting volumes of extracted roundwood to total aboveground biomass (including bark), dimensionless;
f_{BL} : fraction of biomass left to decay in forest (transferred to dead organic matter);
CF : carbon fraction of dry matter (default=.5);
AGB : aboveground living biomass, m^3;
L_{ACS} : carbon loss from aboveground carbon stocks in living biomass, kg C (Eggleston et al., 2006).

Molecular weights of each compound and its atoms are required to convert the total amount of carbon to its CO_2 equivalent. The molecular weight of carbon is 12 g/mol, the molecular weight of oxygen is 16 g/mol, and the molecular weight of CO_2 is 44 g/mol. A coefficient (conversion factor) is needed to calculate the CO_2 equivalent of carbon. This coefficient is obtained by dividing the molecular weight of carbon, by the molecular weight of CO_2 (3.67).

Results

Evaluation of Roadside Barriers in terms of Carbon Emissions

LCA can help to ensure the sustainability of a product, and its environmental effects (Kayo et al., 2014; Noda et al., 2014; Puettmann & Lippke, 2012). The life cycle stages of RHBs are shown in Figure 5. Although Figure 5 lists impregnation and heat treatment as production stages of RHBs, these processes are not essential for RHB production, and are not included in the production process calculations of this study. The amount of materials required for the construction of an RHB of 1.25 m in length are shown in Table 1.

The greenhouse gas emission values of the materials used in RHB production are shown in Table 2 (Ferguson et al., 1996; Hitoe et al., 2013; JEMAI, 2014; Noda et al., 2016). The greenhouse gas emissions produced during RHB, concrete and steel barrier production were calculated using values from Table 1 and Table 2. The total greenhouse gas emissions for each barrier are shown in Table 3. The steel profiles used in RHB production, and the rebar used in concrete barrier production were evaluated as structural carbon steel. In addition, the post, spacer, rail, and connection plate used in the production of the steel barrier were evaluated as general-purpose steel. All materials used in the steel barriers were galvanized, which was considered during the calculations. The greenhouse gas emissions released during the transportation of the sand and vegetable soil used in RHB production were included in the calculations.

Our calculations show that the production of concrete and steel barriers releases approximately 4.5 times more greenhouse gases than RHB production. These results support previous study results, which state that the use of wood materials over more energy-dependent materials, contributes to the reduction of greenhouse gas emissions (Green & Taggart, 2017; Köhl et al., 2020; Sulaiman et al., 2020; Winchester & Reilly, 2020).

Effect of Wood Preservation Methods and Weathering on the Carbon Content

In order to investigate the effect that wood preservation methods and weathering has on the amount of carbon stored in wood, wood samples were impregnated or heat treated, then subjected to weathering. Afterwards, the carbon content of each sample was determined using the elemental carbon analysis method (Table 4).

The control group's carbon ratio (48.52%) was compared to the impregnated and heat treated samples. Results showed that the samples subjected to the heat treatment at 210°C had the highest carbon contents. The average carbon rate of these samples (49.69%) increased after weathering. When the impregnated samples and the control group samples were compared, it was determined that the impregnation process had a negligible effect on the wood's carbon ratio. Furthermore, the carbon ratio of impregnated samples decreased slightly after weathering.

During heat treatment, hemicelluloses are depolymerized into oligomers and monomers by hydrolysis reactions. Secondary chain components, such as arabinose and galactose, are separated, which is followed by the degradation of major components, such as mannose glucose and xylose. Pentoses and hexoses dehydrate to furfural ($C_5H_4O_2$) and hydroxymeth-

Table 1
Amounts of Materials Required for the Construction of RHB, Concrete and Steel Barriers 1.25 m in Length (kg)

Materials	RHB	New Jersey	W-Beam
Post	-	-	11.619
Spacer	-	-	3.856
Rail	-	-	28.740
Connecting plate	-	-	1.928
hexagonal screws and nuts	-	-	1.390
Steel profiles	10.230	3.155	-
Chipboard screw	.181	-	-
Sand (5 mm)	736.000	-	-
Vegetable soil	160.000	-	-
Fir timber (oven dry)	25.800	-	-
Concrete	233.000	1680.000	-

ylfurfural ($C_6H_6O_3$), respectively. Also, other aldehydes, such as formaldehyde (CH_2O), are found in lignin (O=CH-) due to the division of carbohydrates from C6, as in division from Cy. In addition, acetic acid, which is made up of the acetyl secondary chain components of hemicellulose, is separated, and the acetyl ($COCH_3$) content of the wood decreases. Generally, the carbon and lignin content of wood increases with heat treatment. The ether chain of the lignin breaks easier during pyrolysis. CO_2 and other components are separated from lignin at 200°C–250°C (Kocaefe et al., 2008; Korkut & Kocaefe, 2009). These structural changes in wood may have increased the carbon content in the heat treated fir samples.

Determination of Carbon Content Stocked in Timber Used on RHBs

Previous studies have suggested that the effect of wood barriers on carbon offsets should be examined in detail by considering the barrier's production process from forest to disposal (Noda et al., 2016). We, therefore, evaluated the effect of the wood material used in the production of RHBs on carbon offsets. We used

Table 2
Greenhouse Gas Emission Values of the Materials Used in the Production of These Barriers and Processes (Ferguson et al., 1996; Hitoe et al., 2013; JEMAI, 2014; Noda et al., 2016)

Processes	Unit	CO_2	CH_4	N_2O	Total greenhouse
Steel production	kg-CO_2eq/kg	2.3200	.0376	.0444	2.4020
Galvanization	kg-CO_2eq/kg	2.3200	.0376	.0444	2.4020
Steel screw/bolt/nut production	kg-CO_2eq/kg	2.3210	.0390	.0205	2.3804
Structural carbon steel production	kg-CO_2eq/kg	1.8040	.0324	.0104	1.8468
Log production	kg-CO_2eq/m^3	5.8300	.2390	.0498	6.1188
Timber production (planed)	kg-CO_2eq/m^3	5.3080	.0390	.1570	5.5040
Concrete production	kg-CO_2eq/m^3	289.5000	2.8155	1.0609	293.3764
Transportation (truck for 4 ton)	kg-CO_2eq/t km	.1502	.0057	.0007	.1566

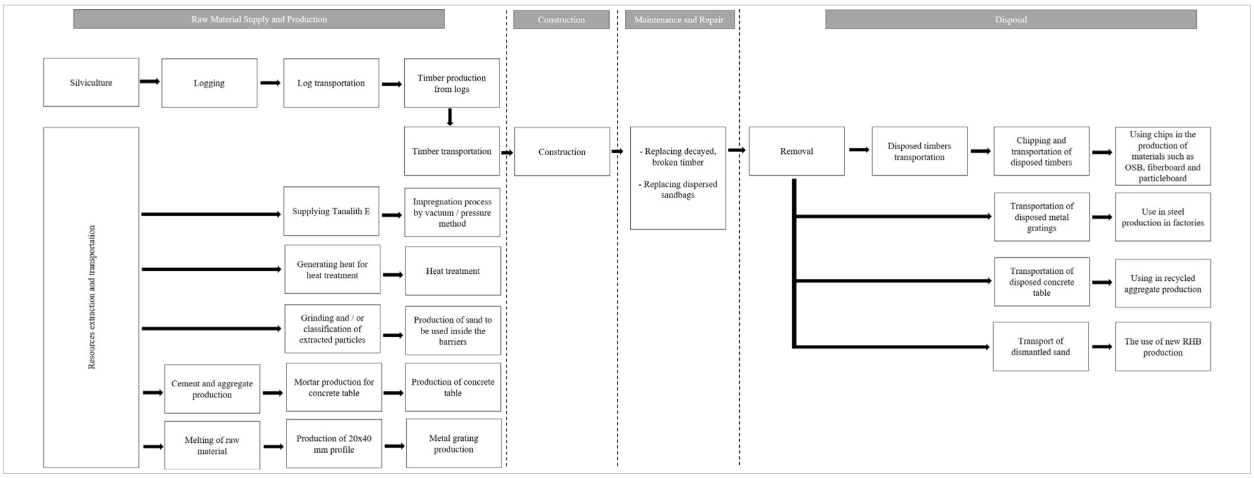

Figure 5
Renewable Hybrid Barrier Life Cycle Analysis

Table 3
Greenhouse Gas Emissions in the Production of RHB, Concrete and Steel Barriers (kg-CO_2eq)

Materials	RHB	New Jersey	W-Beam
Post	-	-	27.909
Spacer	-	-	9.262
Rail	-	-	69.033
Connecting plate	-	-	4.631
Hexagonal screws and nuts	-	-	3.309
Galvanization	-	-	114.174
Steel profiles	18.893	5.827	-
Chipboard screw	.431	-	-
Sand (5 mm)	.072	-	-
Vegetable soil	.016	-	-
Timber production (planed)	.330	-	-
Concrete	29.338	211.524	-
TOTAL	49.080	217.351	228.318

Table 4
Effect of Retention and Weathering on Carbon Content (%)

	Weathering Type		
	Non-Weathered	300 hours	600 hours
Non-Treated Control	48.52	-	-
Weathered Control		47.60	48.24
Impregnated	- (10.13) *	48.43 (9.94) *	48.12 (11.09) *
Heat Treated (150°C)	-	48.35	48.05
Heat Treated (210°C)	-	49.57	49.81

* Values in parentheses are Retention (kg/m³)
Non-Treated Control: Non-treated fir wood samples
Weathered Control: Non-treated and weathered fir wood samples
Impregnated: Fir wood samples impregnated with Tanalith-E
Heat Treated (150°C): Fir wood samples heat treated at 150°C
Heat Treated (210°C): Fir wood samples heat treated at 210°C
Non-Weathered: Non-weathered fir wood samples
300 hours: Fir wood samples that have been weathered for 300 hours
600 hours: Fir wood samples that have been weathered for 600 hours

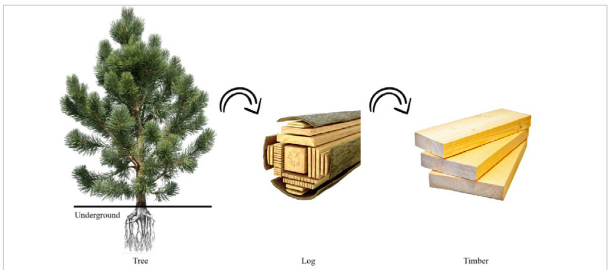

Figure 6
Transformation Process from Tree to Timber

.06 m^3 of fir timber to produce a single RHB. Since the timber was produced from fir logs with approximately 50% loss, .12 m^3 fir logs were needed to produce .06 m^3 fir timber (Figure 6).

To determine how much biomass needs to be removed from forests in order to produce .12 m^3 of fir logs, we calculated AGB using the steps listed in Equation 3. The BEF_2 expansion factor for coniferous trees is 24%, and 26% for broad-leaved trees (Noble et al. 2000).

$AGB = HX(1+BEF_2)$
$AGB = 0.12X(1+24\%)$
$AGB = 0.1488\ m^3$

In summary, in order to produce .06 m^3 of fir timber, .1488 m^3 biomass needs to be removed from nature. The total amount of carbon loss from forest biomass (L_{ACS}) can be calculated using Equation 4. The density of fir wood was considered as D=430 kg.m^{-3}, and the carbon content of untreated fir timber was found to be CF=.4852 (Table 4).

The carbon content of .06 m^3 fir timber used to produce an RHB was thus calculated as follows:

$RHBc = .06XDXCF$
$RHBc = .06X430X.4852$
$RHBc = 12.52$ kgC

Thus, a total of 12.52 kg of carbon is stored during RHB production. With the help of the same equation, the amount of carbon stocked in a felled tree is calculated as:

$L_{ACS} = AGBXDXCF$
$L_{ACS} = .1488X430X.4852$
$L_{ACS} = 31.05$ kg C

The total carbon values were converted to CO_2 equivalents, and was obtained for RHB production using the following equation:

$RHB_C = 12.52X3.67 = 45.94$ kg-CO_2eq

The amount of CO_2 loss from forest live biomass to produce RHB timber was calculated as:

$L_{ACS} = 38.40X3.67 = 113.94$ kg-CO_2eq

It must be emphasized here that this loss in biomass was not only for the production of one RHB. The timber used in RHB production was made of logs resulting from production activities carried out within the scope of ecological and silvicultural forest needs, but this is not the case for the production of steel or concrete barriers, which instead rely on mining activities. Forest products obtained from forests as a result of silvicultural management that are not used for RHBs are likely used in materials with shorter service lives (e.g., construction and packaging). The use of these materials in RHB production, therefore, ensures carbon sequestration endures for longer periods of time.

Discussion, and Conclusion and Recommendations

Roadside barriers are generally produced from steel and concrete, but newly designed RHBs are aesthetically and technically superior. In this study, an LCA was determined to ensure the sustainable production of RHBs and to better understand their environmental impacts. We determined that the amount of greenhouse gases emitted during the production of RHB and steel and concrete barriers was 49.080 kg-CO_2eq, 228.318 kg-CO_2eq, and 217.351 kg-CO_2eq, respectively. Thus, 4.5 times more greenhouse gases are released into nature during the production of steel and concrete barriers than during RHB production.

The total carbon content of fir wood was determined to be 48.52%. The effect of the impregnation process on the carbon content of wood was negligible, but heat treatment and weathering increased the carbon content of the wood. This increase may be caused by the fact that some wood components dissolve during heat treatment. The total amount of biomass equivalency of timber (.06 m^3) required in RHB production was .15 m^3. It was determined that RHB production caused 113.94 kg-CO_2eq to be lost from forest live biomass, whereas 45.94 kg-CO_2eq is stored during the RHB's service life.

These results indicate that RHBs are more environmentally friendly than concrete or steel barriers. This supports the conclusion that the increased use of wood-based materials to replace higher energy materials could be a successful method to mitigate greenhouse gas emissions. Further studies should focus on increasing the use of wood-based materials.

Ethics Committee Approval: Within the scope of this study, no procedure that would require ethics committee approval was applied.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – E.B.; Design – E.B.; Supervision – E.B.; Resources – E.B.; Materials – H.İ.Y.; Data Collection and/or Processing – A.D.; Analysis and/or Interpretation – E.B., H.Y., A.D., H.İ.Y.; Literature Search – E.B., H.Y., A.D., H.İ.Y.; Writing Manuscript – E.B., H.Y., A.D., H.İ.Y.; Critical Review – E.B., H.Y., A.D., H.İ.Y.; Other – E.B., H.Y., A.D., H.İ.Y.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: This study was funded by the Scientific and Technological Research Council of Turkey (TÜBİTAK) with the project number 118M753.

References

- Demirer, G. N. (2011). *Yaşam Döngüsü Analizi*. Sürdürülebilir Üretim ve Tüketim Yayınları 40 sf. Available from: https://recturkey.files.wordpress.com/2017/02/yda.pdf
- Draper, A. M., & Weissburg, M. J. (2019). Impacts of global warming and elevated CO2 on sensory behavior in predator-prey interactions: A review and synthesis. *Frontiers in Ecology and Evolution*, 7, DOI: 10.3389/fevo.2019.00072. [Crossref]
- Eggleston, H. S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (2006). IPCC *Guidelines for National Greenhouse Gas Inventories. Agriculture, Forestry and Other Land Use*. Hayama, 4. Available from: https://www.ipcc-nggip.iges.or.jp/public/2006gl/
- Ferguson, I., Bren, L., Hateley, R., Hermesec, B., & La Fontaine, B. (1996). *Environmental Properties of Timber*. Research Paper commissioned by the FWPRDC.
- Green, M., & Taggart, J. (2017). *Tall wood buildings: Design, construction and performance*. Tall Wood Buildings: Design, Construction and Performance 1-176. [Crossref]
- Hitoe, K., Hasegawa, T., Hasegawa, K., Terazawa, K., Yamanaka, K., & Hattori, N. (2013). Case study of life cycle assessment of domestic logs. *Mokuzai Gakkaishi*, 59, 269-277. [Crossref]
- IPCC., (2014). Cl*imate Change 2014*. In Climate Change 2014: Synthesis Report.
- Jemai, A., Najar, F., Chafra, M., & Ounaies, Z. (2014). *Mathematical Modeling of an Active-Fiber Composite Energy Harvester with Interdigitated Electrodes*. Shock and Vibration Article, ID 971597, DOI: 10.1155/2014/971597. [Crossref]
- Kalaycioglu, H., Deniz, I., & Hiziroglu, S. (2005). Some of the properties of particleboard made from paulownia. Journal of Wood Science, 51(4), 410-414. [Crossref]
- Kayo, C., Noda, R., Sasaki, T., & Takaoku, S. (2014). Carbon balance in the life cycle of wood: targeting a timber check dam. *Journal of Wood Science*, 61(1), 70-80. [Crossref]
- KGM., (2005). *Karayolu Tasarım El Kitabı*. Karayolları Genel Müdürlüğü.
- Kocaefe, D., Poncsak, S., & Boluk, Y. (2008). Effect of thermal treatment on the chemical composition and mechanical properties of birch and aspen. *BioResources, 3*(2), 517-537.
- Köhl, M., Ehrhart, H. P., Knauf, M., & Neupane, P. R. (2020). A viable indicator approach for assessing sustainable forest management in terms of carbon emissions and removals. *Ecological Indicators*, 111. [Crossref]
- Korkut, S., & Kocaefe, D. (2009). Isıl İşlemin Odun Özellikleri Üzerine Etkisi. *Düzce Üniveristesi Ormancılık Dergisi, 5*(2), 11-34.
- Lal, R. (2004). Soil carbon sequestration to mitigate climate change. *Geoderma, 123*(1-2), 1-22. [Crossref]
- Lee, J., Makineci, E., Tolunay, D., & Son, Y. (2018). Estimating the effect of abandoning coppice management on carbon sequestration by oak forests in Turkey with a modeling approach. *Science of the Total Environment, 640-641*, 400-405. [Crossref]
- NASA., (2020). *Overview: Weather, Global Warming and Climate Change*. Global Climate Change - Vital Sings of the Planet. Available from: https://climate.nasa.gov/resources/global-warming-vs-climate-change/
- Noble, I., Bolin, B., Ravindranath, N., Verardo, D., & Dokken, D. (2000). Land use, land use change, and forestry. *Environmental Conservation, 28*(3), 284-293.
- Noda, R., Kayo, C., Sasaki, T., & Takaoku, S. (2014). Evaluation of CO2 emissions reductions by timber check dams and their economic effectiveness. *Journal of Wood Science, 60*(6), 461-472. [Crossref]
- Noda, R., Kayo, C., Yamanouchi, M., & Shibata, N. (2016). Life Cycle Greenhouse Gas Emission of Wooden Guardrails: A Study in Nagano Prefecture. *Journal of Wood Science, 62*(2), 181-193. [Crossref]
- Pilia, F., Maltinti, F., & Annunziata, F. (2012). Preliminary Results on a New Safety Road Barrier Made Completely of Wood. *Environmental Semeiotics, 5*(2), 11-23. [Crossref]
- Pingoud, K., Pohjola, J., & Valsta, L. (2010). Assessing the integrated climatic impacts of forestry and wood products. *Silva Fennica, 44*(1), 155-175. [Crossref]

- Puettmann, M. E., & Lippke, B. (2012). Woody biomass substitution for thermal energy at softwood lumber mills in the US inland Northwest. *Forest Products Journal, 62*(4), 273-279. [Crossref]
- Saraçoğlu, N. (2010). *Küresel İklim Değişimi, Biyoenerji ve Enerji Ormancılığı*. Elif Yayınevi. ISBN: 6054334409 page: 298. Ankara, Türkiye
- Selin, H., & Mann, M. E. (2020). *Global warming*. Britannica Retrieved from: https://www.britannica.com/science/global-warming
- Settele, J., Scholes, R., Betts, R. A., Bunn, S., Leadley, P., Nepstad, D., Overpeck, J., Taboada, M. A., Fischlin, A., Moreno, J. M., Root, T., Musche, M., & Winter, M. (2015). *Terrestrial and Inland Water Systems*. In Climate Change 2014 Impacts, Adaptation, and Vulnerability.
- Sofuoğlu, S. D., & Kurtoğlu, A. (2012). A survey for determination of wastage rates at massive wood materials processing. *Wood Research, 57*(2), 297-308.
- Sulaiman, C., Abdul-Rahim, A. S., & Ofozor, C. A. (2020). Does wood biomass energy use reduce CO2 emissions in European Union member countries? Evidence from 27 members. *Journal of Cleaner Production, 253*, 119996. [Crossref]
- Tunç, A. (2004). *Yol Güvenlik Mühendisliği ve Uygulamaları*. Asil Yayın Dağıtım. ISBN: 9789758784417, page: 528. Ankara, Türkiye
- Winchester, N. & Reilly, J. M. (2020). The economic and emissions benefits of engineered wood products in a low-carbon future. *Energy Economics, 85*, 10. [Crossref]
- Xu, Y., Ramanathan, V., & Victor, D. G. (2018). Global warming will happen faster than we think. *Nature, 564*(7734), 30-32. [Crossref]
- Zhang, Q., Li, Y., Yu, C., Qi, J., Yang, C., Cheng, B., & Liang, S. (2020). Global timber harvest footprints of nations and virtual timber trade flows. *Journal of Cleaner Production, 250*, 119503. [Crossref]