Comparative Life-Cycle Assessment of California Redwood Decking

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Introduction

Redwood is a unique species that has a limited natural range along the coastal zone of northern California. It is commonly used for decking because of its natural beauty and resistance to decay. For the consumer, choices to buy or use redwood decking or comparable products made from metal, wood, plastic, or concrete are done daily. Product selection is based on a spectrum of attributes including price, quality, and intended service application. In recent decades, the burdens that a particular product may place on human health and the physical environment are receiving increased consideration. In particular there is great concern about the environmental impacts associated with all phases of manufacturing, use, and disposal of forest products (Bowyer et al 2001).

Life Cycle Assessment (or Analysis) (LCA) is a scientific technique commonly used to quantify the environmental footprint of producing and consuming products we use in our everyday life. Increasing societal interest in identifying the environmental impacts of consumer choices has led to the expanded use of LCA for everything from consumer electronics and tennis shoes to building products and jet fuel. Producers also benefit from LCA as the approach can be used to identify opportunities for environmental improvement and cost reduction as well as to provide scientifically defensible data in support claims of environmental benefits of their products.

Life cycle inventory and assessment measures inputs and outputs per unit of product so that it is easy to compare embodied energy (the amount of energy it takes to make a product), and emissions to land, air and water and what impacts those emissions may have. LCI results can also report the amount of renewable and/or non-renewable materials consumed during the process, both for energy generation and for inclusion in the product itself. For renewable products like redwood decking, additional assessment tools are available to characterize sustainability of growing and harvesting systems.

In the United States evaluation criteria to determine harvest sustainability for forest products are set forth in ASTM standard D7612. This standard sets forth what is needed to identify harvests as legal, responsible, and/or certified. California's forest practices code is one of the most stringent regulatory frameworks found in the USA (Dicus and Delfino 2003) so any wood procured from California forests would be classified as a responsible source under ASTM D7612. Under the stringent California regulations there is a high confidence that the redwood forests that are harvested to supply redwood decking are sustainably harvested.

Under the assumption that forests are sustainably managed, and therefore the forest itself is neither a carbon source or a carbon sink, a LCA was undertaken to quantify the environmental footprint of redwood decking produced and sold in western North America. The goal of the study was to quantify the environmental impacts of redwood decking production and use over a 25 year life span in what is known as a cradle to grave LCA. The results were used to compare the environmental footprint of redwood decking to plastic (cellular PVC) and wood-plastic composite (WPC) decking as the two dominant competing products in the residential decking market in western North America.

How LCA works

LCA studies have four main components: goal and scope definition, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), and the interpretation of results. The goal and scope indicates what system you are examining, and why, and provides a boundary that defines what is included as an input, and what is defined as an output. LCI measures the inputs of energy and materials needed to produce a given product as well as measuring the output of products, co-products, and associated emissions to air, water, and land. The LCI generates hundreds, and sometimes thousands, of data points per unit of product depending on the chemistry and complexity of the system being measured. In order to make sense of the large amount of data produced, during the LCIA, data are aggregated into categories that show the environmental impacts of interest. If one is concerned about air quality, the data can be grouped to show their aggregate impact on ozone depletion or the generation of smog for example. Emissions that affect water quality can also be grouped. Common water quality measures include eutrophication, which is the nutrient enrichment that leads to algae blooms and subsequent dead zones such as are common in the Gulf of Mexico during summer months and acidification, which measures the potential for acid rain.

LCIA methods vary in the categories used, and whether the impacts are reported as an aggregate of emissions or assumptions are used to estimate the impacts on human health or other environmental factors. The US Environmental Protection Agency has developed a LCIA method called TRACI (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) and it has grown to become the dominant impact assessment method used in North America. There are many impact categories in TRACI. Six of the most commonly used are global warming potential (GWP), ozone depletion, smog, acidification, eutrophication, and respiratory effects. These six impact categories are used in the comparative LCA of redwood decking that follows.

GWP measures the heat trapping capability of airborne compounds relative to the heat trapping capability of carbon dioxide (CO_2) so it is measured in CO_2 equivalents (CO_2e). As an example, the chemical composition of methane (CH_4) is such that it is more effective than CO_2 at trapping heat, but it doesn't last as long in the atmosphere. The US EPA reports that a single molecule of CH_4 has a GWP 21 times that of a single molecule of CO_2 over a 100 year period. So if a process emits 100 molecules of CO_2 and 1 molecule of CH_4, a total GWP of 121 would be reported for that process using the TRACI impact method. A similar approach is taken for airborne chemicals that contribute ozone depletion, smog, and acidification which are measured relative to the impact of Chlorofluorocarbons (CFC's), ozone (O_3), and a mole of hydrogen ions (H+) respectively. Respiratory effects are quantified relative to the emissions of particulate matter that is 2.5 microns in size (PM 2.5 eq). Eutrophication is the only impact category reported here that is specific to water borne emissions. It measures the impact of emissions relative to the impact of nitrogen on water quality and is reported in nitrogen equivalents (N-eq). This impact assessment method allows for the quantification and summarization of the myriad of chemical emissions that occur in the production of inputs to a manufacturing process (eg gasoline, diesel, electricity) as well as during the manufacturing of the product itself and places them in a common metric so comparisons can be made between products that can serve an equivalent function. The TRACI method does not account for carbon dioxide emissions from burning biomass consistent with existing EPA regulations. However, it does track other emissions associated with burning biomass, such as those from methane.

Elements of LCA explained

It is necessary to standardize the way that products are measured in order to capture real differences in the environmental footprint, rather than differences that are attributable to the way the products are measured. The environmental impacts were determined using LCA techniques conducted to International Standards Organization (ISO) 14040 and 14044 standards. A critical element to standardize is what is called the functional unit. For example to build a 500 square foot deck takes 675 kg of redwood boards and 1330 kg of WPC boards. If we were to compare decking products on a per ton basis, the relative impacts of WPC would be approximately 3.75 what they are if they were compared on a per square foot basis and redwood would be 7.4 times higher. Per ton comparisons would generate flawed results because the function of the deck is derived from the area covered, not by how much the deck weighs. For that reason decking products were compared on the basis of the amount of area covered over a time duration that was deemed representative of the average lifespan of a residential deck. The LCI for each decking product used a functional unit of 100 square feet of decking with an assumed service life of 25 years. LCIA results were tallied using this same functional unit.

In order to generate impacts the LCI measures inputs and outputs relative to a common system boundary. The system boundaries used for the LCI covering all products was from cradle to grave which is this case was the landfill site at the end of the deck's useful life. For polyvinyl and WPC products the cradle begins in the manufacturing process, whereas for redwood decking the cradle includes forest operations starting with site preparation, planting and growing the seedlings, and forest management activities through to harvest and transportation to the manufacturing facility. At the manufacturing facility all operations were considered and the emissions associated with them were quantified in the LCI. Emissions associated with the production of inputs into the system boundary such as gasoline, diesel, and electricity generation are carried forward and allocated to the final product so that the full environmental burden is accurately characterized. Once products left the manufacturing facility, assumptions were made regarding the amount of maintenance required to meet the requirement for a 25 year useful life for each decking material type, and disposal of decking into a landfill with current methane capture equipment with energy recovery was assumed at the end of the 25 year period.

In LCA, environmental burdens can be allocated in a number of ways. The most common allocation method is by mass (sum of kg of material inputs/functional unit), though economic allocations are commonly used when there is a large disparity between the relative value of co-products. PVC and WPC products have no co-products so the choice of allocation method does not materially affect the comparison. Redwood decking does have co-products as chips, sawdust and hogfuel are produced as part of the process. These co-products have a value that is approximately 10% of the value of the decking material so the allocation of environmental burdens for redwood decking uses an economic (value based) allocation. This allocation approach places all environmental burdens for redwood decking onto the decking itself and is therefore a conservative estimate of the true impacts of redwood decking production.

Comparison of LCA results for common decking products

Transportation emissions from the manufacturing location to the consumer have to be accounted for in a cradle to grave assessment. In this study, the impact of transportation to two main distribution centers was modeled. Half the decking was assumed to be distributed from San Francisco, California and the other half from Seattle, Washington.

Table 1 shows the LCIA per 100 ft^2 for PVC, virgin WPC, recycled WPC, and redwood. PVC and both WPC decking products assumed a 2.3% loss whereas redwood decking assumed a 3% loss over their whole life cycle. Results are shown for the six impact categories described above. As other impacts are sometimes of concern, comparative values for total energy (embodied energy), fossil fuel energy, biomass energy, water consumption, and solid waste are also provided in Table 1.

The global warming potential (GWP) for redwood (-163 kg CO_2-eq) is negative because it accounts for the carbon sequestered in the trees (-262 kg CO_2-eq) that are used as raw material for the redwood decking that is balanced against the amount air emissions measured in kg CO_2-eq (99) that are needed to produce 100 ft^2 of decking. Even though the two WPC decking materials stored carbon in a final product as the wood flour used in them is 50% carbon by weight, all six key impact categories were still substantially higher for the alternative decking materials than for redwood decking. This can be partly attributed to the fact that redwood decking consumed little energy for drying which is usually the most energy-intensive process for wood products. But it is mostly attributable to the fact that total energy used for redwood was substantially lower than the other decking products: 4.2% (447/10600) of PVC, 3.0% (447/14700) of virgin WPC and 6.7% (447/6690) of recycled WPC. There are two categories where redwood decking has a higher environmental impact. One is for biomass energy consumption, because wood product production typically utilizes the wood residue generated during production as a fuel source. The second is for renewable material use because redwood is a renewable resource.

Table 1: Cradle to Grave LCA Comparison of 100 ft^2 of western US residential decking products

Impact Category	Unit	Polyvinyl chloride	Virgin wood plastic composite	Recycled wood plastic composite	Redwood
Global warming	kg CO_2 eq	426	264	144	-163
Ozone depletion	kg CFC-11 eq	1.60E-05	1.37E-05	1.16E-05	1.36E-06
Smog	kg O_3 eq	30.0	36.3	28.5	9.5
Acidification	kg SO_2 eq	4.61	5.94	2.86	0.37
Eutrophication	kg N eq	0.108	0.237	0.203	0.022
Respiratory effects	kg PM2.5 eq	0.276	0.338	0.157	0.006
Primary Energy Consumption	**Unit**				
Non-renewable fossil	MJ	10169	13840	5820	280
Non-renewable nuclear	MJ	449	238	168	39
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	15	614	693	35
Renewable, biomass	MJ	6	9	9	94
Total primary energy	MJ	10600	14700	6690	447
Material resources consumption[a]	**Unit**				
Non-renewable materials	kg	157	134	134	0.8
Renewable materials	kg	0	133	133	136
Fresh water	L	4500	3360	3440	229
Waste generated	**Unit**				
Solid Waste	kg	0.736	0.070	8.60	0.223

[1] Functional unit of decking selected (100 ft^2 (9.29 m^2)

[a] Non-fuel resources

In order to capture the magnitude of the differences between the four decking materials in each impact category, in Figures 1 through 3 they are compared relative to the maximum value in each category. For example, in Figure 1 the maximum value for global warming potential is 426 kg CO_2e per 100 ft^2 of PVC decking and it represents 100% with every other value in that category scaled as a percentage of 426. Figure 1 shows the relative impacts for each LCA category that was analyzed, Figure 2 shows the relative impacts for energy use, and Figure 3 shows the relative impacts for material use and waste generated across all four decking products.

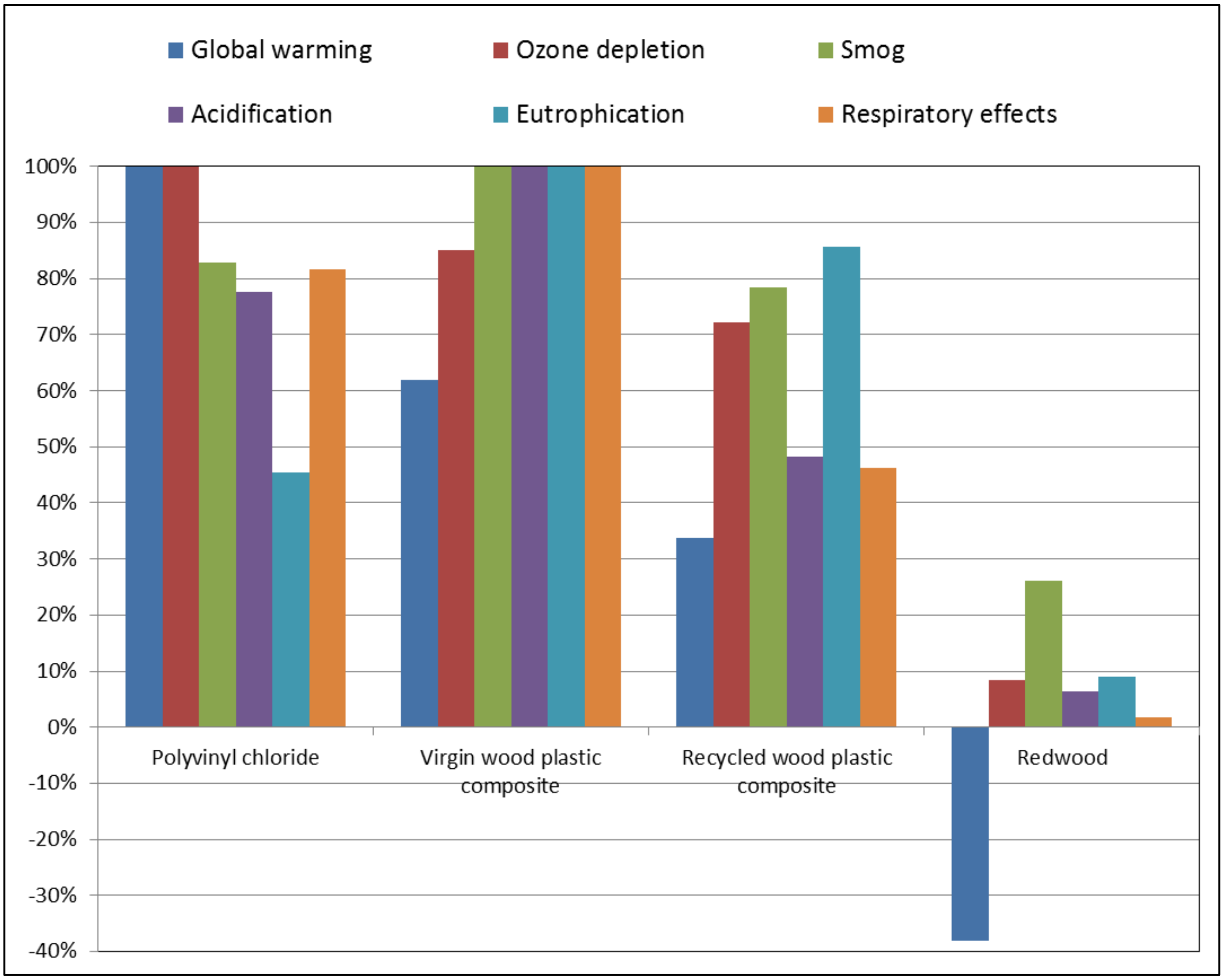

Figure 1: A Comparison of Life-Cycle Impact Categories for the Four Decking Products

The uptake of carbon dioxide from the atmosphere into the raw materials (i.e. trees) used to make redwood decking and the storage of CO_2 as carbon in the decking over the life of the product is a significant environmental benefit. The CO_2e stored in the redwood decking not only offsets all growing, harvesting, hauling and processing emissions, it reduces overall emissions below zero over the life of the product as shown in Figure 1. While CO_2e is also stored in the WPC products, the stored CO_2e is not sufficient to offset the CO_2e emissions generated during the production, use and disposal of the product. For the remaining impact categories, only smog has a relative impact greater than 10% of the decking product with the highest impact (Table 2).

For energy use, redwood decking has the maximum value for biomass energy usage, with other energy use categories at less than 10% of the decking product with the highest impact (Table 2). Of interest is that the total energy used over the life of the redwood decking is only 3% of the energy used by the decking product with the highest impact. Total fossil fuels usage is 21 – 49 times higher for PVC and the WPC products as compared to redwood decking whereas total energy usage is 15 – 33 times higher for PVC and WPC products as compared to redwood decking. This is the reason that the GWP for redwood is negative whereas other decking products with a wood component still have a large footprint. These differences in energy usage, and particularly in fossil fuel usage, show the very high substitution leverage of using wood products over those that use large amounts of fossil fuel during the manufacturing phase. Other life-cycle studies have shown similar results for other wood products when compared to their functional equivalents because of the inherent low embodied energy of wood products and the relatively simple manufacturing processes used to create a finished product.

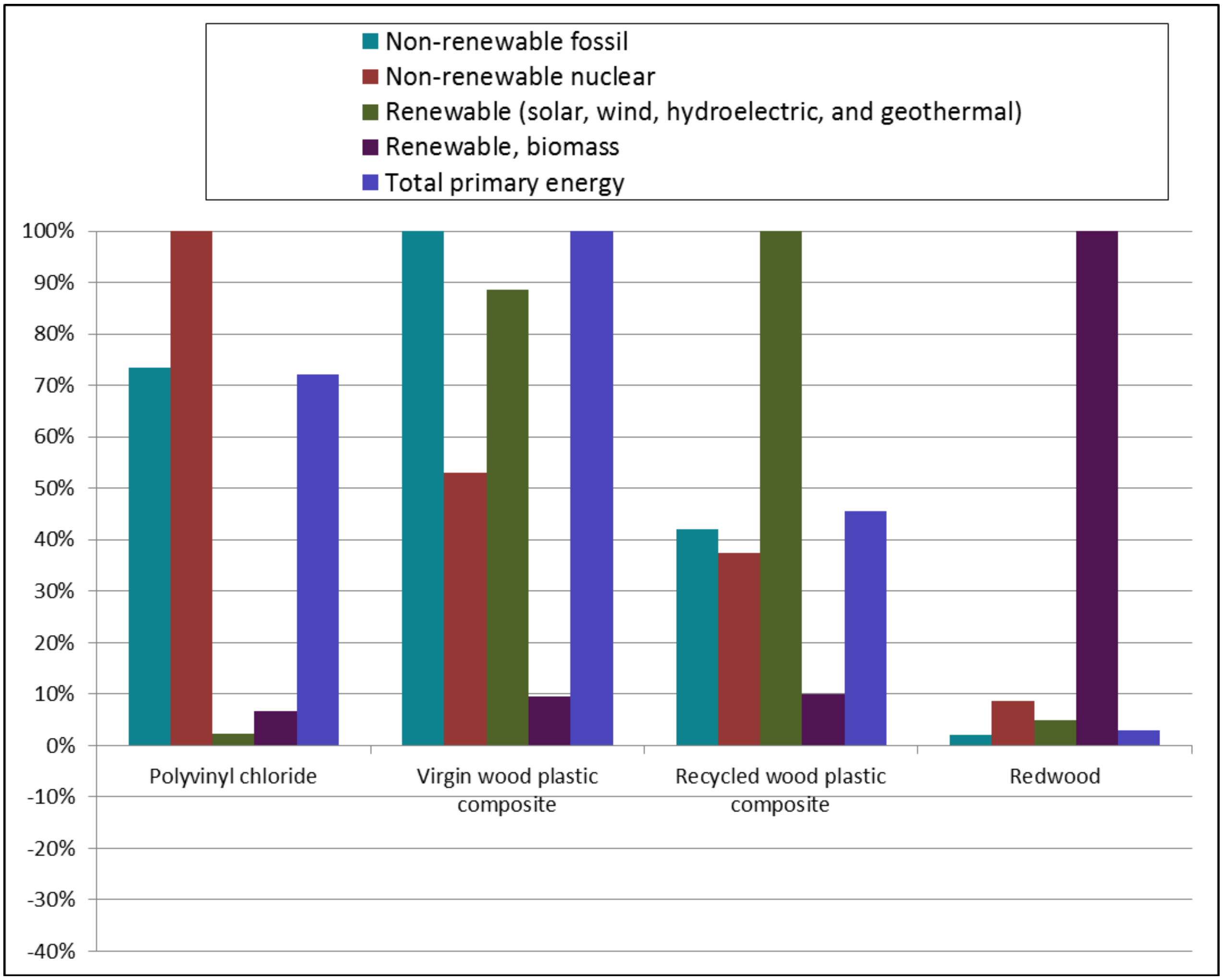

Figure 2: Primary Energy Consumption by Type for the Four Decking Products

Because redwood is entirely made from renewable feedstocks, it has the highest impact in the renewable material usage category. At 133 kg of renewable material used per 100 ft^2, WPC decking uses 98% of the amount of renewable materials used in redwood decking (136 kg), so from a renewability perspective there is not a lot of difference between the products, though WPC takes 23-32 times more energy over the life of the product. Other material resource use in the redwood decking life cycle is small compared to the other decking products (Figure 3) and makes up a very small percentage of the mass of the input materials.

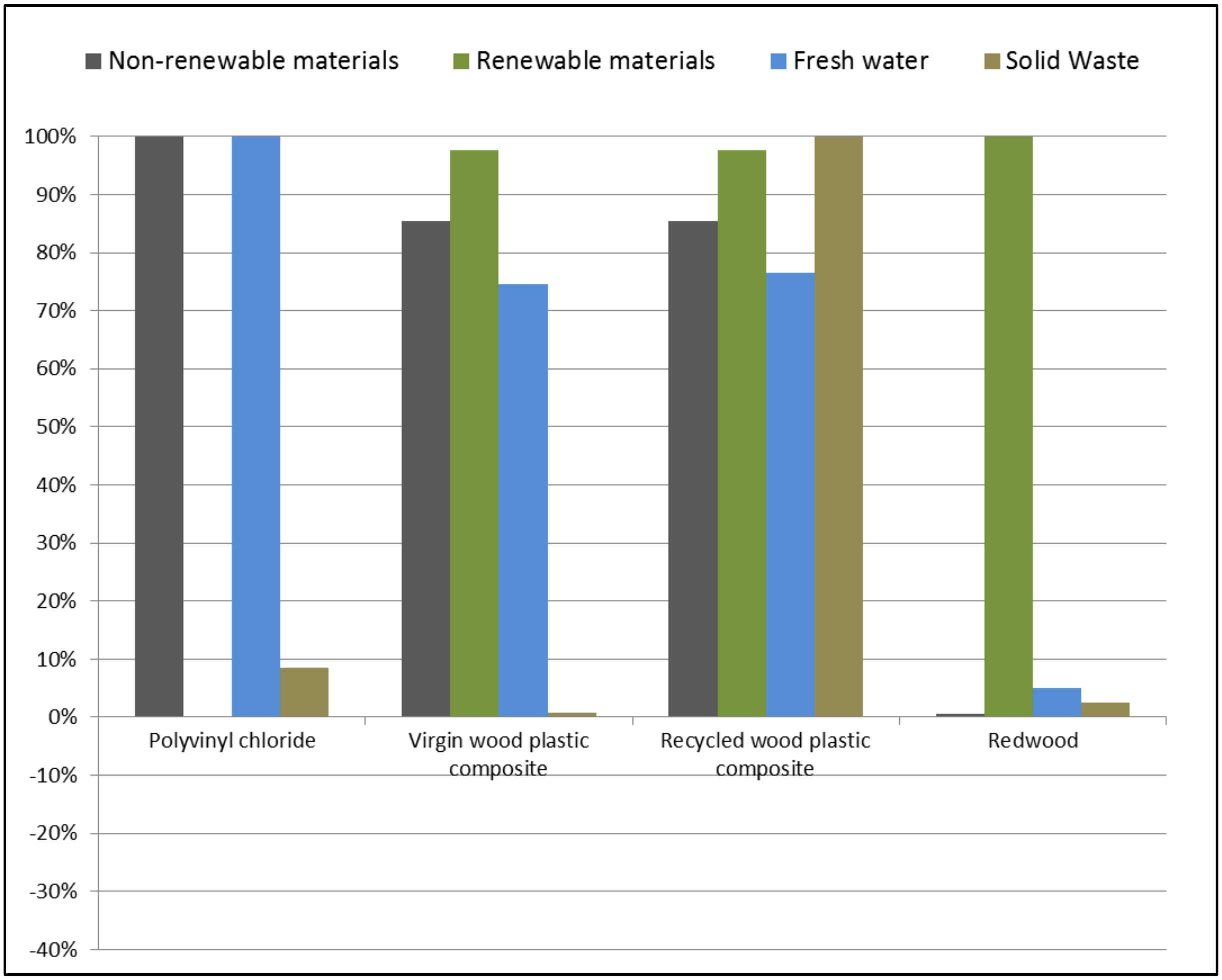

Figure 3: Material Resources Consumption and Waste Generated for the Four Decking Products

Table 2: Redwood decking impact as a percentage of the highest impact of comparable products

Impact Category	Redwood % of maximum value
Global warming	0.2%
Ozone depletion	8.5%
Smog	26.2%
Acidification	6.2%
Eutrophication	9.3%
Respiratory effects	1.8%
Non-renewable fossil	2.0%
Non-renewable nuclear	8.7%
Renewable (solar, wind, hydroelectric, and geothermal)	5.1%
Total primary energy	3.0%
Non-renewable materials	0.6%
Fresh water	5.1%
Solid Waste	30.3%

Conclusions

The comparative LCA of redwood, PVC, and WPC decking provides the scientific basis for asserting the environmental benefits of using renewable products like redwood decking in place of products that are heavily dependent on non-renewable energy and materials in their production. The global warming potential is perhaps the most strikingly positive result of using redwood decking sourced from sustainably managed forests to meet the demand for residential decking because it shows how wood structural materials serve as carbon sinks over the entire life of the product and beyond. A comparison of the very low fossil fuel input into the production of redwood decking and the overall low energy usage for redwood decking relative to other materials demonstrates how durable wood products can reduce fossil fuel use by substituting for products with a high fossil fuel footprint.

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