Deconstruction vs. Demolition:

An evaluation of carbon and energy impacts from deconstructed homes in the City of Portland

Submitted to: City of Portland Bureau of Planning and Sustainability (BPS)

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Executive Summary

In October 2016, in an effort to reduce waste, support material reuse, and reduce environmental impacts of demolition, the City of Portland, Oregon, enacted an ordinance requiring manual deconstruction of residential homes built in 1916 or earlier. This study analyzes the material quantity data from the first 36 deconstruction projects in Portland to measure carbon and energy impacts. The carbon and energy impacts were also calculated for a hypothetical scenario in which the same houses were mechanically demolished.

The goal of this project is to calculate the carbon and energy impacts of deconstruction and demolition of single-family houses in Portland, Oregon. The results will allow the City of Portland to measure the effectiveness of their deconstruction policy in achieving climate and energy goals.

Results indicate the following:

- The sample of 36 homes had an average age of 112 years and average size of 1,177 square feet.
- The average deconstruction of a single-family home in Portland, Oregon, yielded 39,362 pounds of material (excluding foundation), of which 10,587 pounds (27 percent) was salvaged. The vast majority of salvaged material by weight was softwood lumber, in the form of framing lumber, structural beams, and sheathing (shiplap on walls and plank subfloor). This material made up over 85 percent of the total weight of salvaged materials.
- The average deconstructed home showed a carbon benefit of 13.8 MTCO2e while demolition showed a carbon benefit of 6.2 MTCO2e. Deconstruction yields a net carbon benefit of approximately 7.6 metric tons of CO_2eq per house compared to demolition. The carbon benefits are mainly attributed to the avoided production of new materials and the continued sequestration of biogenic carbon in the wood.
- Landfilling wood does result in a benefit for carbon storage but reuse of wood yields a benefit almost twice as large.
- When considering biogenic carbon as an emissions source and sink, burning wood for energy emits more carbon than it offsets when replacing natural gas as a fuel in industrial boilers.
- Although the end-of-life fate of recoverable wood greatly influenced the relative carbon benefits of the deconstruction scenario, sensitivity analyses revealed that deconstruction will always have a carbon benefit over demolition even with extreme swings in the market for recoverable wood.
- Results are less clear when looking at primary energy demand. The average deconstructed home showed an energy benefit of 89 GJ, while demolition showed a benefit of 115 GJ, a difference of 26 GJ. Based on DEQ surveys of recovered and disposed materials, much of the clean recoverable wood (56 percent) is used as a fuel that offsets natural gas use in industrial boilers regionally. This pathway yields a large energy credit, which is contrasted by this pathway being a net emitter of carbon.
- For energy impacts, the rate of wood incineration for energy recovery, which offsets the use of natural gas, highly influenced the results. A decrease in the wood recovery rate from the current 56 percent to 30 percent would make the energy benefits of both the deconstruction and demolition scenarios approximately equal.
- Material transport, worker transport and equipment use on site was analyzed in detail. Results indicate that the impacts were inconsequential compared to much larger impacts of material reuse, recovery and disposal.

- There was no correlation between salvage quantity and house age. Correlation with house age could become more pronounced if deconstruction is applied to newer houses that contain lower quality/value material and are physically more challenging to deconstruct due to adhesives.
- Although there was little correlation between the quantity of material salvaged and house size, the study did find that salvage quantities were more closely tied with specific contractors, indicating some contractors were able to salvage a higher percentage of material per house. Among more experienced contractors, salvaged rates were as high as 37 percent by weight and yielded a net carbon benefit as high as 10 MT CO2e/average home. As the deconstruction industry matures, we may see average salvage rates rise slightly.

One limitation of the study was the use of regionally adjusted material composition data for the dropbox materials. Although exact weights of dropbox materials were known, the exact recovery or disposal of those materials was assumed using regionally adjusted averages. Considering the high influence of recoverable wood on the study results, future work would benefit from a more detailed account of the recovery and disposal fates of dropbox materials. Additionally, an investigation into the reused materials market would give insight into the true amounts of material being reused, what it is used for, and what that material is replacing. This latter point is a challenging issue, and more data would help to provide evidence for the environmental credits applied to the avoided production of new materials used in this study.

The City of Portland was the first city in the country to require deconstruction of single-family homes. This study provides a good snapshot of the environmental implications of a deconstruction policy for a population of single-family homes. It is clear that increasing deconstruction can help the City of Portland achieve carbon reduction goals. For energy, however, sensitivity analyses show that a slight change to the end-of-life fate of wood waste can make both scenarios comparable to each other.

Finally, it should be noted that this study uses local variables and end-of-life scenarios specific to the Portland metro region. Any conclusions or applicability to other areas of the country should be carefully considered given differences in markets, building materials, and recovery rates.

1. Introduction and Background

Deconstruction is the systematic dismantling of a structure that prioritizes salvage of materials for reuse over recycling, recycles what is not reusable, and minimizes unusable/non-recyclable residuals that end up in the landfill (City of Portland, 2016). This report summarizes a selection of the environmental implications from the City of Portland's Deconstruction Ordinance, which became effective on October 31, 2016. The policy requires that houses built in 1916 or earlier be fully deconstructed, i.e., dismantled by hand, in order to maximize the amount of material salvaged and reused.

During the first full calendar year of the policy, over 100 detached single-family homes were permitted for deconstruction. This evaluation focuses on the first 36 homes deconstructed, due to timing and data availability. Using actual material quantity data from these homes, combined with established material impact factors and regional assumptions, the global warming potential (GWP) and primary energy demand impacts of each deconstruction project can be evaluated. Comparing this to the 'business as usual' scenario in which all houses are mechanically demolished, an estimation of the net impact of the ordinance can be produced.

1.1 Background

1.1.1 Portland's Deconstruction Ordinance

In October 2016, in an effort to reduce waste, support material reuse, and reduce environmental impacts of demolition, the City of Portland enacted an ordinance requiring manual deconstruction of residential homes built in 1916 or earlier, or designated as a historic resource regardless of age. Approximately 30-35 percent (by weight) of the landfill bound waste in Portland is construction and demolition debris. Deconstruction and material reuse provides an opportunity to reduce this waste and help offset the environmental impacts of producing new materials.

1.2 Impetus for this Study

The City of Portland's deconstruction ordinance provided an opportunity to collect material salvage quantities on a large number of deconstruction projects. Combining these material quantities with a selection of environmental impact factors allows the evaluation of the relative impacts of deconstruction compared against mechanical demolition projects. Since the City of Portland, Oregon was the first city in the United States to enact a residential deconstruction requirement, this project represents the first attempt to quantify a selection of environmental impacts for a citywide policy related to building deconstruction. In particular, the City of Portland set goals to increase the salvage and reuse of building materials in their 2015 Climate Action Plan. This analysis allows them to quantify the carbon impacts of their policy. Oregon DEQ or others may use this information to help inform policy development in other locations.

1.3 Definitions

In this report, "deconstruction" or "decon" means the systematic dismantling of a structure, typically in the opposite order it was constructed, in order to maximize the salvage of materials for reuse, in preference over salvaging materials for recycling, energy recovery, or sending the materials to the landfill. Typically, material is removed by hand and processed (e.g., de-nailing) on site. Salvaged material is transported to another location for resale, while non-salvageable material is placed into a dropbox and taken to a material recovery facility (MRF).

“Demolition” or “demo” refers to the removal of a structure using mechanized equipment (such as a track hoe). Typically, this process results in much more physical damage to materials, preventing salvage and reuse. All material from a mechanical demolition is assumed to be removed by dropbox and taken to a material recovery facility (MRF).

The foundation of the house is excluded from the definitions of deconstruction and demolition in this analysis, as foundation removal is not typically carried out by deconstruction contractors. The process for removing and disposing of a concrete foundation is identical between deconstruction and mechanical demolition.

“Disposal” refers to deposition of materials in a solid waste landfill.

“Dropbox” refers to a receptacle on a deconstruction or demolition site into which non-salvaged materials are placed, to be sent to a MRF.

“End of life” (EOL) refers to the processes that occur after the useful life of a component or material, including deconstruction, reuse, demolition, recycling and disposal. In this study “EOL fate” is used to refer to the final stages for each respective material.

“Materials recovery facility” (MRF, pronounced “murf”), is a permitted solid waste facility where solid wastes or recyclable materials are sorted or separated. There are many types of MRFs, and in this study this may refer to facilities that receive general solid waste, only construction and demolition waste, or only wood waste.

“Non-Recoverable wood” refers to wood that cannot be reused, recycled or used for energy generation, such as painted, treated, dirty or rotten wood.

“Recoverable wood” refers to wood that can be reused, recycled OR used for energy generation. Note that recoverable does not necessarily imply reusable (e.g., a small broken piece of trim may only be suitable for energy generation).

2. Project Methodology

2.1 Goal and Scope

2.1.1 Goal

The goal of this project is to calculate the carbon and energy impacts of deconstruction and demolition of single-family houses in Portland, Oregon. The results will allow the City of Portland to measure the effectiveness of their deconstruction policy in achieving climate and energy goals. The results may be used by DEQ and others to provide policy guidance and recommendations regarding deconstruction.

2.1.2 Objectives

The objective for this project was to produce a report outlining the findings of this study, including:

1. The average salvage percentage by weight across all projects.
2. The net environmental impacts of 36 residential home deconstruction projects in the City of Portland from October 2016 to December 2017.
3. The average home net benefit of deconstruction versus mechanical demolition for the 36 deconstruction projects in the City of Portland.

2.1.3 System Boundary

Figure 1 below illustrates the different life cycle stages of a building product organized in so-called "information modules," as defined in the ISO 21930:2017 standard for sustainability in buildings (ISO, 2017). The system boundary of this study covers the end-of-life stages C1-C4 and potential net benefits from reuse, recycling, or energy recovery in stage D. In this study, included within these stages are the following processes:

C1: Deconstruction/Demolition

- Worker transport to/from worksite
- Equipment use on site

C2: Transport to waste processing or disposal

- Transport of salvaged material to reuse location
- Transport of dropboxes to MRFs
- Transport of sorted waste streams from MRFs to final EOL fate

C3: Waste Processing

- Energy and material use for recycling
- Fuel use at landfill (loaders, etc.)
- Emissions from energy recovery (combustion)

C4: Disposal of Waste

- Decomposition emissions in landfill (fugitive emissions)
- Biogenic carbon storage in landfill

D: System Expansion

- Avoided production of new goods (for salvaged and recycled materials)
- Avoided natural gas used to generate steam for heat (wood energy recovery)

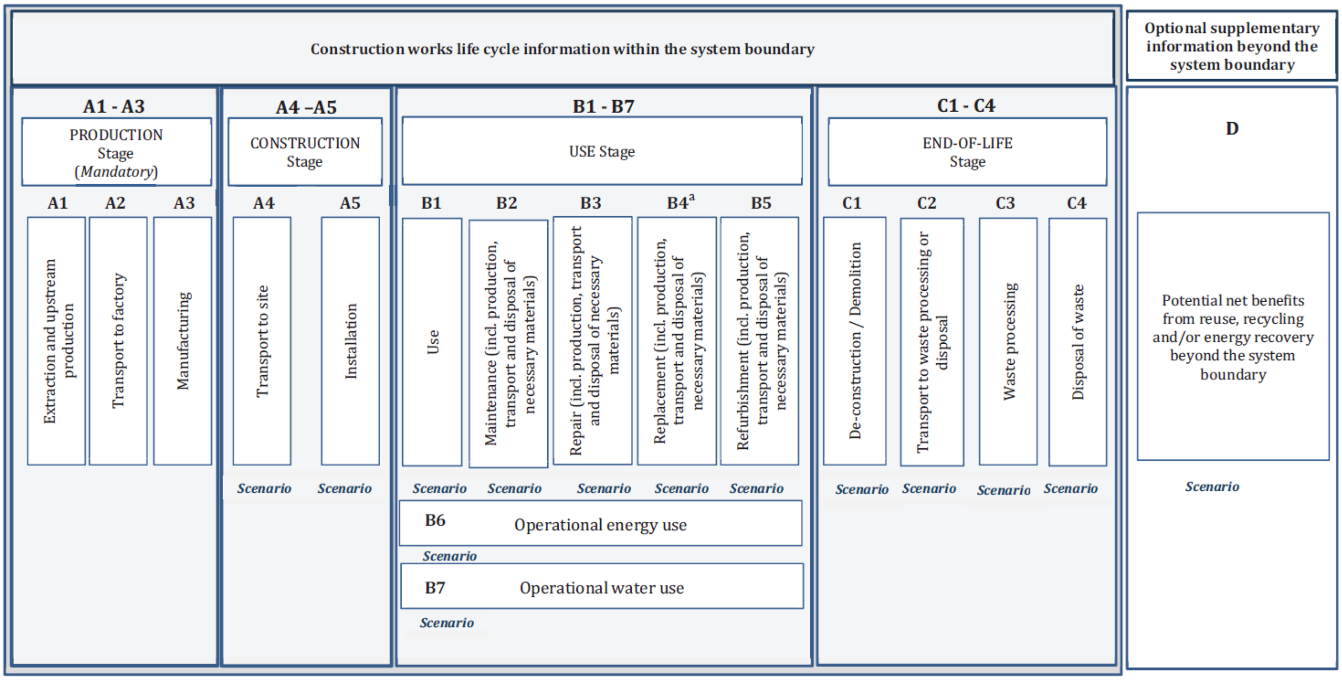

Figure 1: Life cycle stages of building products (ISO 21930:2017)

2.2. Project Dataset

2.2.1 Dataset Description

The study sample consists of 36 single-family homes deconstructed between November 2016 and December 2017. Figure 2 shows the location of these homes. All but one of the projects were on the East side of the Willamette River, which is representative of where the majority of demolitions were occurring in the City of Portland in 2017. The data are a cross-sectional snapshot of all materials reported as removed from the job site including salvage inventory, dropbox quantities and the destination recipient.

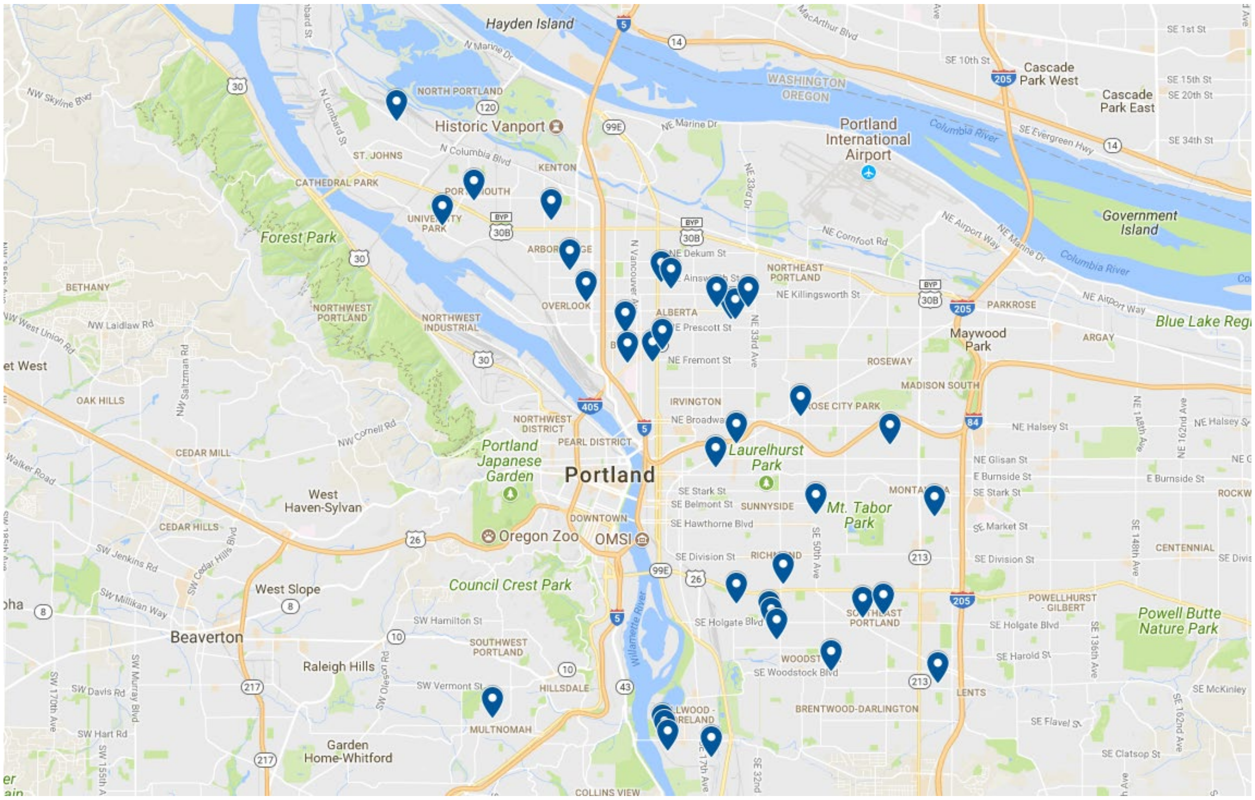

Figure 2: Map of deconstruction dataset samples (36 projects included in the analysis)

The maximum, minimum, median and average house age and size for the houses included in this study are shown in Table 1. The newest house in the study was 90 years old – outside of the ordinance year-built threshold, but required to deconstruct because it was designated a historic resource. The houses were typical for the Pacific Northwest – timber-framed, with Douglas fir being the predominant species used for framing, sheathing (shiplap), subfloors and many finished floors.

Table 1: House age and size range for houses in sample

	Minimum	Maximum	Median	Average
House Age (years)	90	137	111	112
House Size (square feet)	640	2,341	1,132	1177

2.2.2 Data Collection

Project data from deconstruction contractors was collected by the City of Portland, and provided to DEQ for the purposes of this report. Project-specific material data was received in the form of receipts from dropbox and recycling haulers, pictures of handwritten sale or donation slips from salvage retailers, and inventory forms and lists. This information was manually entered into a Microsoft Excel master spreadsheet to facilitate DEQ internal data sharing, comments and cleaning.

2.2.3 Data Cleaning

After data entry, all items were assigned a material name, then inspected for accurate translation and entry of necessary descriptive information such as the material physical dimensions and composition. Where adequate material composition information or physical dimensions were not given, default dimensions/composition/material names were used. The appropriate reported or default unit dimensions were used to generate a *per-unit value,* which was in turn multiplied by the reported quantity of the material to obtain a line item subtotal, called the *calculated quantity.* This calculated value was converted to units compatible with the impact factors, usually kilograms, and saved as *converted quantity*. This converted quantity is the quantity used to determine the impacts associated with each material from each project.

2.2.4 Project Workflow

All data cleaning, preparation, transformations, and analysis work was developed in the R language (R v3.4.4) using RStudio (v1.1.383) and the tidyverse packages (v.1.2.1). Additional packages used and verbose detail of software settings are included in the Deconstruction R project notebook files. For open access purposes, all R data table outputs are saved as comma separated values (csv) file types, and all input data files were exported from Excel spreadsheets to csv files prior to importing into R, and all R Markdown notebooks are published as HTML files. The entire coding project was developed to be reproducible and open-sourced for free public use and access. Figure 3 shows the workflow from the raw contractor receipts to data input collection in Excel spreadsheets converted to csv files for upload, cleaning, and analysis procedures in RStudio, which produce the final output and report. Detail of the RStudio analysis routine is documented in detail in the R project notebooks and is summarized as follows.

Material salvage and disposal receipts were collected for each deconstruction project to estimate the total material quantity by weight (kg). The material weights were then multiplied by their respective carbon and energy impact factors, which were developed using life-cycle-analysis (LCA) best practices. Transport of materials, transport of workers, and the use of on-site diesel heavy-machinery equipment was also included in the development of the project impacts.

For each deconstruction project, two modeling scenarios were conducted: 1) actual salvage scenario, and 2) hypothetical mechanical demolition scenario that assumed the materials would go to their typical EOL fates based on Metro regional recovery and disposal data. Net impacts for carbon and energy were then determined on a project level between each scenario modeled.

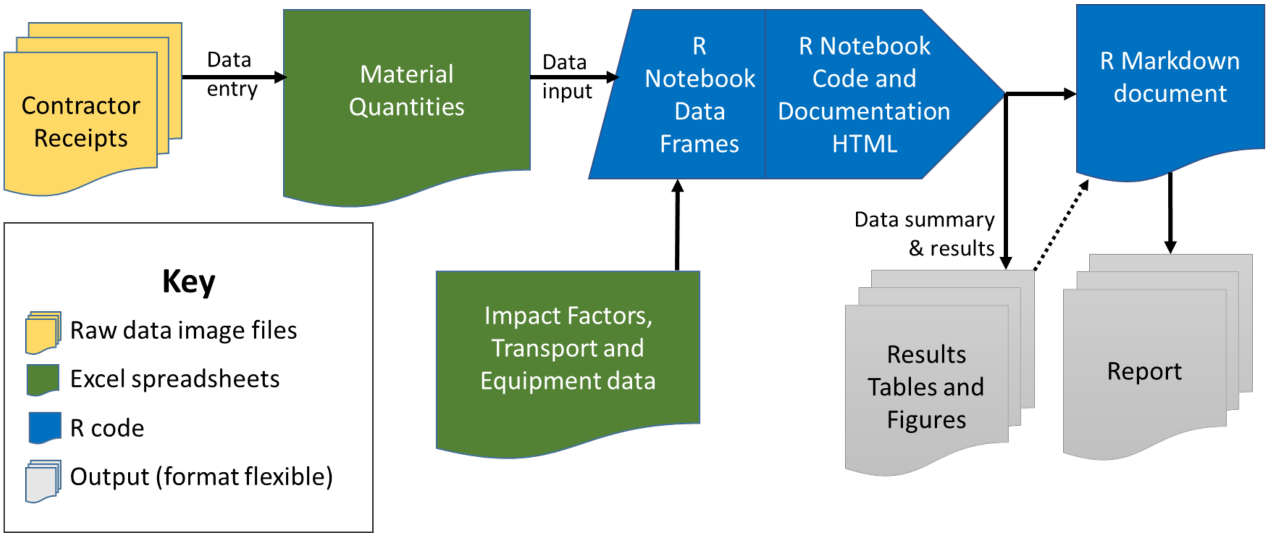

Figure 3: Project workflow

2.3 Assumptions

2.3.1 Material Assumptions

Because of the age of the houses, construction styles and material standards are different from today's construction. Much of the dimensional lumber salvaged from the projects differed from today's dimensions. A 2x4 piece of lumber would measure 1.5" x 3.5" using the current standard, but older lumber could be the full 2"x4", or somewhere in between. Sometimes the notation "rough cut" is used to describe lumber that measures the actual dimensions of the name. Some of the contractor receipts in this study did not specify whether their recorded dimensions were actual or nominal; when this was the case, actual (rough cut) dimensions were assumed. This assumption could potentially make a large difference to results: An 8-foot-long rough cut 2x4 is 768 cubic inches, while a nominal 2x4 (1.5"x3.5") would be 504 cubic inches in volume, almost 35 percent smaller.

The assumed dimensions and weights for building components were compiled from literature, weighing samples of salvaged building materials, and some professional judgement. These assumptions can be found in Appendix A. Softwood density was sourced from a recent study of lumber properties for salvaged wood coming from Portland-area deconstructed homes. The Oregon State University study concluded that the average density of salvaged Doug-fir lumber from Portland-area homes is 530.7 kg per cubic meter (Raphael Arbelaez, personal communication, October 2018). Hardwood density was assumed to be 770 kg per cubic meter, the value for American white oak (International Timber, 2018).

Foundations were excluded from this study, as deconstruction typically does not include removal of the foundation. Even if the foundation were included, there would be no difference between deconstruction and demolition, as the process for breaking up and removing the foundation is the same in both scenarios.

Deconstruction contractors do not in practice record the relative quantities of each material type going into dropboxes. The contents of these dropboxes were estimated using the average relative makeup of construction and demolition (C&D) debris generated in the Portland metro area using 2016 DEQ Waste Composition Study[1] and 2016 Material Recovery Survey[2] data and adjusted based on professional judgement. The reason these figures were adjusted is that material coming from the demolition of old homes is different from the average C&D waste generated in the Portland region, which is what DEQ's field surveys measure. For example, the average C&D waste stream contains more metal and cardboard than was observed in the projects in this study. New construction generates cardboard—not residential demolitions. Additionally, commercial construction and renovation generates more metal than residential home demolitions. The average waste stream also contains higher amounts of roofing material than typically seen on residential demolitions because a lot of roofing material is coming from reroofing projects as opposed to demolitions. Overall, best professional judgement was used to adjust the dropboxes to have a material composition that more accurately represents residential demolition sites.

Table 2 shows the total waste generated in 2016 for the material categories used in this study, and how they were adjusted to better represent a residential demolition projects. The analysis treats the composition of all drop boxes the same, which is discussed further in Section 6 "Limitations" in this report.

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[1] https://www.oregon.gov/deq/mm/Pages/Waste-Composition-Study.aspx

[2] https://www.oregon.gov/deq/mm/Pages/survey.aspx

Table 2: Original and adjusted material category composition of dropboxes

Material Category	Construction and Demolition (C&D) Waste Generated		
	Total Oregon Metro 2016 (Portland area) Generated Waste (tons)	% of total C+D waste	Adjusted % based on best professional judgement for residential demos
Recoverable Wood	224,009	29%	41%
Non-Recoverable Wood	94,080	12%	23%
Metal	224,029	29%	5%
other	241,284	31%	31%

Additionally, dropbox material has been simplified into four categories: ‘recoverable wood,’ ‘non-recoverable wood,’ ‘metal,’ and ‘other’. The specific components that fall into these categories are shown in Table 3.

Table 3: Assumed material composition of dropboxes and materials included in each dropbox category

Material Category	% of Total Dropbox Weight	Material Name (components)
Recoverable Wood	41%	Hardwood Flooring Doors Softwood lumber Cedar shingles (unpainted) Wood siding Medium Density Fiberboard (MDF) Plywood Oriented Strand Board (OSB)(Cabinets Hardwood lumber
Non-Recoverable Wood	23%	Any wood that did not fit in the above categories (such as pressure-treated wood, painted wood such as siding, and dirty, decayed or damaged wood)
Metal	5%	Steel products Aluminum siding Cast iron Light fixture
Other	31%	Carpeting Windows Fiber cement siding Ceramics Plaster Vinyl siding Fiberglass tub Concrete roofing

2.3.2 End-of-Life Assumptions

Each material and each dropbox material category in this study, has an assigned end-of-life (EOL) fate; i.e., a relative percentage split between the four possible EOL options (reuse, landfill, recycle, energy recovery).

In the deconstruction scenario, it has been assumed that 100 percent of salvaged material is reused, and displaces production of new product. The material that was removed from the site in dropboxes (i.e., not salvaged) has been categorized using the assumptions in Table 3 and an EOL fate has been assigned to each of these categories (Table 4). These splits were based on Portland metro area recovery rates, using 2016 data from Oregon DEQ's Material Recovery Survey combined with the 2016 Waste Composition Study. The EOL fates represented in Table 4 are very representative of C+D waste generated at a regional scale but not necessarily representative at a project level. For example, dropbox material coming from a deconstruction site may be more easily recoverable than wood coming from a demolition site. Demolition site debris is often mashed up with other materials and not easily separated on the floor of a material recovery facility. In the absence of more detailed generation and recovery rates from dropboxes from different sites, we used the same EOL compositions and fates for all dropboxes. A further discussion around varying the EOL fates can be found in section 4.3—Sensitivity Analysis.

Table 4: End-of-life fates for dropbox material categories

Material Category	% Recycling	% Energy Recovery	% Landfill
Recoverable Wood	0%	56%	44%
Non-Recoverable Wood	0%	0%	100%
Metal	93%	0%	7%
Other	0%	0%	100%

The impacts and offsets for each material, based on these respective EOL fates, was calculated using EPA WARM v14, and the Ecoinvent 2.2 and GaBi v8.7 databases. The impact factors used have been included in the accompanying Excel file to this report. The reason for 'negative' EOL carbon and energy impacts (i.e., benefits) is due to the system expansion employed, in which recycled material and energy generated from waste replaces virgin material and energy generated from fossil fuels, respectively. This benefit can be larger than the emissions and energy consumed in the EOL process itself. In Portland, for example, recovered clean wood is used for heat generation in paper and packaging plants, instead of natural gas. A summary of these system expansion processes is given in Table 5.

Table 5: End-of-life fates and descriptions

End-of-Life Disposition	Processes taken into account
Disposal in Landfill	Impact of landfill operations, including carbon storage and landfill gas flaring/utilization.
Recycling	Impact of recycling process Offset of virgin material by recycled material
Energy Recovery	Impact of incineration (including carbon emissions) Offset of applicable energy source (natural gas)
Reuse	Offset of production of new material Carbon stored in reused material (wood products only)

2.3.3 Wood Products – biogenic carbon and energy offset assumptions

In this study, biogenic carbon (carbon related to the natural carbon cycle, such as that in wood), is considered where emissions and sinks occur. The treatment of biogenic carbon depends on the EOL fate of each relevant material. When wood is sent to landfill, much of the biogenic carbon (that which doesn't decompose into landfill gas) is stored long-term, and so a credit is given for this. In the case of energy recovery, the carbon in the wood is released as CO_2, and these emissions are counted, while the emissions from the likely alternative source of energy (natural gas) are offset. The assumed carbon quantities stored, release and offset per kg of wood are shown in Table 6a. Table 6b shows the energy released and offset from EOL fates for wood. It should be noted that the energy recovery scenario assumed a 15 percent moisture content in the wood and the reuse scenario used 10% moisture content based on best professional judgement. Furthermore, all of the offsets used for energy recovery in this study were replacing natural gas as a fuel. Besides landfilling, replacement of natural gas as a fuel in boilers is the only current use of recovered wood waste (hogged fuel) in the Portland metro area. In other parts of Oregon, wood waste is used to generate electricity, which is why the carbon values for electricity replacement are listed in the Tables 6a and 6b below.

Table 6a: Carbon stored, released and offset from EOL fates for wood (kg CO_2eq/kg wood)

EOL Fate	Production avoidance offset	Carbon stored	Carbon released	Carbon offset	Total	Data Sources + Notes
Reuse	-0.20	-1.65	0	0	-1.85	Production offset calculated with EPA WARM base data, carbon storage from calculated carbon storage based on weight and moisture content of wood using EPA ECFR emissions factors here
Landfill		-1.20	0.07	-0.01	-1.15	EPA WARM v14
Energy Recovery (replace natural gas)			1.72	-1.25	0.47	GaBi v8.7 used for biomas and natural gas process steam processes.
Energy Recovery (replace electricity)			1.72	-0.37	1.35	GaBi v8.7 used for boiler GHG releases. EPA WARM conversion efficiency used for electricity, and Oregon electricity mix used.

Table 6b: Energy released and offset from EOL fates for wood (MJ per kg wood)

EOL Fate	Production avoidance offset	Landfill Energy Use	Electricity Offset	Natural Gas Offset	Total	Data Sources + Notes
Reuse					-4.27	EPA WARM v14
Landfill					0.23	EPA WARM v14
Energy Recovery (replace natural gas)				-20.96	-20.96	GaBi v8.7 used for primary energy (MJ/MJ). Used EPA ECFR energy content converted to 15% moisture content, assume 80% efficiency for wood boiler and 85% efficiency for natural gas boiler.
Energy Recovery (replace electricity)			-6.88		-6.88	GaBi v8.7 used for primary energy (MJ/MJ). Use EPA ECFR energy content as above, assumed 17.8% conversion efficiency based on WARM.

2.3.4 Material Transport

Table 7 shows the transport assumptions for all materials in the deconstruction and demolition scenarios. The distances are round trip and represent an empty backhaul, which is representative for the Portland, Oregon area. The transport impact factors were adjusted to account for the varying “utilization” of the truck during the roundtrip transport legs. For all materials, the carbon and energy impacts of transporting a specific weight of material the total distance listed in Table 7 below were calculated. Some transport legs were volume limited, which means that multiple trips had to occur even though the total weight of materials could have been supported by that truck classification. Total number of trips were assumed based on an average of actual dropbox receipts, discussions with contractors, and best professional judgement. The roundtrip distances were based on actual distances to salvage retail locations, material recovery facilities, and landfills utilized in the Portland area. These distances were supplied by Oregon Metro and Oregon DEQ. The carbon and energy impacts of each truck classification were taken from Gabi[3] version 8.7.

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[3] Gabi Class 6 truck; Gabi class 8b truck

Table 7: Transport assumptions for materials

Activity	Material	Transport Leg	Roundtrip Distance (miles)	Number of Trips	Total Distance (miles	Truck Classification (Gross Vehicle Weight)
Deconstruction	salvaged items	site to retail	22	2	44	6 (19,501 - 26,000lbs)
Deconstruction	dropbox	site to transfer	10	3	30	8b (33,000lbs+)
Deconstruction	recoverable wood	transfer to wood end use	114	1	114	8b (33,000lbs+)
Deconstruction	metal	transfer to metal end use	120	1	120	8b (33,000lbs+)
Deconstruction	disposed	transfer to landfill	200	1	200	8b (33,000lbs+)
Demolition	dropbox	site to transfer	10	4	40	8b (33,000lbs+)
Demolition	recoverable wood	transfer to wood end use	114	1	114	8b (33,000lbs+)
Demolition	metal	transfer to metal end use	120	1	120	8b (33,000lbs+)
Demolition	disposed	transfer to landfill	200	1	200	8b (33,000lbs+)

2.3.5 Worker Transport and Equipment Use

The amount of labor and the use of heavy machinery are areas where deconstruction and mechanical demolition differ. In general, deconstruction requires more workers, over a longer period of time, and does not use heavy machinery. Mechanical demolition requires fewer workers, over a shorter period of time and uses heavy machinery such as excavators. The assumptions for project duration, workers on site per day, distance driven by each worker, and excavator use are given in Table 8 and were developed based on best professional judgement of the project team. For passenger car transport, we assumed an average of 24 miles per gallon and used the carbon and energy intensities from the Oregon Clean Fuels Program (State of Oregon, 2017). The intensities used are 12.34 kgCO$_2$e/gallon for gasoline and 157.02 MJ/gallon. The excavator impact factors were taken from Ecoinvent 3.3 database and are 20.1 kgCO2e/equipment hour and 293 MJ/equipment hour.

Table 8: Worker transport and heavy equipment use assumptions

Scenario	Duration (days)	Workers	Distance driven per worker, per day (miles)	Total Passenger Car Miles	Excavator/track hoe use (hours)
Deconstruction	10	4	30	1200	0
Demolition	2	2	30	120	12

4. Results

4.1 Material Quantities

Average material quantities per deconstruction project were calculated on a weight basis. On average, a total of 39,362 lbs was removed from each site, with 10,587 lbs (26.9 percent) being salvaged (Figure 4). The remaining 28,775 lbs of material was removed from the site via dropboxes and sent to MRFs.

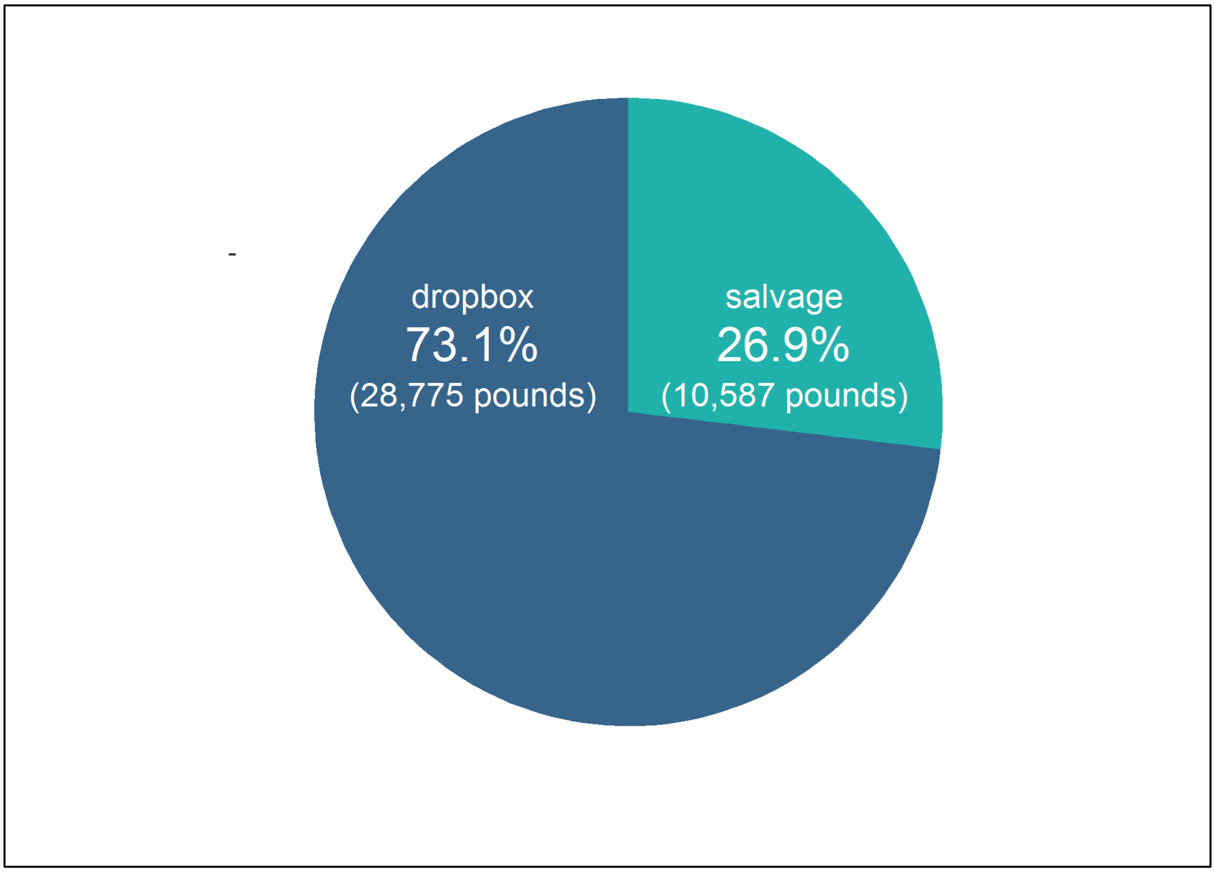

Figure 4: Relative percentage by weight of material removed by dropbox and salvaged from an average deconstructed home

Of the salvaged materials, roughly 85% (by weight) was softwood lumber, followed by 3.4 percent plywood, 1.3% interior wood doors, and 1.25 percent steel products (Figure 5). This indicates that the vast majority of material salvaged from the deconstruction projects was wood – specifically softwood lumber. This aligns with the fact that most houses of this generation in Portland use Douglas fir for framing, plank subfloor, and sheathing (shiplap under the siding). Douglas fir flooring was also common during this time period.

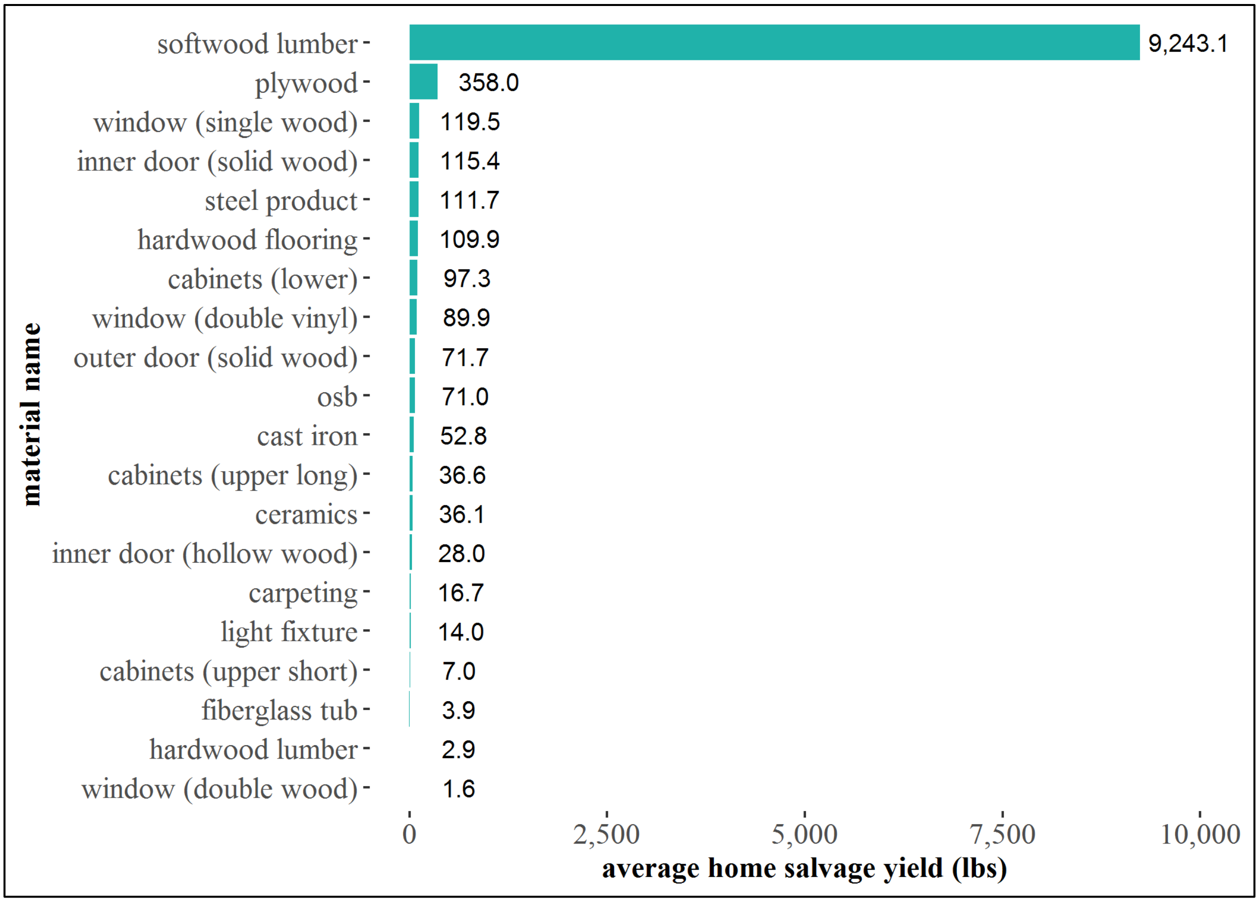

Figure 5: Quantity of materials salvaged from an average home

Using the broader dropbox material categories, the average quantity of each category was calculated on a per-project basis (Figure 6). The largest of these categories was Recoverable Wood, with 11,798 lbs. This indicates that there is a large amount of clean wood going to dropboxes with little economic value; this could include pieces too small to sell, unconventional dimensions, or split/broken wood. This material is suitable for energy recovery, but not for reuse.

The next category is Other, of which an average of 8,920 lbs per project was removed. This large figure is due to non-salvageable material such as asphalt roofing, carpet, fiber cement and vinyl siding, any broken ceramics, and damaged/broken windows. Non-Recoverable Wood (6,618 lbs) was the next largest category, influenced by the fact that most houses in the study had painted wood siding which is not suitable for reuse or energy recovery. The final and smallest category is metal (1,439 lbs), which includes steel and cast iron plumbing, as well as aluminum siding and light fixtures.

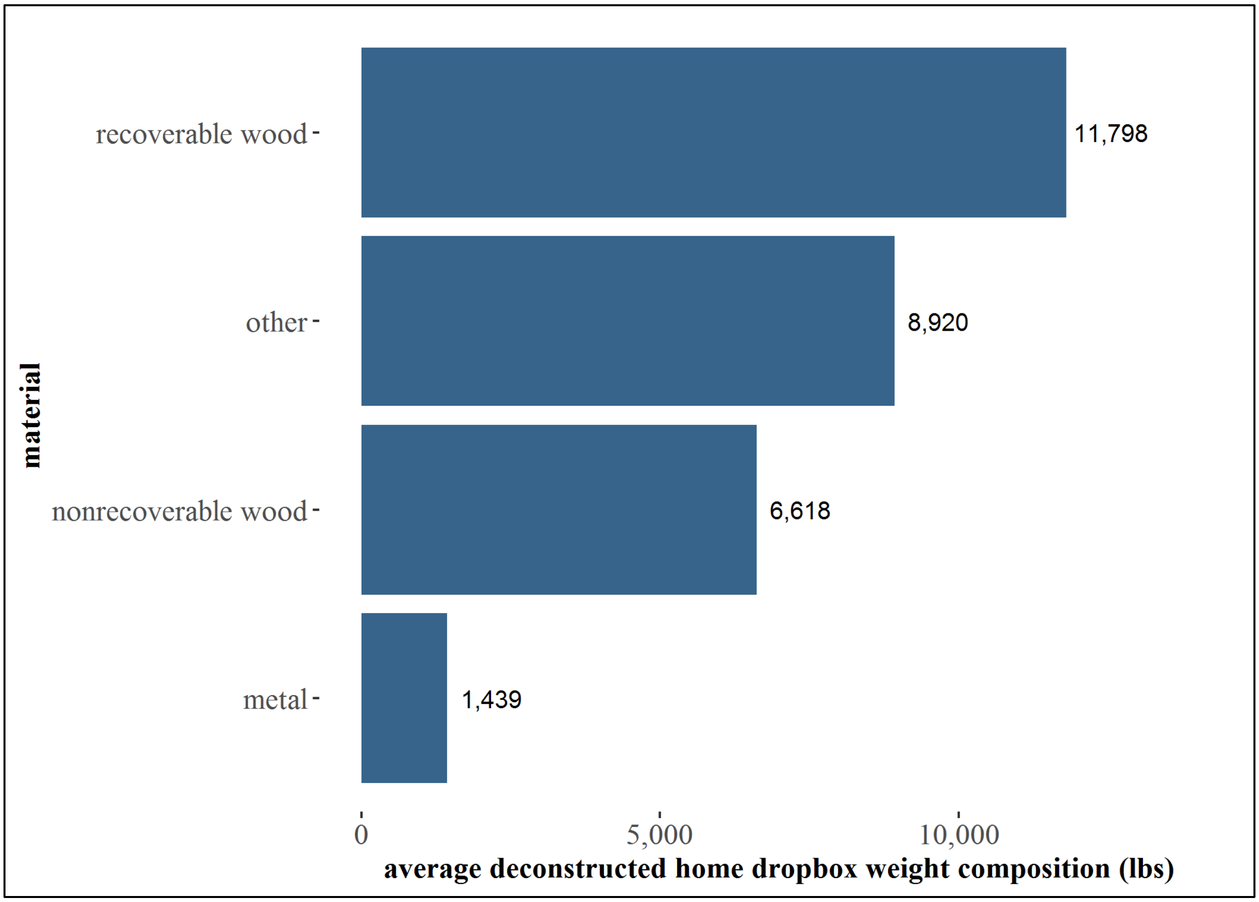

Figure 6: Estimated quantity (pounds) of material removed in dropboxes from an average deconstruction project by material category

4.2 Carbon and Energy Impacts

4.2.1 Total Carbon and Energy Impacts per Project

The carbon (as Global Warming Potential (GWP), in its standard units of kg CO_2eq) and energy impacts (as primary energy demand, in MJ) of deconstruction and demolition have been calculated as for the entire 36 projects, and in this section are presented as impacts per average project. These have been broken down into five categories: material impacts, material transport to either a reuse location or a MRF, material transport from MRF to end of life, worker transport, and equipment use on site. Material impacts includes the impacts from the EOL processes for each material.

In Table 9, the average GWP impacts per project indicate that material impacts (i.e., impacts from each material's EOL fate) account for the majority of the impact in both scenarios. Both scenarios show a negative value for material impacts, meaning there is a net carbon benefit from these processes. This is due to the large percentage of wood in the material stream: both scenarios benefit from the landfill carbon storage of a large portion the wood in dropboxes, while the deconstruction scenario benefits from the reuse of the clean salvaged wood. Wood used for energy recovery does not show a carbon benefit, as the amount of CO_2eq released is larger than offset emissions. Material and worker transport make up a very small fraction of the total impacts in both scenarios. These results are shown graphically in Figure 7.

Table 9: Average global warming potential impacts per project (kg CO2eq)

	Deconstruction	Demolition	Difference
Material impacts	-15,104	-7,175	7,929
Material transport (to MRF or reuse)	177	118	-59
Material transport (MRF to EOL)	461	584	123
Worker transport	617	62	-555
Equipment use on site	0	241	241
Total	-13,849	-6,170	7,679

Figure 7: GWP per average home by activity (kg CO_2eq)

Deconstruction shows approximately double the GWP benefit when compared with demolition (Figure 8). The difference between the two scenarios equates to 7,679 kg of CO_2eq, meaning that for every house deconstructed instead of demolished, approximately 7.6 metric tons of CO_2eq is saved. Again, the majority of this comes from the reuse of wood.

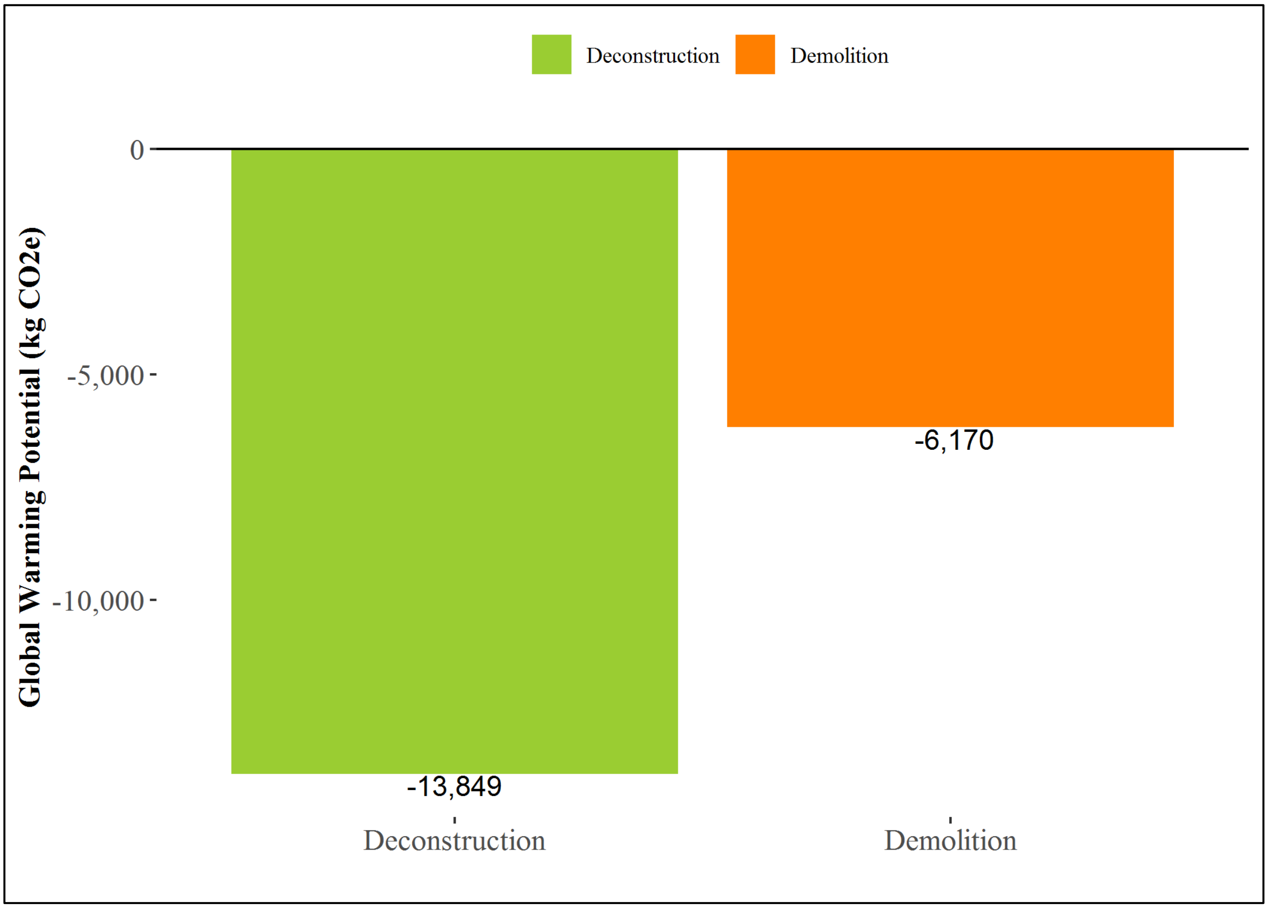

Figure 8: Total GWP per average home (kg CO_2eq)

Energy demand for an average home removal for the two scenarios is shown in Table 10. In this case, the relative difference between the two scenarios is reversed. One of the main reasons for this is that wood is a material with a relatively low energy intensity (by nature, its main energy input during production is solar energy). The other main reason is that energy is recovered from much of the clean wood and offsets energy produced other ways.

Table 10: Average Energy demand per project (MJ)

	Deconstruction	Demolition	Difference
Material impacts	-106,180	-129,839	-23,659
Material transport (to MRF or reuse)	2,584	1,724	-860
Material transport (MRF to EOL)	6,751	8,548	1,797
Worker transport	7,851	785	-7,066
Equipment use on site	0	3,516	3,516
Total	**-88,994**	**-115,266**	**-26,272**

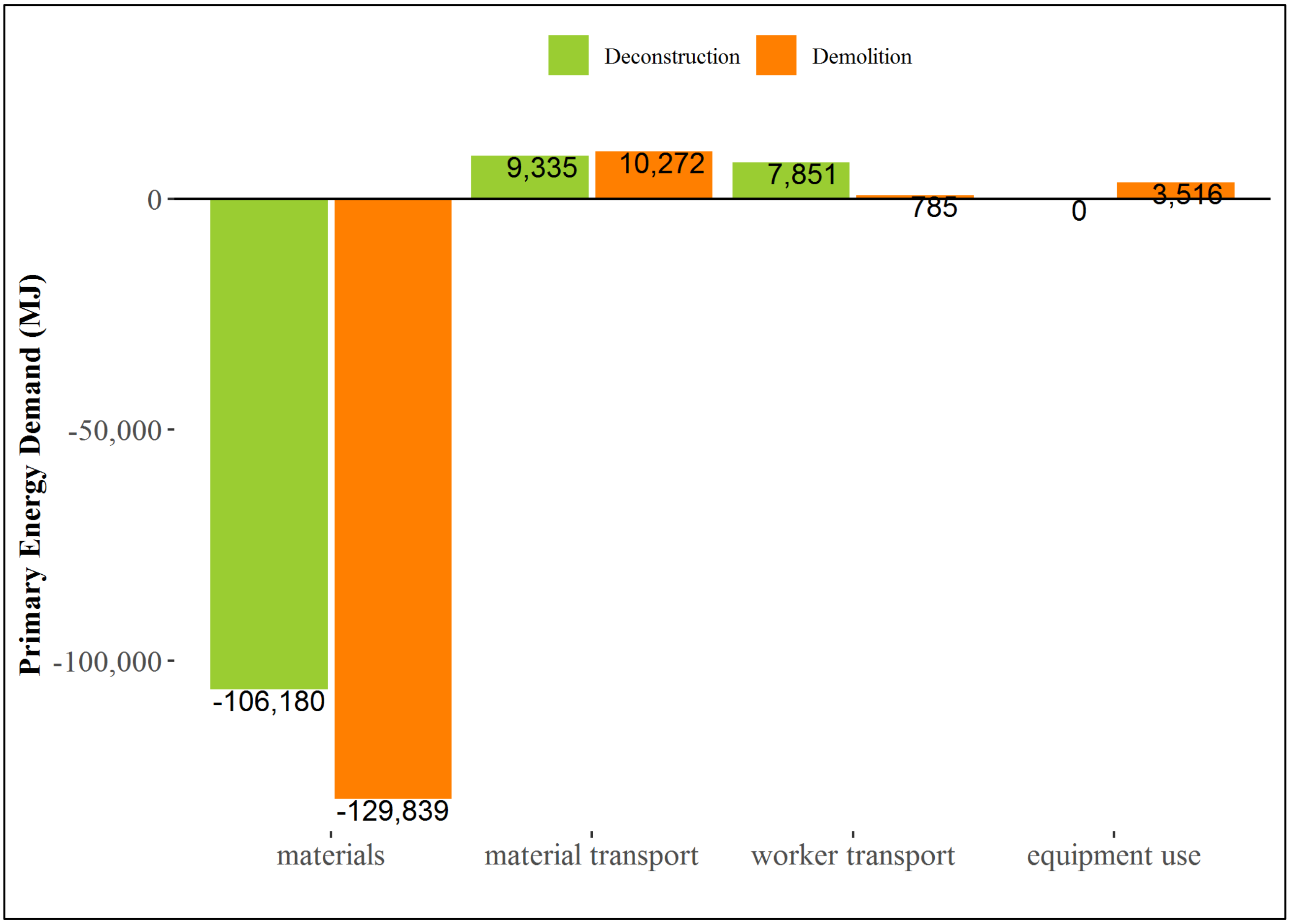

Figure 9. Energy demand per average home by activity (MJ)

Much like the GWP impacts, the energy impacts of the material are by far the largest influence on total results. Material transport makes a small impact to the totals, while the impact of worker transport and equipment use is minimal.

In Figure 10, the total energy demand per average home is shown, with deconstruction saving approximately 89 GJ, and demolition saving 115 GJ.

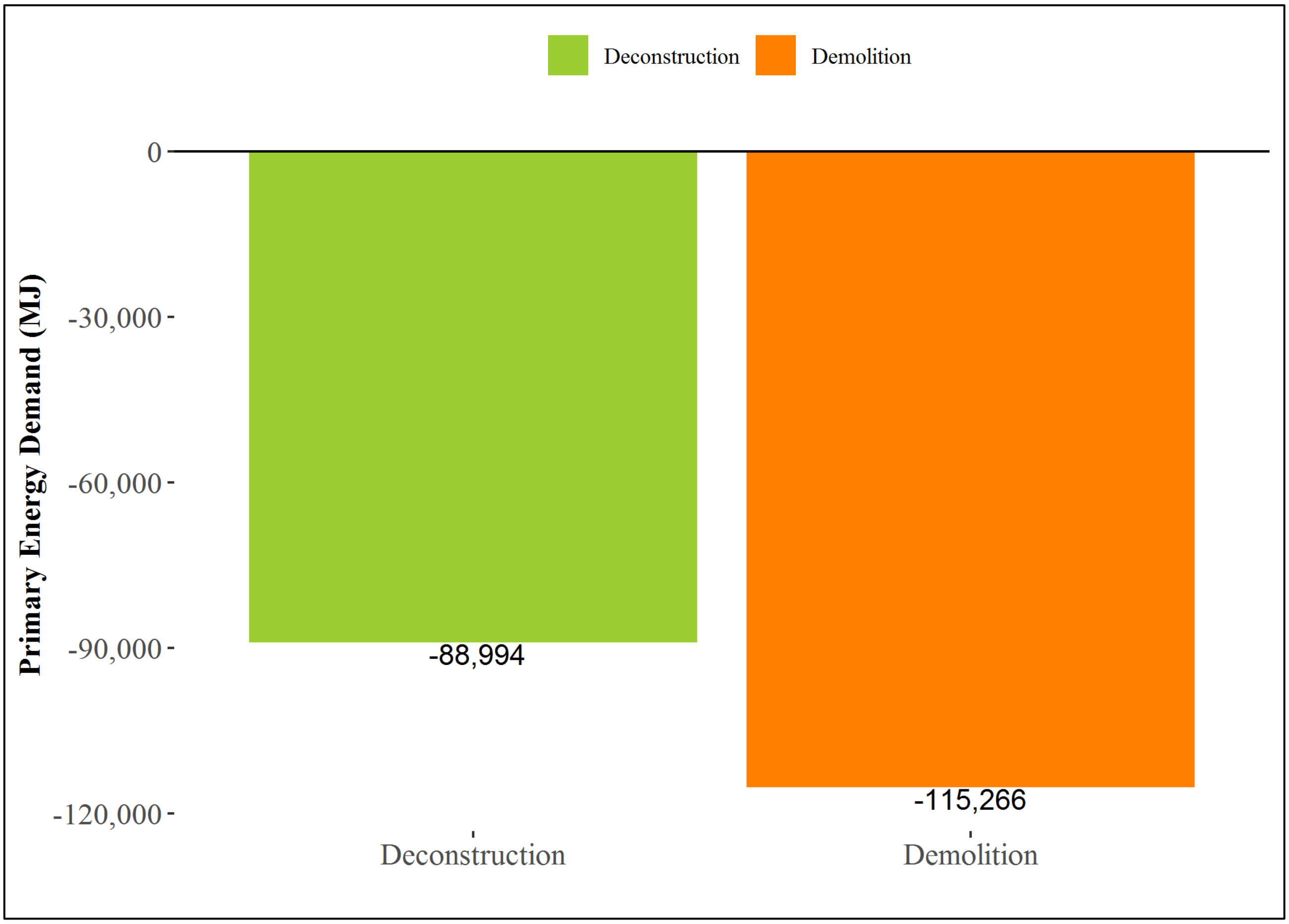

Figure 10: Total energy demand per average home (MJ)

4.2.2 Individual Material Impacts

In this section, the transport and equipment use impacts are excluded from analysis, due to their low contribution to overall impacts. This allows analysis of the GWP and energy contributions of the materials, from removal on site to EOL. In Figure 11, the GWP contributions of each material category are shown. Recoverable wood has the largest negative contribution (benefit) to the GWP of the deconstruction scenario, while it has a much smaller contribution to the GWP of demolition. Both scenarios assume a landfill fate for all painted and treated wood, resulting in identical values for non-recoverable wood. Both scenarios see the benefit of metal recycling, while deconstruction also accounts for reuse of some metal and 'other' materials, resulting in further benefits.

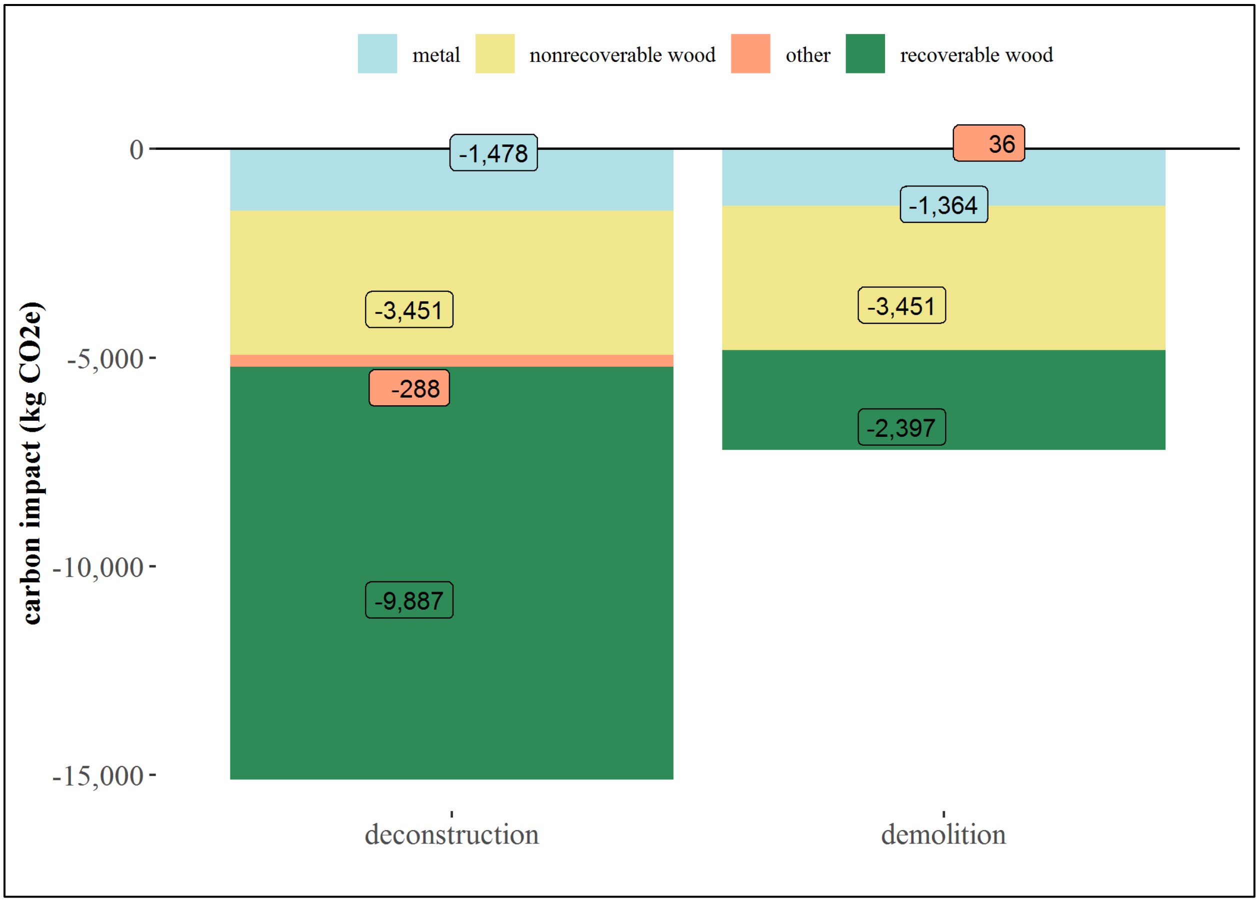

Figure 11: GWP impacts of material categories per average home

Because the largest difference between the two scenarios is in recoverable wood, this material category is split into the impacts of each EOL pathway in Figure 12. This shows more clearly that in the deconstruction scenario less material is incinerated, and more material is reused, which has a greater per-pound carbon benefit than landfilling. The carbon benefit of non-recoverable wood is identical in both scenarios, as all of this material goes to landfill.

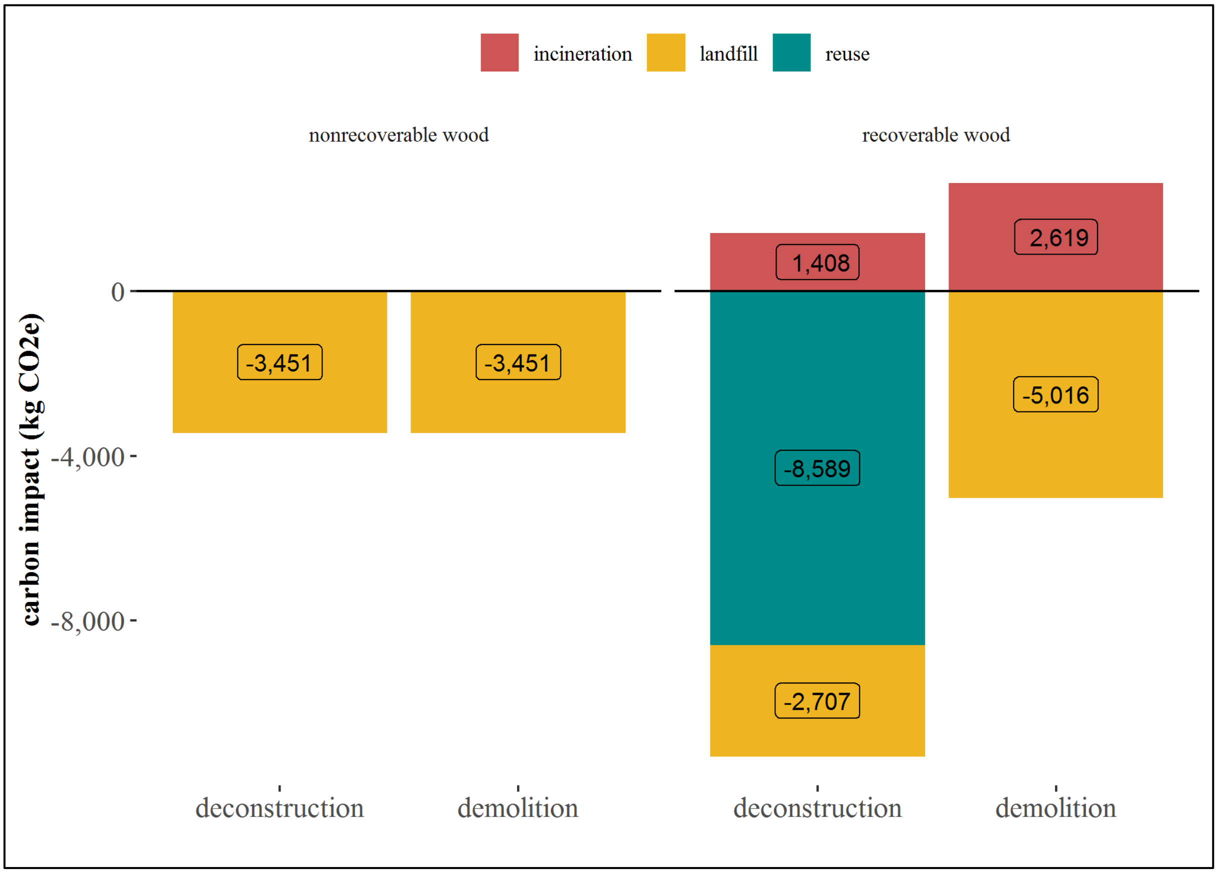

Figure 12: GWP of recoverable wood by end-of-life fate per average home

When looking at energy from each material category, both scenarios see a large benefit from recoverable wood and metal (Figure 13). Metal, while contributing a relatively small amount by weight to the total materials removed, shows a significant energy benefit, through both reuse and recycling. The ‘other’ category shows the benefit of reusing materials such as lights, doors and cabinets from deconstruction, while this material uses energy when it is landfilled from demolition.

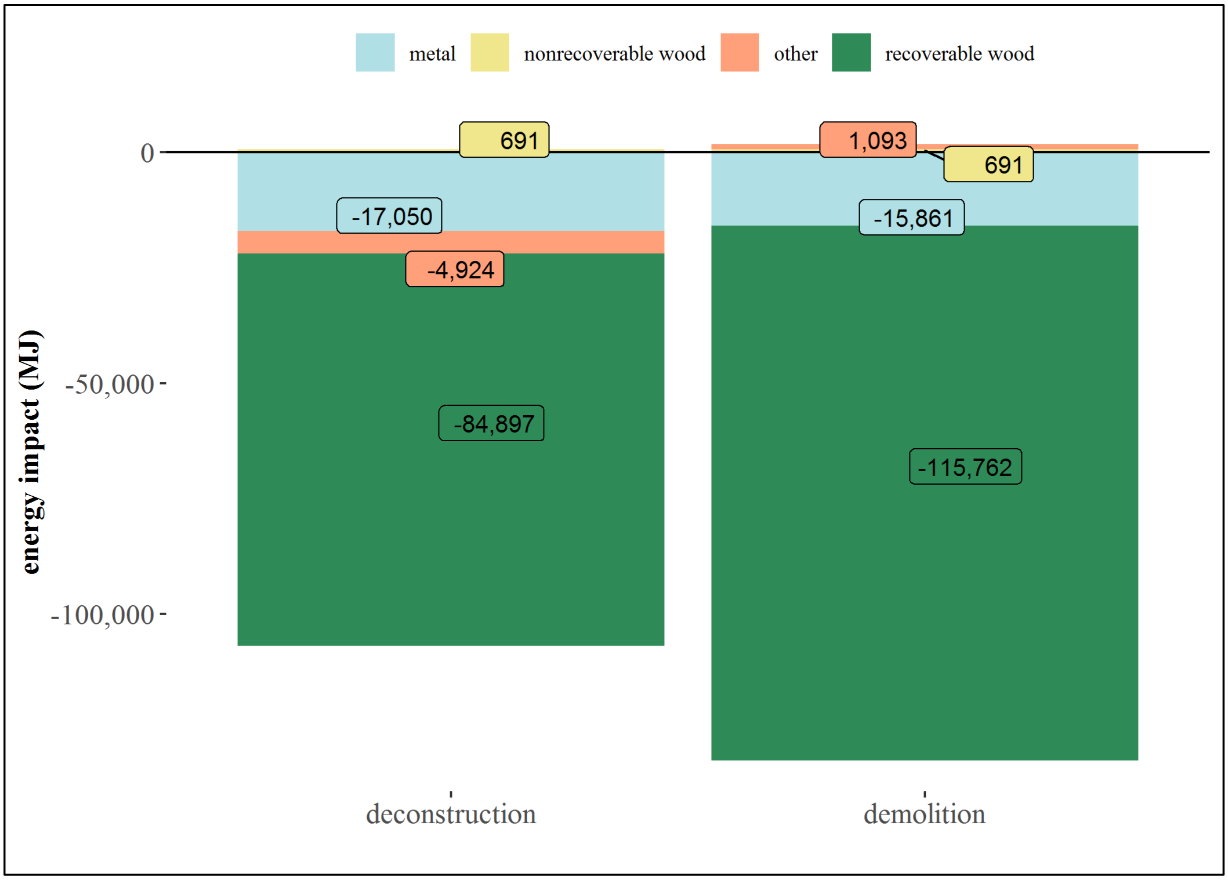

Figure 13: Energy impacts of material categories per average home

To investigate recoverable wood energy impacts further, the energy demand by EOL fate is shown in Figure 14. This shows that while deconstruction and demolition show net benefits, this benefit is achieved in different ways. Deconstruction achieves this benefit through reuse by offsetting the energy impacts of new lumber production and gains even larger benefits when non-salvaged clean wood is sent for energy recovery. The larger quantities of clean wood for energy recovery in the demolition scenario result in a larger benefit for demolition.

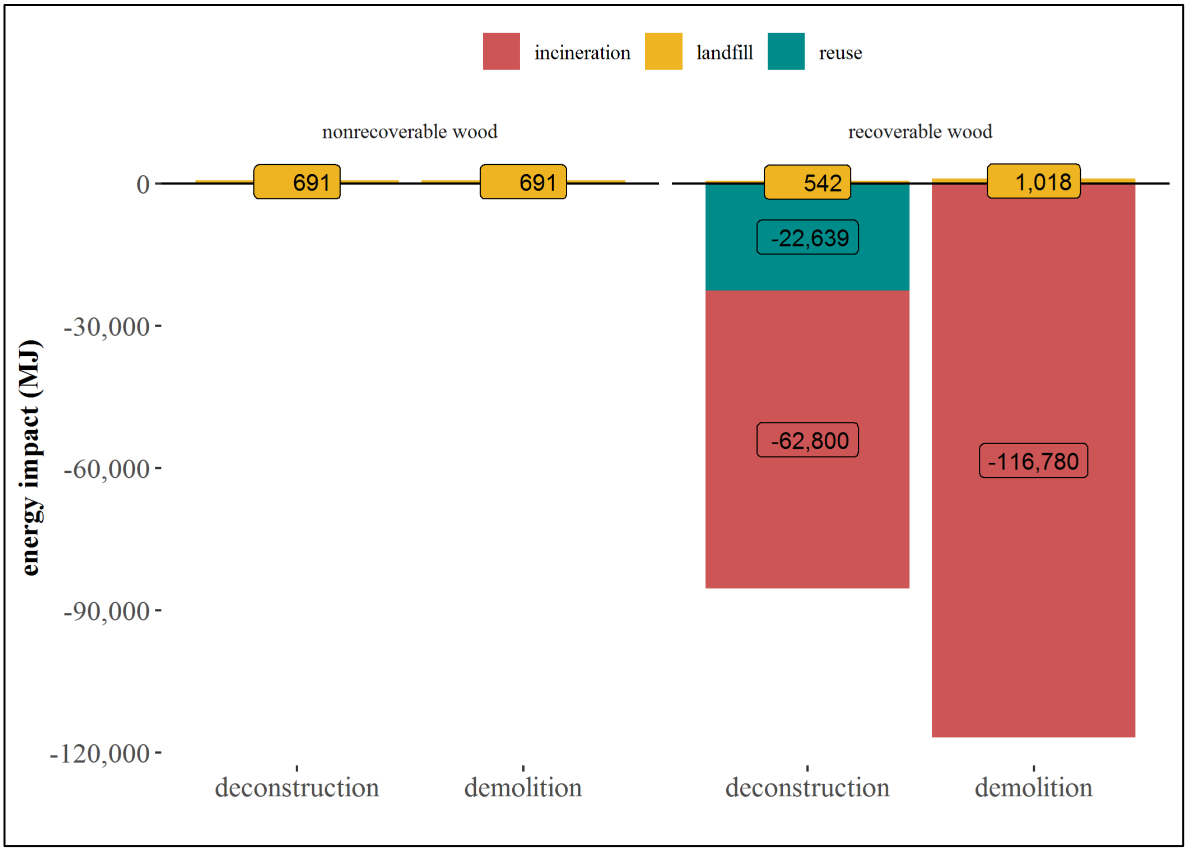

Figure 14: Energy demand of recoverable wood by end-of-life fate

4.3 Sensitivity Analysis

The EOL fate of recoverable wood is the among the most influential factors in this study. Since the wood recovery markets have changed significantly over the last few years (less energy recovery and more landfilling) we've modelled a few scenarios to show the potential market or policy influenced conditions. Tables 11 and 12 below only consider the current market technologies of wood recovery replacing natural gas for process heat applications. Wood to electricity values are not modeled here but the impact factors are presented in Section 2.3.3. The tables show hypothetical scenarios to demonstrate how the EOL fate for recoverable wood changes the results of the study.

Table 11 – Sensitivity analysis for Carbon impacts per average home (kgCO2e)

Scenario	recoverable wood split		Deconstruction	Demolition	Net
	incineration w/ energy recovery	landfill			
Reported	56%	44%	-13,849	-6,170	7,679
30/70 split	30%	70%	-16,102	-10,350	5,752
100% incineration	100%	0%	-10,035	904	10,939
100% landfill	0%	100%	-18,702	-15,173	3,529

Table 12 – Sensitivity analysis for Energy impacts per average home (MJ)

Scenario	recoverable wood split		Deconstruction	Demolition	Net
	incineration w/ energy recovery	landfill			
Reported	56%	44%	-88,994	-115,266	-26,272
30/70 split	30%	70%	-59,517	-60,445	-928
100% incineration	100%	0%	-138,878	-208,041	-69,163
100% landfill	0%	100%	-25,504	2,810	28,314

Tables 12 shows that when reducing energy recovery of wood waste to only 30 percent of the waste stream, demolition and deconstruction provide roughly equal energy benefits. This lower recovery rates scenario may be more realistic for debris arriving in dropboxes and crunched together from residential demolitions. From an energy perspective, the relative benefits of deconstruction increase as more recoverable wood is sent to landfill and decrease when more wood is incinerated for energy recovery.

Table 11 shows that under any EOL fate scenario, deconstruction will always have carbon benefits over demolition. However, the magnitude of those benefits change according to the EOL fate for recoverable wood. Unlike the energy scenarios, the relative benefits of deconstruction decrease as more wood is sent to landfill. This is because landfills store some of the carbon in wood whereas burning for energy recovery has a net carbon impact because the carbon emissions from burning wood for energy exceed the carbon savings from offsetting natural gas use.

4.4 Correlation to House Size and Age

To investigate if there is a correlation between salvage percentage and house size, the weights of salvaged material and material removed by dropbox for each project has been plotted on the scatter plot in Figure 15. The median material weight of each are denoted by the cross-hairs labeled with the median values. Each deconstructed house is represented by a point on the axis where the size of the point corresponds to the square feet size of the house and the color of the point corresponds to the contractor that completed the work. The number labels next to the points are the percentage values of total materials salvaged, calculated as: $\frac{salvage}{salvage+dropbox} * 100$

Features to notice in the scatter plot include no pattern in point sizes and the relative positions on either axis, for example a couple of smaller points appear to yield more salvage material than some larger points. Color-based point differentiation by contractor reveals some clustering around the percent salvage value labels. No clear trends are visible between dropbox quantity and house size. Instead, it is clear that certain contractors are more able to salvage larger quantities of material per house.

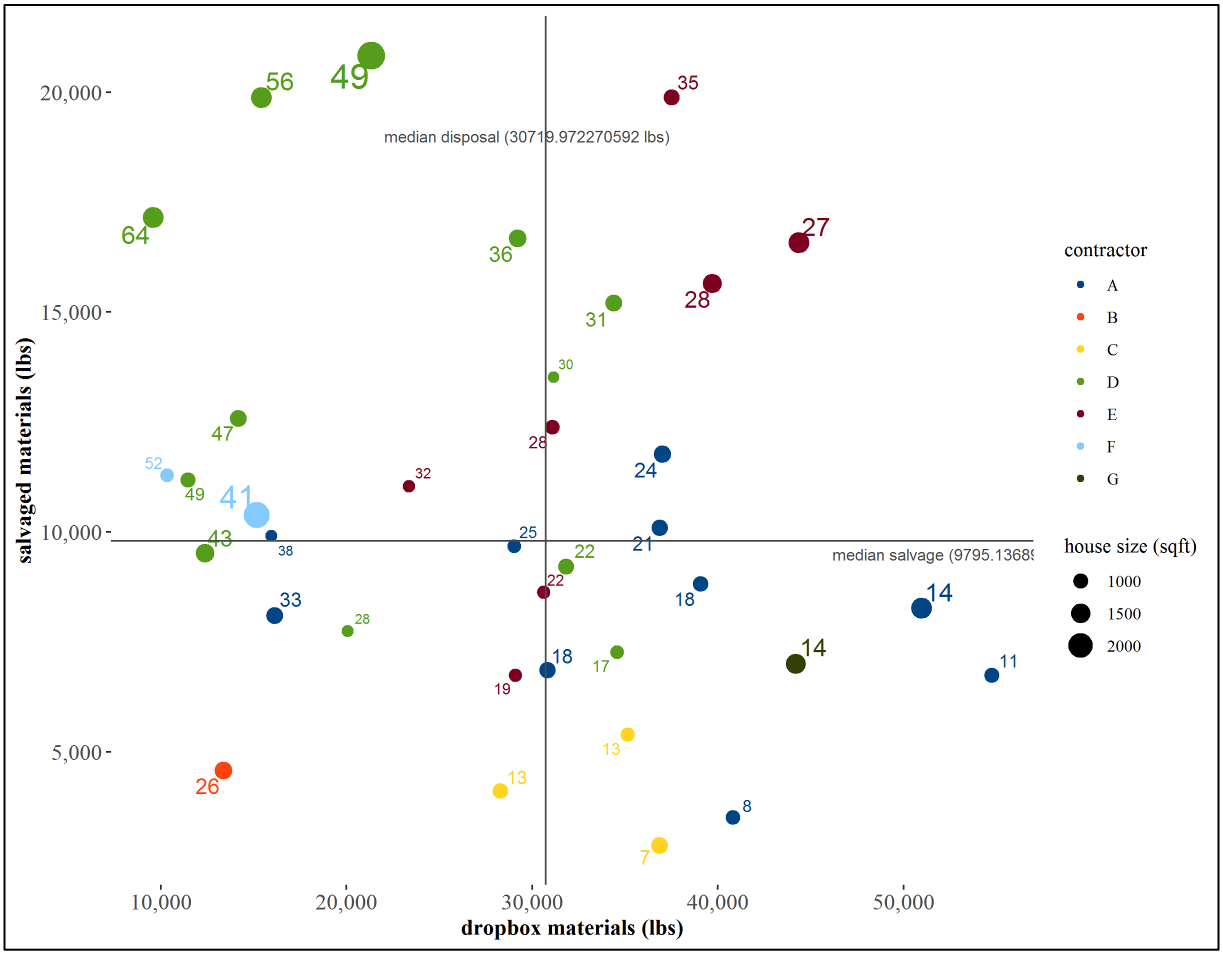

Figure 15: Weight of salvaged and dropbox material by deconstruction project. Each deconstruction contractor is represented by a different color.

A statistical correlation analysis found that there is no correlation (r = 0.1) between salvage quantity and house age, and only a weak correlation (r = 0.41) between salvage quantity and house size. Further statistical analysis can be found in Appendix B.

5. Discussion and Interpretation

5.1 City-Scale Impacts

City of Portland data shows that since the ordinance, about 100 single-family homes per year are being deconstructed instead of demolished. With a net carbon reduction per home of 7.6 metric tons of CO_2eq over demolition, this equates to a roughly 760 metric tons per year of CO_2eq benefit. According to the EPA greenhouse gas equivalencies calculator, this is the same as removing 161 cars from the road for one year, or preventing the use of about 85,000 gallons of gasoline[4].

5.2 Policy Implications

While approximately 100 single-family houses are deconstructed in Portland each year, there are an average of 344 total residential demolition permits issued per year (using the average of the last five years). If all 344 houses were to be deconstructed, the total annual benefit would be 2,614 metric tons of CO_2eq saved per year. This could help the City of Portland meet its future climate and waste recovery goals. Given reduced markets for recycling and energy recovery, salvaging materials for reuse may increasingly become a preferred strategy in managing materials associated with building removal.

5.3 Variation in Salvage Quantities

No correlation was found between house age and salvaged material quantities, and only a weak correlation was found between house size and salvaged material quantities. The strongest correlation was between contractors and the percentage of material salvaged from their projects. When looking at the salvage rate among the more experienced contractors, rates were as high as 37% salvage by weight. Additionally, a few contractors averaged a net carbon benefit on their projects around 10 MT kgCO2e per average home, an increase from the 7.6 MT kgCO2e savings per average home from the whole sample of 36 homes. This suggests that a more mature market may yield slightly higher salvage rates and carbon benefits per average home. This will a valuable metric to monitor as the City of Portland's program continues to collect material salvage quantities.

The experience of the contractor is just one of many potential factors affecting salvage quantities. It is possible that some contractors took on projects in which there was little salvageable material. This could be houses in poor condition, newer houses with fewer architectural details and more mixed materials, or some other factor such as multiple layers of asphalt roofing that added significantly to the disposal weight. Some variance in salvage rates could be attributed to variance in reporting formats. For example, a few contractors provided very detailed salvage inventory forms for every project and include basic details of all fixtures whether sold or donated. Other contractors are inconsistent in reporting quantity and material details from project to project.

Another consideration is that the 36 homes analyzed in this study were the first 36 homes through the program after the City's Deconstruction ordinance took effect. As mentioned before, this is another reason to evaluate the program again once the workforce and salvage market mature. Overall, however, the average home results presented in this study are a good representation of the variety of conditions encountered in a population of homes.

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[4] https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

5.4 Reuse

Reuse is a complex issue, both from a practical standpoint and in terms of assessment of environmental impact. In this study, it was assumed that all of the clean lumber was used, and offset the production of new lumber. In reality, much of this material is available in smaller quantities, and can have non-standard dimensions. Despite Oregon residential building code allowing the use of reclaimed lumber in new construction, a strong market for contractors buying this material for new construction (framing) does not yet exist. This market is expected to develop as deconstruction becomes more common. In the meantime, much of this lumber may actually be used for decorative and other non-structural uses where the aesthetics of reclaimed old-growth lumber offer value. When salvaged lumber is being used for decorative purposes, it is still displacing the production of a material. The material being displaced, however, has considerable uncertainty compared to a “one to one” structural framing displacement scenario.

Another issue not strongly considered in this study is ‘bad reuse’. This refers to reuse of components and materials that have negative overall environmental effects. For example, reusing single-pane windows would result in a window well below current energy efficiency requirements in the building code. Reusing doors coated in lead-based paint could have health impacts, and reuse of older energy-inefficient appliances and furnaces would result in extra electricity and natural gas consumption. These effects on the results of this study are expected to be low, due to the fact that windows and doors make up a very small proportion of salvaged materials, painted and treated wood is landfilled, and appliances were not included in the scope.

5.5 Other Impact Categories

The scope of this study was limited to two impact categories – global warming potential (carbon), and primary energy demand. Although the results are not comprehensive, the carbon and energy results of this study are quite similar to past DEQ research on deconstruction (Oregon DEQ, 2010). This past research, which used models instead of actual measurements from deconstructed homes, showed very comparable carbon and energy results, which suggests it can be used as a proxy for estimating other environmental impacts. Using information from the past study, results indicate that deconstruction and reuse have even larger benefits in other impact categories like eutrophication, smog creation and human/ecological health endpoints.

Deconstruction may have other benefits not quantified in this study. Local contractors have noted that deconstruction allows then to identify and abate asbestos more effectively. In fact, one local contractor tracked that additional asbestos containing materials was identified and abated in approximately 50 percent of their projects after the initial asbestos survey and abatement was complete. During deconstruction, layers of materials are often removed to reveal an older layer of materials underneath. Flooring is a common example of a multi-layer material. Deconstruction allows the identification and abatement of asbestos containing materials that may have otherwise not been identified or abated in the initial survey for traditional mechanical demolitions.

Deconstruction is also a recommended practice in the Oregon Health Authority and DEQ’s recent January 2018 publication on *Best Practices for the Demolition of Residences with Lead-Based Paint* (Oregon Health Authority, 2018). Deconstruction, if done according to best practices, has the potential to reduce fugitive dust caused by mechanical demolition.

6. Limitations

6.1 Data Quality

Deconstruction and demolition sites are fast-moving sites – as the saying goes, "time is money". This fact alone makes accurate reporting of all materials coming from the site very difficult. The raw data in this study relies on the accuracy of reports and receipts from contractors, as no third party was present to verify quantities. Compounding this, old houses have quirks, old timber has varying dimensions, and houses can contain materials spanning many generations. Even so, every attempt has been made to ensure accuracy of the material quantities from this project through rigorous data quality checking and exclusion of outliers or unreliable datasets.

Location-specific data has been used wherever possible. Impact factors are primarily from established, documented sources, though some factors are from national (WARM v14) or international (Ecoinvent v2.2 GaBi v8.7) datasets. In Table 13, a data quality analysis for this project has been completed, with comments.

Table 13: Data quality analysis for this project

Data Component	Quality Level	Corresponding Quality Rating (1=best, 5=worst)	Comments
Technological Representativeness	Very Good	2	Actual deconstruction process is represented. Demolition is assumed based on local observations and conversations.
Geographical Representativeness	Good	3	Material and EOL pathway data is from Portland. Impact factors from EPA WARM and Ecoinvent data are for U.S. and Europe, respectively. GaBi US datasets were used.
Time-related Representativeness	Excellent	1	Actual contractor data from 2016-2017 used.
Completeness	Very Good	2	Actual quantities reported by contractors, with receipts as evidence. Some assumptions and material conversions required.
Precision/Uncertainty	Good	3	Material quantities in dropboxes estimated in broad categories, and many assumptions made for salvage material weights per unit and density.
Methodological completeness and consistency	Good	3	Used system boundary and techniques from Life Cycle Assessment, and data from established databases with limited changes to the carbon accounting in wood products

One limitation of using region-wide C&D waste data is that it is difficult to apply that data to specific situations. Particularly of interest is the split between clean wood recovered for energy use and clean wood landfilled. Transfer stations have hand-sorting lines for all waste, but still the 56 percent/44 percent split of recovered/landfilled wood waste will come from a mix of clean, wood-only loads, and mixed loads. It may be that deconstructed waste is easier to separate as it has been removed by hand, while waste from a mechanical demolition site will have been crushed by heavy machinery. Unfortunately, the exact amount of wood recovered for energy from a mixed dropbox load from each scenario is unknown.

Dropbox composition is another source of uncertainty that could be improved upon with a more detailed measurement of material weights in dropboxes from both deconstruction and demolition sites.

7. Conclusions

Material quantity data from 36 manual deconstruction projects of single-family homes in the City of Portland was analyzed to measure the carbon and energy impacts. The analysis resulted in the following conclusions:

- The sample of 36 homes had an average age of 112 years and average size of 1,177 square feet.
- The average deconstruction of a single-family home in Portland, Oregon yielded 39,362 pounds of material (excluding foundation), of which 10,587 pounds (27 percent) was salvaged. The vast majority of salvaged material by weight was softwood lumber, in the form of framing lumber, structural beams, and sheathing (shiplap on walls and plank subfloor). This material made up over 85 percent of the total weight of salvaged materials.
- The average deconstructed home has net carbon benefit of approximately 7.6 metric tons of CO_2eq per house compared to demolition. The carbon benefits are mainly attributed to the avoided production of new materials and the continued sequestration of biogenic carbon in the wood.
- Landfilling wood does result in a benefit for carbon storage but reuse of wood yields a benefit almost twice as large.
- When considering biogenic carbon as an emissions source and sink, burning wood for energy emits more carbon than it offsets when replacing natural gas as a fuel in industrial boilers.
- Although the end-of-life fate of recoverable wood greatly influenced the relative carbon benefits of the deconstruction scenario, sensitivity analyses revealed that deconstruction will always have a carbon benefit over demolition even with extreme swings in the market for recoverable wood.
- Results are less clear when looking at primary energy demand. The average deconstructed home showed an energy benefit of 89 GJ, while demolition showed a benefit of 115 GJ, a difference of 26 GJ. Based on DEQ surveys of recovered and disposed materials, much of the clean recoverable wood (56 percent) is used as a fuel that offsets natural gas use in industrial boilers regionally. This pathway yields a large energy credit, which is contrasted by this pathway being a net emitter of carbon.
- For energy impacts, the rate of wood incineration for energy recovery, which offsets the use of natural gas, highly influenced the results. A decrease in the wood recovery rate from the current 56 percent to 30 percent would make the energy benefits of both the deconstruction and demolition scenarios approximately equal.
- Material transport, worker transport and equipment use on site were analyzed in detail. Results indicate that the impacts were inconsequential compared to much larger impacts of material reuse, recovery, and disposal.
- There was no correlation between salvage quantity and house age. Correlation with house age could become more pronounced if deconstruction is applied to newer houses that contain lower quality/value material and are physically more challenging to deconstruct due to adhesives.
- Although there was little correlation between the quantity of material salvaged and house size the study did find that salvage quantities were more closely tied with specific contractors, indicating

some contractors were able to salvage a higher percentage of material per house. Among more experienced contractors, salvaged rates were as high as 37 percent by weight and yielded a net carbon benefit as high as 10 MT CO2e/average home. As the deconstruction industry matures, we may see average salvage rates rise slightly. However, on a population-scale of homes, this study represents a good snapshot of the environmental implications of a deconstruction policy for single-family homes.

8. Recommendations for Future Work

Recommendations for future work are primarily related to improving reporting and data quality and expanding the analysis to additional environmental and human health impact factors. Cleaning and sorting the data for this project was a time-consuming process, as was making assumptions about the composition of dropboxes. A way to improve this could be to engage a person to be on-site while deconstruction is happening, specifically to measure, describe and photograph the material. This would result in more accurate numbers, as well as improved transparency and reporting.

The results of this study showed that the majority of carbon and energy impacts were from the materials, depending on their EOL fate. Further research into the specific fates of materials from deconstruction and demolition sites would help to improve accuracy of results. From a policy perspective, completing a second phase of this study after the deconstruction market is more mature may be helpful to see if salvage rates and impacts change over time.

Finally, an investigation into the reused materials market would give insight into the true amounts of material being reused, what it is used for, and what that material is replacing. This latter point is a challenging issue, and more data would help to provide evidence for the system boundary expansion used in this study.

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Appendix A: Material Assumptions

1 Unless contractor specifies a hardwood species in the receipt line item, all dimensional lumber is assumed to be softwood (fir, pine, cedar, redwood, hemlock)

2 Unless contractor specifies a softwood species (fir, pine) in the receipt line item, all wood flooring is assumed to be hardwood

3 Wood flooring specified as fir is categorized as softwood lumber

4 Wood products specified as fir or other softwood variety are categorized as softwood lumber regardless of dimension

5 All light fixtures are assumed to be the same

6 All plumbing fixtures not specified as cast iron, steel, or fiberglass are assumed to be ceramics, except bathtubs, which are assumed to be fiberglass unless specified otherwise

7 Unless specified otherwise, all pipe and ducting is assumed to be made of steel

8 Doors without specification are assumed to be solid wood interior doors

9 Windows without specification are assumed to be single pane wood windows

10 All windows are assumed to be 12 square feet in area with 3'x 4' frame dimensions

11 Default weights for doors and fixtures are based on measurements of available stock in reuse stores in Portland, OR

12 All fractions of pounds for metal and lineal, board, or square feet for wood & finish materials are rounded to the nearest whole unit (lb or linear foot/board foot/square foot) where <0.5 is rounded down and ≥0.5 is rounded up

13 Cabinets specified as salvaged where quantity & type information is missing are assumed to be thee linear feet of lower cabinet

14 Where quantity information is missing for salvage fixtures (lights, plumbing, etc), it is assumed that there is only 1 (count) of the default type

15 All dropbox tickets are reported in short tons: 2000 lbs = 1 ton = 907.185 kg

16 Appliances (including furnaces) and furniture (which includes medicine cabinets and ‘built-in shelving’ not specified as wood in linear feet, square feet, board feed or lbs) are not included in the raw data summary

Table 2: Material assumptions used in this project

Description	Assigned Material Name	Value	Units
tub	fiberglass tub	60	lbs
sink	fiberglass tub	10	lbs
tub	cast iron	300	lbs
sink	cast iron	50	lbs
angle iron	cast iron	222.85	kg per cu_ft
toilet	ceramics	100	lbs
sink	ceramics	20	lbs
tile (box)	ceramics	50	lbs
sink	steel product	10	lbs
screen door	steel product	15	lbs
garage door	steel product	250	lbs
security door	steel product	100	lbs
window bars	steel product	50	lbs
metal post	steel product	50	lbs
hardware	steel product	5	lbs
railing	steel product	25	lbs
vent	steel product	5	lbs
gutter	steel product	5	lbs
grab bar	steel product	5	lbs
tub	steel product	75	lbs
corrugated sheetmetal	steel product	1	lbs per sq_ft
carpet	carpeting	2	lbs per sq_ft
plywood	plywood	2.5	lbs per sq_ft per inch thickness
osb	osb	2.75	lbs per sq_ft per inch thickness
lath	softwood lumber	18.4	lbs per bundle
flooring (sq_ft)	softwood lumber	0.083333	ft thickness
porch corbels	softwood lumber	5	lbs
newel post	softwood lumber	10	lbs
banister	softwood lumber	20	lbs
column	softwood lumber	50	lbs
mantel	softwood lumber	100	lbs
bench	hardwood lumber	100	lbs
grate	hardwood lumber	5	lbs

flooring (sq_ft)	hardwood flooring	0.083333	ft thickness
steps	hardwood flooring	0.25	cu_ft per 12x36x1_inch step
doors	outer door (solid wood)	46.83	kg per door
doors	inner door (solid wood)	23.26	kg per door
doors	inner door (hollow wood)	18.29	kg per door
windows	window (single wood)	19.518	kg per (3'x4' = 12sq_ft) window
windows	window (double wood)	26.2764	kg per (3'x4' = 12sq_ft) window
windows	window (double vinyl)	29.3652	kg per (3'x4' = 12sq_ft) window
cabinets	cabinets (lower)	15.27	kg per lineal ft
cabinets	cabinets (upper short)	8.21	kg per lineal ft
cabinets	cabinets (upper long)	11.08	kg per lineal ft
light fixtures	light fixture	5	lbs per fixture
softwood lumber	softwood lumber	530.7	kg per cubic meter
hardwood lumber	hardwood lumber	770	kg per cubic meter

Appendix B: Additional Figures and Tables

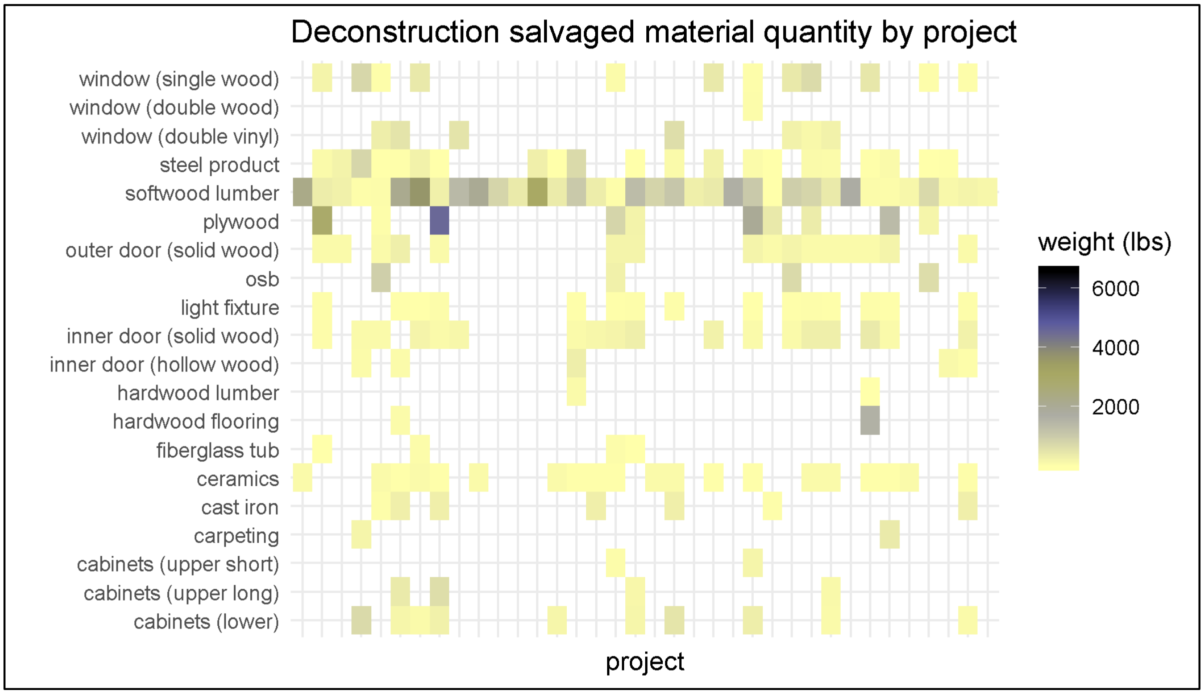

Figure 16: Heat map diagram of material quantities salvaged from each project

Detailed breakout of the total material weight by the specific material types on each project, showing larger yield with increasing color intensity. The greatest single material quantity from any project was one project that reported ~1700 kg of plywood, while the greatest yield of any material from each project was in the Softwood lumber category (which is mostly framing wood and some fir flooring).

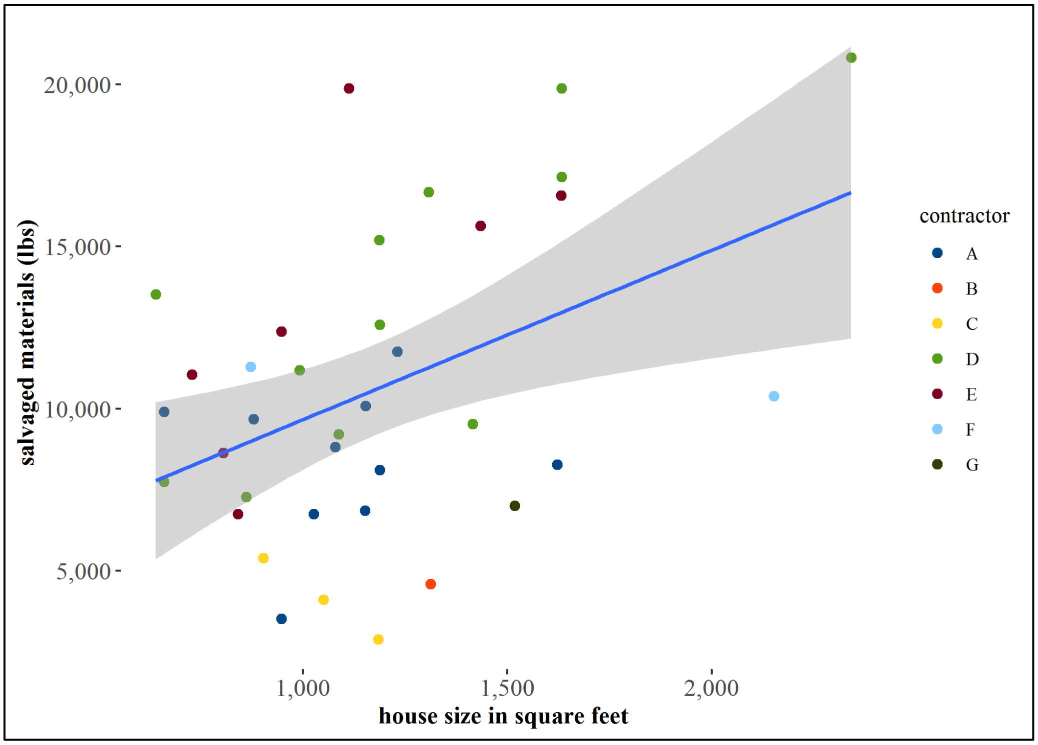

Figure 17: Correlation of material salvaged (lbs) by house size (square feet)

Slight positive trend in kg of salvage materials with increasing house size, but still only a modest correlation (0.4).

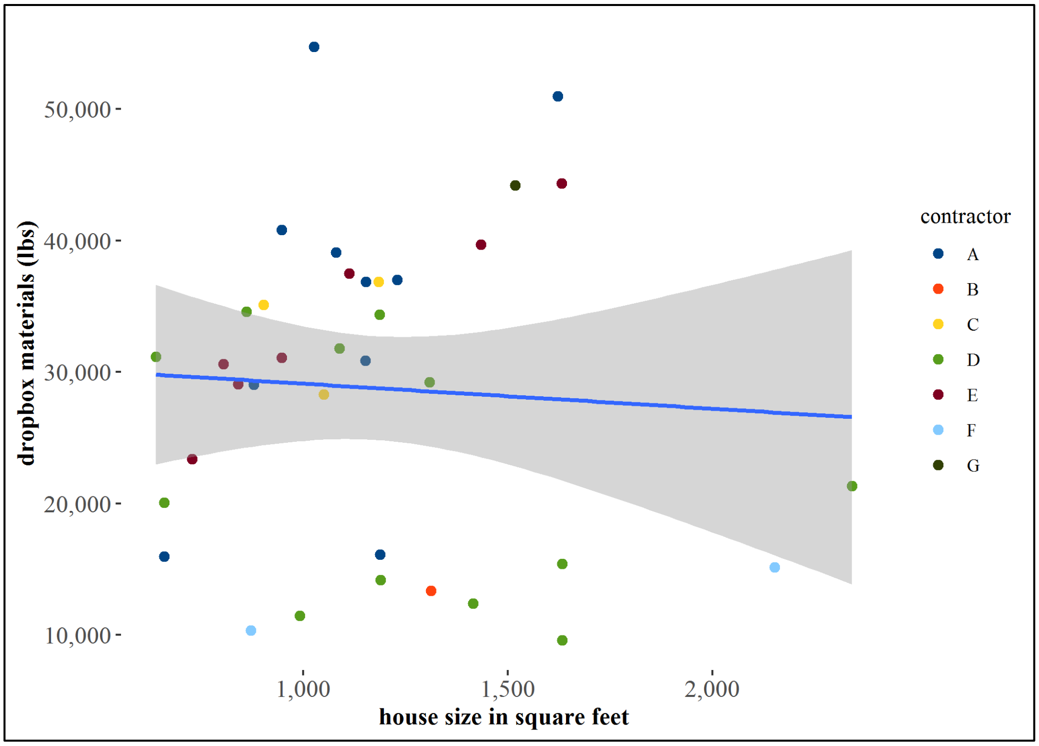

Figure 18: Correlation of materials removed by dropbox (lbs) by house size in square feet

Nearly flat (indicating no correlation) trend in disposal quantity over house size. Note, in both salvage and disposal quantity, the confidence band is nearly 3x larger than the width of the band nearer to the median values

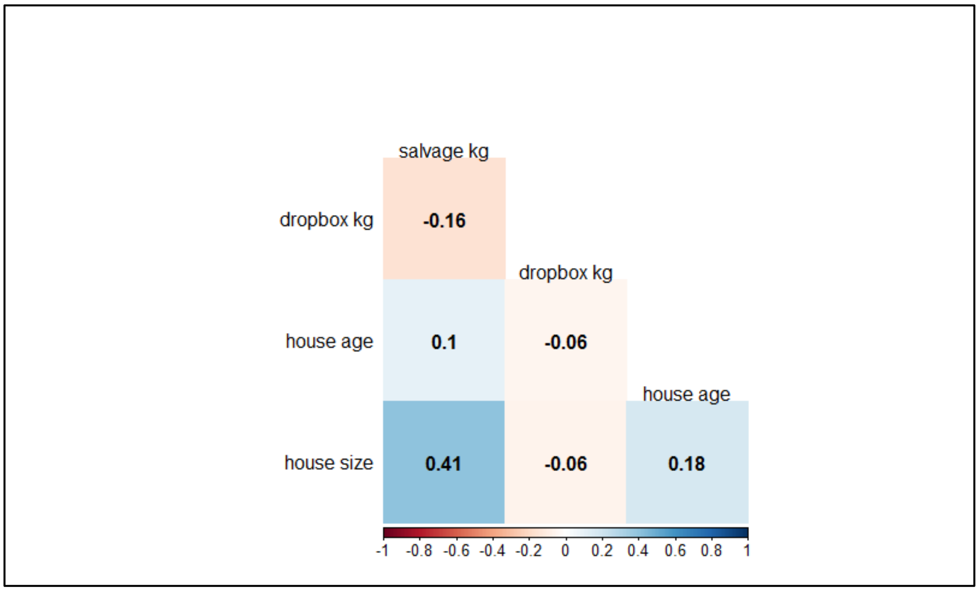

Figure 19: Correlations of salvage and dropbox quantities by house size and age