DOI
https://doi.org/
10.18690/um.fkkt.1.2025.14

ISBN
978-961-286-959-5

THE CARBON FOOTPRINT OF DIFFERENT CONSTRUCTION AND DEMOLITION WASTE MANAGEMENT METHODS

JANEZ TURK,[1] PATRICIJA OSTRUH,[1] ANJA KODRIČ,[1]
TAJDA POTRČ OBRECHT[2]

[1] Slovenian National Building and Civil Engineering Institute, Ljubljana, Slovenia
janez.turk@zag.si, patricija.ostruh@zag.si, anja.kodric@zag.si
[2] Graz University of Technology, Graz, Austria
tajda.obrecht@tugraz.at

End-of-life management with three CDW fractions are considered in this study: wood, steel, and broken concrete. The goal of the study is to evaluate the Global Warming Potential (GWP) of different end-of-life management approaches and to benchmark the circular approaches versus the linear approaches. In the case of waste wood, the circular scenario refers to wood recycling and the production of recycled particle board or glue-laminated timber. Waste wood landfilling and the production of particle board/glue-laminated timber from primary wood are considered in the linear scenario. Considering the production of particle board, the circular scenario shows 4 times lower GWP than the linear scenario. Considering the production of glue-laminated timber, the circular scenario shows comparable GWP as the linear scenario. In the case of waste steel, the GWP of two circular scenarios were compared; recycling versus reuse. The reuse scenario shows around 8 times lower GWP than the recycling. In the case of waste concrete, the circular scenario refers to the recycling of broken concrete into recycled aggregate. The linear scenario includes the landfilling of waste concrete and the production of natural aggregate. LCA results show around 2 times lower impact on GWP in the case of the circular scenario.

Keywords:
LCA,
Global Warming Potential,
concrete,
steel,
wood

University of Maribor Press

1 Introduction

Construction and Demolition Wastes (CDWs) pose significant environmental challenges, accounting for nearly half of all solid waste sent to landfills worldwide. In the European Union, this share is lower, but still around 38% (Tonini et al., 2023). Moreover, CDWs are among the heaviest and most voluminous waste streams, which is just one of the concerns relating to their landfilling (Zhang et al., 2020). Other concerns refer to problems such as resource efficiency and climate change, the latter is indirectly related to carbon embodied in CDW (Liu et al., 2023).

Construction and demolition waste (CDW) consists of various materials such as concrete, bricks, tiles, plaster, timber, wood, glass, metals, plastic, stones, and others. Given its high potential for recycling or reuse, the European Commission has prioritized CDW as a key waste stream. The waste hierarchy serves as a framework for managing materials at the end of their life cycle, focusing on preserving their economic value in the market wherever feasible and environmentally acceptable. This approach prioritizes waste prevention above all else, followed by re-use, recycling, recovery, and disposal (landfilling) – the latter considered the least favorable option (Stahel and MacArthur, 2019; Kabirifar et al., 2020).

The goal of this study is to compare the environmental performance of different end-of-life management practices for selected fractions of CDW: wood, steel, and broken concrete. Only global warming potential (known also as carbon footprint) was considered in the comparative analysis. Special attention was given to the comparison of linear circular versus linear end-of-life management practices.

2 Material and methods

2.1 Life Cycle Assessment (LCA)

End-of-life (EoL) management practices for selected fractions of CDW are benchmarked with Life Cycle Assessment (LCA) method. This method is commonly used comparatively in order to find among different options the most environmentally sustainable solutions, for instance regarding waste management (Guinée et al., 2002). The end-of-life management scenarios were compared in terms of the impact on global warming potential (GWP), known also as carbon footprint, expressed in kg CO_2 equivalents. "LCA for experts" professional tool was applied to conduct LCA and to calculate GWPs.

The functional unit in this study refers to the end-of-life management with 1 tone of specific CDW fraction.

Demolition of the building and generation of CDW fractions are not considered in the system boundaries, considering the "cut-off" approach (Potrč Obrecht, 2021). System boundaries of the circular end-of-life management scenarios include processes related to recycling and the production of new products with recycled content. In the case of steel, system boundaries include processes related to reuse. In the case of linear end-of-life management scenarios, processes related to landfilling are included as well as the processes related to the production of products based on primary materials. These products are a functional equivalent to the same products from recycled materials, considered in the system boundaries of the circular end-of-life management scenarios. Transport of waste fractions to the recycling facility or to the landfill is also considered.

2.2 Wood

The most common linear end-of-life management of wood is incineration. Two circular scenarios were taken into account to make a comparison with the linear scenario; the first one is the recycling of waste wood into wood chips, which is further used in the process of particle board production. In the case of the linear scenario, system expansion was considered, which means that the linear scenario includes not only the incineration of waste wood but also the production of particle board from primary wood. Such particle board from primary wood is a functional equivalent of particle board from recycled wood. Life cycle inventory data for the production of particle boards were taken from Hossain and Poon (2018).

The second circular scenario considered in this study is the production of glue-laminated timber from waste wood. For environmental comparison with the linear scenario, system expansion was conducted in the latter scenario; e.g. production of glue-laminated timber from primary wood was accounted to incineration of waste wood. Life cycle inventory data were gathered from the paper of Risse et al (2019).

2.3 Steel

Considering end-of-life management with steel recovered from CDW, recycling is a common end-of-life practice. Steel is a completely recyclable material. It can be continuously recycled without losing its quality or properties (Broadbent, 2016). Some steel components (claddings, beams, columns) recovered from demolished buildings can be reused (Tonini et al., 2023). Both recycling and reuse are circular end-of-life management practices. Landfilling as a linear approach is not practiced, because steel is a valuable and fully recyclable material. Life cycle inventory data for recycling and reusing steel components were taken from the literature (Andersen et al., 2022).

2.4 Broken concrete

The linear end-of-life practice for broken concrete is landfilling. A typical circular end-of-life practice of broken concrete is recycling at a stationary or mobile recycling plant to produce recycled aggregate, which can be used for road construction or even for concrete production – depending on the purity of raw material and consequent quality of produced recycled aggregate (Gruhler and Schiller, 2023). In the case of the linear scenario related to landfilling, system expansion includes the production of natural aggregate in a quarry as a functional equivalent of recycled aggregate produced in a circular scenario. Life cycle inventory data for recycling of broken concrete were taken from the study of Gruhler and Schiller (2023).

3 Results and discussion

3.1 GWP of end-of-life wood

The linear scenario, which considers not only the incineration of EoL wood but also the production of particle board from primary wood, shows a significantly higher impact on GWP than the circular scenario, which deals with the recycling of EoL wood to woodchips and their further utilization in the process of particle board production. GHG emissions associated with incineration of waste wood predominate. For this reason, the linear scenario shows around 4 times higher impact on GWP than the circular scenario (Table 1). In the comparative LCA analysis, credits related to heat production during waste wood incineration (e.g., benefits beyond the system boundary) are accounted for.

The GWP of particle board produced from EoL wood and the GWP of particle board produced from primary wood are also compared. The one produced from EoL wood yields a lower impact. Both particle boards contain similar amounts of biogenic carbon, contributing to the mitigation of GWP. Hower, biogenic carbon was excluded from LCA, due to so so-called carbon-neutral approach. The lifecycle emissions of CO_2 from bio-based products are offset by equivalent CO_2 absorption during biomass growth. From this point of view, the uptake and release of biogenic CO_2 can be omitted from the LCA (Hoxha et al., 2020).

Excluding biogenic carbon storage in the final product, particle boards produced from primary wood show almost 50% higher impact on the GWP than particle boards produced from EoL wood. Production of primary wood as a raw material is directly related to deforestation, e.g. cutting down trees, which is the main reason for the higher GWP of the particle board produced from primary wood.

Recycling EoL wood to glue-laminated timber shows a relatively low yield considering the literature data; e.g. only 26%. However, the yield (or recycling rate) depends on the contamination of the EoL wood with preservatives. Mechanical cleaning of the surfaces results in a significant share of rejects (shavings, off-cuts) and a relatively low recycling rate (Risse et al., 2019). However, when using primary wood to produce glue-laminated timber, the yield is much higher; 77% considering the literature data (Risse et al., 2019). However, a similar amount of energy is consumed in the production process of glue-laminated timber from the same amount of raw materials whether EoL wood or primary wood. For these reasons, glue-laminated timber produced from EoL wood shows higher GWP than glue-laminated timber produced from primary wood; the difference is around a factor of 6. Accounting credits associated with heat production during the incineration of shavings and off-cuts (e.g. benefits beyond system boundary), the difference in GWP between two benchmarked glue-laminated timbers is reduced to 1 versus 4.5, still in favor of glue-laminated timber produced from EoL wood. A greater amount of shavings and off-cuts is generated when using EoL wood as a raw material. The incineration of rejected parts (shavings, off-cuts) is associated with heat recovery, which results in the reduction of GWP.

When accounting incineration of EoL wood to the linear scenario, in addition to the production of glue-laminated timber from primary wood as a functional equivalent of glue-laminated timber from EoL wood in the circular scenario, the difference in GWP between the two scenarios becomes minor. It is 1 versus 1.2 in favor of the circular scenario (Table 1). The incineration of the EoL wood in the linear scenario is the main contributor to the GWP, making the linear approach relatively less sustainable regarding GWP.

3.2 GWP of end-of-life steel

Recycling of EoL steel takes place in an electric arc furnace (EAF). A 100% recycling rate was assumed in this study. Considering the reuse scenario, it was also assumed that the EoL steel component is completely reusable. The reuse includes sandblasting, landfilling of removed paint, and adding a new protective layer. LCA results showed that reuse yields around 8 times lower impact on GWP than recycling (Table 1). However, the GWP of the reuse is influenced by the surface area of the steel component. The larger the surface area per certain mass of the steel component, the more energy is required for the sandblasting and the higher the GWP.

3.3 GWP of broken concrete

LCA results show that processing pure broken concrete at a recycling plant into recycled aggregate results in a similar impact on GWP as the production of natural aggregate in a quarry. The difference in GWP is in the range of data uncertainty.

When accounting for the landfilling of pure broken concrete alongside the production of natural aggregate in a linear scenario, the difference between the two scenarios becomes significant. The linear scenario shows a double GWP impact compared to the circular scenario (Table 1). Landfilling of broken concrete is associated with the use of machinery (compactor), and the use of sealing materials, causing additional impact on GWP.

Table 1: Global warming potential of benchmarked end-of-life management scenarios, considering wood, steel, and broken concrete

	EoL wood	EoL steel	EoL broken concrete
Circular scenario (recycling)	341* / 803**	542	5.5
Circular scenario (reuse)	-	70	-
Linear scenario	1333* / 1000**	-	10.4

* considering the production of particle board

** considering the production of glue-laminated timber

4 Conclusions

The environmental benefits of circular end-of-life management practices were confirmed compared to linear end-of-life management practices for selected CDW fractions; e.g. broken concrete and waste wood. In the case of the recovered steel component, the reuse was confirmed to yield significantly lower environmental impact than recycling. Attention was given to Global Warming Potential (carbon footprint) expressed in kg of emissions equivalent to CO_2. Further research should consider other CDW fractions and evaluate additional environmental impacts, especially the abiotic depletion of minerals and metals. This is related to another crucial aspect of the circular economy, such as resource efficiency.

Acknowledgments

The research was conducted within the scope of the CirCon4Climate project, financed by the European Climate Initiative (EUKI) of the German Federal Ministry for Economic Affairs and Climate Action. Part of the research was financially supported by the Slovenian Research and Innovation Agency (research core funding No. P2-0273).

References

Andersen, R., Stokbro Ravn, A., Walbech Ryberg, M. (2022). Environmental benefits of applying selective demolition to buildings: A case study of the reuse of façade steel cladding. *Resources, Conservation and Recycling 184,* 106430. https://doi.org/10.1016/j.resconrec.2022.106430.

Broadbent, C. (2016). Steel's recyclability: demonstrating the benefits of recycling steel to achieve a circular economy. *Int J Life Cycle Assess, 21,* 1658–1665, https://doi.org/10.1007/s11367-016-1081-1

Gruhler, K., Schiller, G. (2023). Grey energy impact of building material recycling – a new assessment method based on process chains. *Resources, Conservation & Recycling Advances 18,* 200139, https://doi.org/10.1016/j.rcradv.2023.200139.

Guinée, J.B., Gorrée, M., Heijungs, R., Huppes, G., Kleijn, R., Koning, A. de, Oers, L. van, Wegener Sleeswijk, A., Suh, S., Udo de Haes, H.A., Bruijn, H. de, Duin, R. van, Huijbregts, M.A.J. (2002). Handbook on life cycle assessment. Operational guide to the ISO standards. I: LCA in perspective. IIa: Guide. IIb: Operational annex. III: Scientific background. Kluwer Academic Publishers, ISBN 1-4020-0228-9, Dordrecht, 692 pp.

Hossain, M.U., Poon, C.S. (2018). Comparative LCA of wood waste management strategies generated from building construction activities. *Journal of Cleaner Production 177,* 387-397.

Hoxha, E., Passer, A., Saade, M.R.M., Trigaux, D., Shuttleworth, A., Pittau, F., Allacker, K., Habert, G. (2020). Biogenic carbon in buildings: a critical overview of LCA methods. *Buildings and Cities, 1(1),* 504–524. https://doi.org/10.5334/bc.46.

Kabirifar, K., Mojtahedi, M., Wang, C., Tam, V. W. Y. (2020). Construction and demolition waste management contributing factors coupled with reduce, reuse, and recycle strategies for effective waste management: A review. *Journal of Cleaner Production, 263,* 121265. https://doi.org/10.1016/j.jclepro.2020.121265

Liu, J., Li, Y., Wang, Z. (2023). The potential for carbon reduction in construction waste sorting: A dynamic simulation. *Energy, 275,* 127477, https://doi.org/10.1016/j.energy.2023.127477

Potrč Obrecht, T., Jordan, S., Legat, A., Ruschi Mendes Saade, M., Passer, A. (2021). An LCA methodolody for assessing the environmental impacts of building components before and after refurbishment. *Journal of Cleaner Production. 327,* 129527, https://doi.org/10.1016/j.jclepro.2021.129527.

Risse, M., Weber-Blaschke, G., Richter, K. (2019). Eco-efficiency analysis of recycling recovered solid wood from construction into laminated timber products. *Science of The Total Environment 661,* 107-119. https://doi.org/10.1016/j.scitotenv.2019.01.117.

Stahel, W. R., MacArthur, E. (2019). The Circular Economy: A User's Guide. DOI:10.4324/9780429259203

Tonini, D., Caro, D., Cristobal, J., Foster, G., Pristera, G. (2023). Techno-economic and environmental assessment of construction and demolition waste management. With a view to support the feasibility assessment of preparation for re-use and recycling targets for individual material fractions. JRC Science for policy report.

Zhang, C., Hu, M., Yang, X., Xicotencatl, B. M., Sprecher, B., Di Maio, F., Zhong, X., Tukker, A. (2020). Upgrading construction and demolition waste management from downcycling to recycling in the Netherlands. *Journal of Cleaner Production, 266.* https://doi.org/10.1016/j.jclepro.2020.121718.