iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 12 Issue: III Month of publication: March 2024

DOI: https://doi.org/10.22214/ijraset.2024.58804

An Assessment of Residential Building Materials Impact on Environment Using BIM through a Case Study Approach

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Abstract: Building construction can result in carbon emissions that have a substantial negative influence on the environment. Studies show that 40% of global Co_2 emissions each year are caused by the built environment and Cement is a widely utilized building ingredient in the construction industry, an essential part of the concrete mix. Approximately 7 % of the carbon emissions in the world are caused by cement. By substituting low-emission and sustainable building materials for those with higher carbon emissions, the building's carbon emissions can be decreased. Using materials that are long-lasting and have low embodied carbon when are sourced ethically. Reduced carbon emissions from construction materials can be achieved in large part by early decision making in AEC phases. In this paper an assessment of residential building materials impact on environment is carried by using BIM and LCA tools and difference in embodied energy is observed by optimizing the building plan.
Keywords: BIM (Building Information Modelling), LCA (Life Cycle Analysis), Global Warming and Embodied energy.

I. INTRODUCTION

In the construction industry, two key concepts are gaining traction for their ability to promote sustainable design and decision-making - **Building Information Modeling (BIM)** and **Life Cycle Assessment (LCA)**. While they serve different purposes, their integration offers significant advantages for environmental impact reduction and overall project success. **BIM** is a technology for creating and managing digital representations of physical buildings. It goes beyond 3D modelling by incorporating rich data about building components, their properties, and relationships. This allows for better collaboration, improved design decision-making, and efficient project execution. **LCA** is a methodology for assessing the environmental impacts of a product or service throughout its entire life cycle, from raw material extraction and manufacturing to use, maintenance, and end-of-life disposal. This holistic approach helps identify potential environmental hotspots and make informed choices for sustainability. Despite these challenges, the construction industry is actively addressing them through standards development, software advancements, and educational initiatives. The future of sustainable design lies in leveraging the power of BIM and LCA together, paving the way for environmentally responsible and efficient building practices.

According to current projections and future developments, the sustainable development process heavily relies on the combination of BIM and LCA.

The construction industry's use of lowemission building materials is crucial to the creation of sustainable designs with minimal carb on emissions. As a result, there is less eutrophication, acidification, global warming, and embodied energy. As discussed above BIM tool – Revit Software is used for the developing of 3D model. Two models were created using Revit with optimization in plan for the area of 1500 m^2. These models are directly integrated with different LCA tools like One Click LCA, Tally and IdeMatLCA.

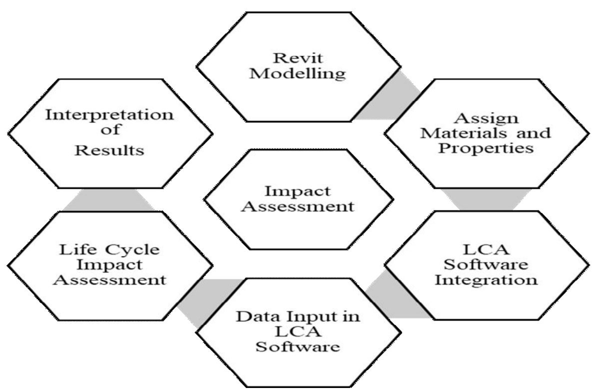
II. LITERATURE REVIEW AND METHODOLOGY

BIM is found to be ideally suited to the delivery of information needed for improved design and building performance. Two most significant benefits of BIM for sustainable building design are: integrated project delivery (IPD) and design optimization. However, there are also barriers to adopting BIM for sustainable design [1] (Wong, K. and Fan, Q, 2013). European governments continuously update their building regulations to optimize the building envelope and energy systems to achieve this during the building use stage, at least in Spain the building regulations do not take into account the impact of emissions resulting from urbanization and construction activities prior to building use [2] (Rodríguez Serrano, A. and Porras Álvarez, S, 2016).

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 12 Issue III Mar 2024- Available at www.ijraset.com

Aiming to investigate the environmental impacts, Life Cycle Assessment (LCA) methodology evaluates products and services showing the similarities and differences in evaluating midpoint and endpoint impact categories [3] (Najjar, M.K. et al, 2019). Digital tools based on Building Information Modelling (BIM) provide the potential to facilitate environmental performance assessments of buildings. Various tools that use a BIM model for automatic quantity take-off as basis for Life Cycle Assessment (LCA) have been developed recently. It describes the first application of such a BIM-LCA tool to evaluate the embodied global warming potential (GWP) throughout the whole design process of a real building [4] (Hollberg, A., Genova, G. and Habert, G, 2020). In the early building design stage, there are numerous uncertainties due to the lack of information on materials and processes. Designers therefore cannot quantify the environmental impacts of buildings in order to evaluate the environmental performance of their designs early on [5] (Rezaei, F., Bulle, C. and Lesage, P, 2019). The study assessed the environmental assessment of the three most used structural systems for residential buildings in the local context (concrete, steel and composite structures). This was compared for four main points: 1) life cycle stages, 2) main building elements, 3) building materials and 4) impact categories [6] (Morsi, D.M.A. et al, 2022). Studies on embodied carbon and carbon emission of construction materials in India are intensively taking place. The Indian infrastructure sector is associated with carbon emission, which is to be immensely optimized to control the carbon emission [7] (Naga Dheeraj Kumar Reddy Chukka, 2022). Despite the apparent simplicity of existing BIM-LCA tools, there is a lack of integration with the main BIM software, and the double-effort of design development and parallel simulations is a barrier to their implementation in the design process. Moreover, simplifications on these tools may provide misleading results to the designer [8] (Lucas Melchiori Pereiral, 2018). The construction industry has become more interested in moving towards implementing an innovative method to reduce wastes and Environmental Impacts (EIs) during the construction stage. Tools and methods represented in different frameworks to estimate construction wastes are limited to the end-of-life stage of building projects. A common method employed for this quantification is Life Cycle Assessment (LCA), which is globally recognized as one of the most complete methods for the environmental impact assessment of buildings [9] (Milad Zoghi & Afshin Khoshandb, 2019).

III. METHODOLOGY



A. *Revit Modelling*

An apartment building of G+5 storey building is modeled with in the area 1500m^2. This model is optimized and another building is modelled. The optimization involves in the number of rooms and its sizes in each floor. The plan and its 3D of building models are tagged below (Fig. 1 & Fig. 2).

Fig. 1 3D Model – 1

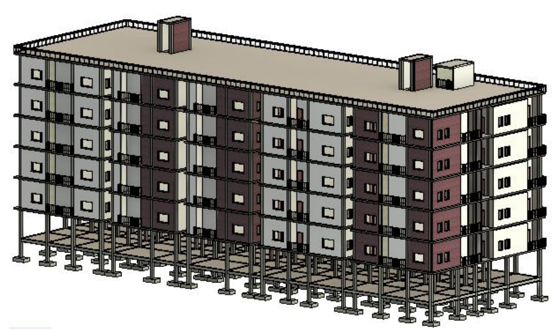


Fig.2 3D Model - 2

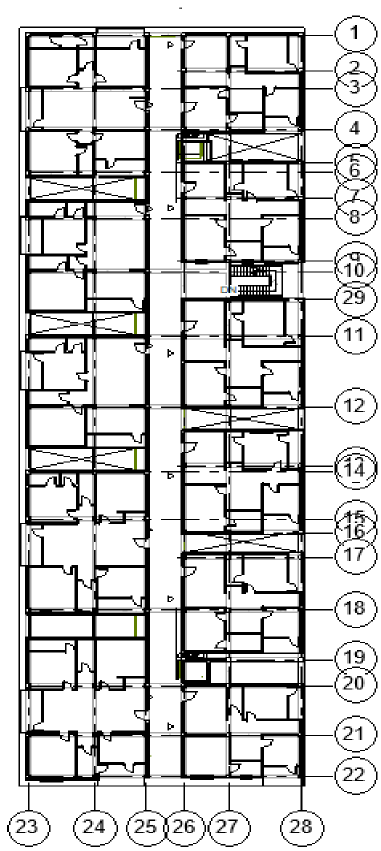


Fig. 3 Plan of the respective Model – 1

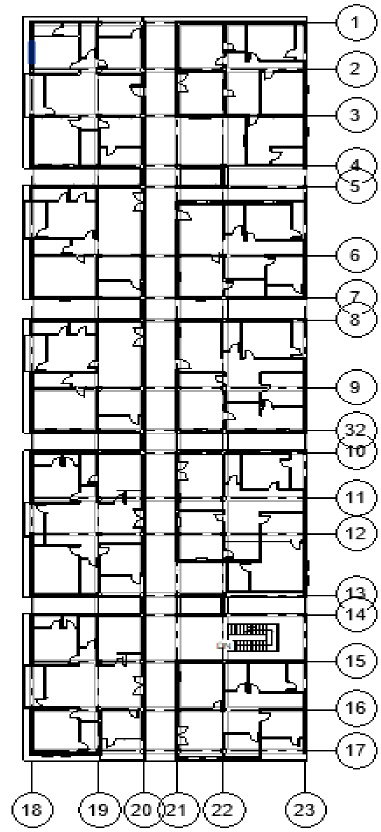


Fig. 4 Plan of the respective Model - 2

B. Assign Materials and Properties

Assign different type of material for each of the element in the two different Models.

C. LCA Software Integration

The Revit model is directly integrated with the available LCA tools like One Click LCA and Tally. One Click LCA is a Comprehensive Life Cycle Assessment (LCA) across all stages of a building's life cycle (materials, construction, operation, end-of-life).

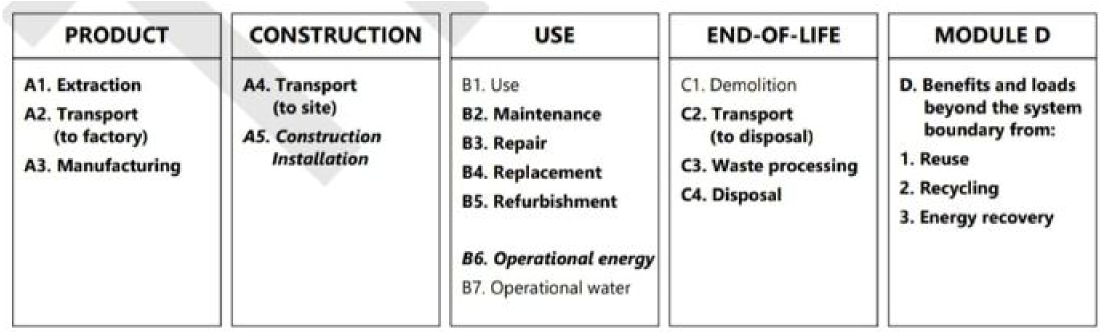
1) Extensive database of Environmental Product Declarations (EPDs) for accurate material assessments.
2) Integration with BIM software for seamless data transfer and early-stage analysis.
3) Advanced features for scenario analysis and reporting.

D. Data Input in LCA Software

After integrating the Revit model to the LCA tool the default materials from the Revit model are directly imported to the LCA tool. If any modifications required in the materials can be modified easily in the LCA cloud data base. The input in the LCA requires the type of materials used for the construction, area of construction and the period of life of a building. The volumes of the different materials used in the Revit modelling is directly imported through add-in. Further change in the volume, quantity and area can be modified for the different types of materials. The volume of the materials of model can either directly imported through Revit or material take off can be identified.

E. Life Cycle Impact Assessment

The life cycle impact is directly calculated by the tool and it gives the detail information of emission of carbons throughout its life cycle stages. The stages involve as Product [A1 – A3], Construction [A4 & A5], Use [B1 – B7], End- Of – Life [C1 – C4] and Module D. The detail information of the stages can be observed below.



F. Interpretation of Results

The LCA results includes Embodied carbon benchmark, Embodied carbon by life cycle stage, Embodied carbon by structure [A1 – A3]. The results are discussed below.

IV. RESULTS AND DISCUSSIONS

After importing the respective data in LCA tools different environmental effecting factors like Global Warming Potential, Acidification Potential, Eutrophication Potential and Embodied energy at different life cycle stages are observed and discussions carried as follows.

A. Embodied Energy

The total amount of energy consumed by a building during its complete life cycle stages is called as embodied energy. The difference can be observed (Fig. 5) in the embodied energy before and after optimizing the model plan.

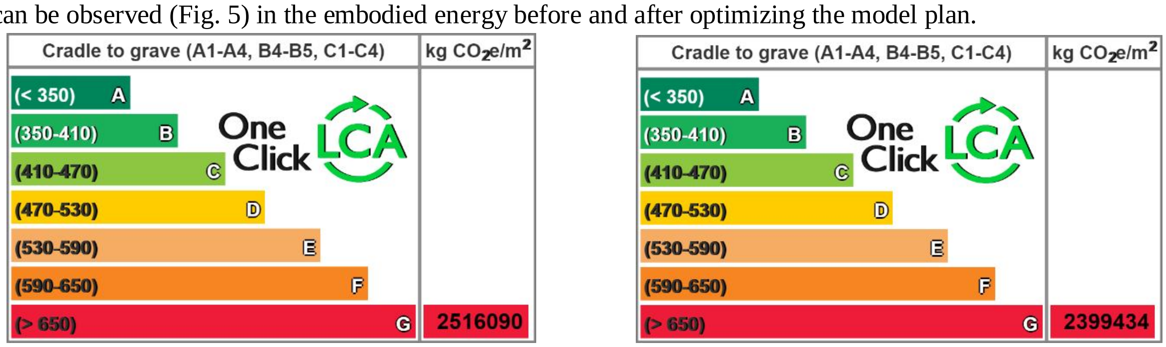


Fig. 5 Embodied carbon benchmark of Model 1 and Model 2.

B. Embodied Carbon by life-cycle Stage

Global warming potential (GWP) is a metric used to compare the ability of different greenhouse gases (Fig 6 & Fig 7) to trap heat in the atmosphere. It is a relative measure, with carbon dioxide (CO_2) being assigned a GWP of 1. This means that any other greenhouse gas with a GWP of 2 will trap twice as much heat as CO_2 over a given period, typically 100 years.

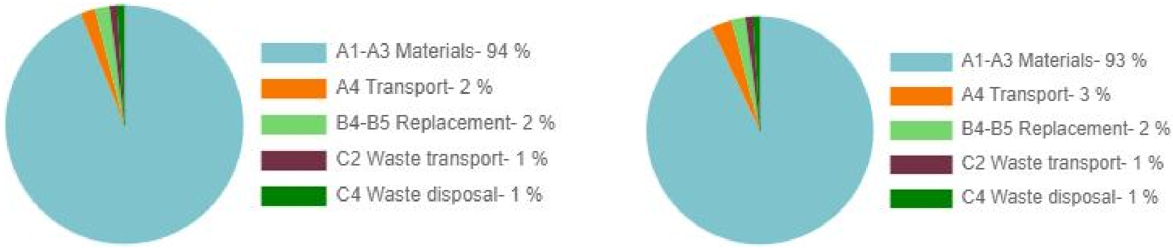


Fig.6 Global Warming Potential

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 12 Issue III Mar 2024- Available at www.ijraset.com

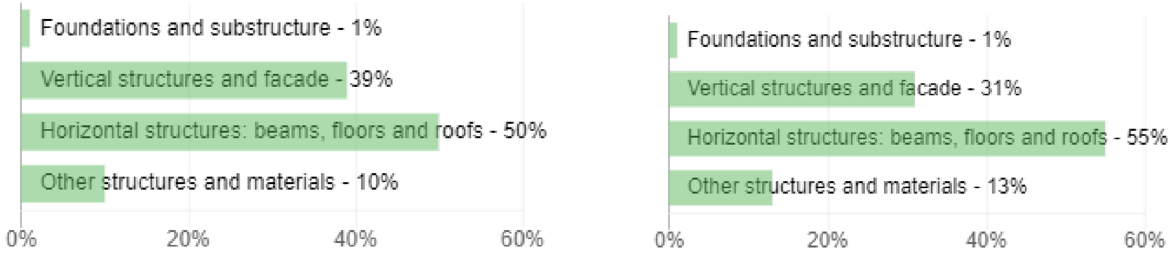


Fig. 7 Embodied carbon by structure - A1-A3

Here is the interpretation of data of carbon emissions that contribute to the environment by means of different resource types. A detail observation can be determined from the below data where different materials in different model contribute carbon that impacts the environment.

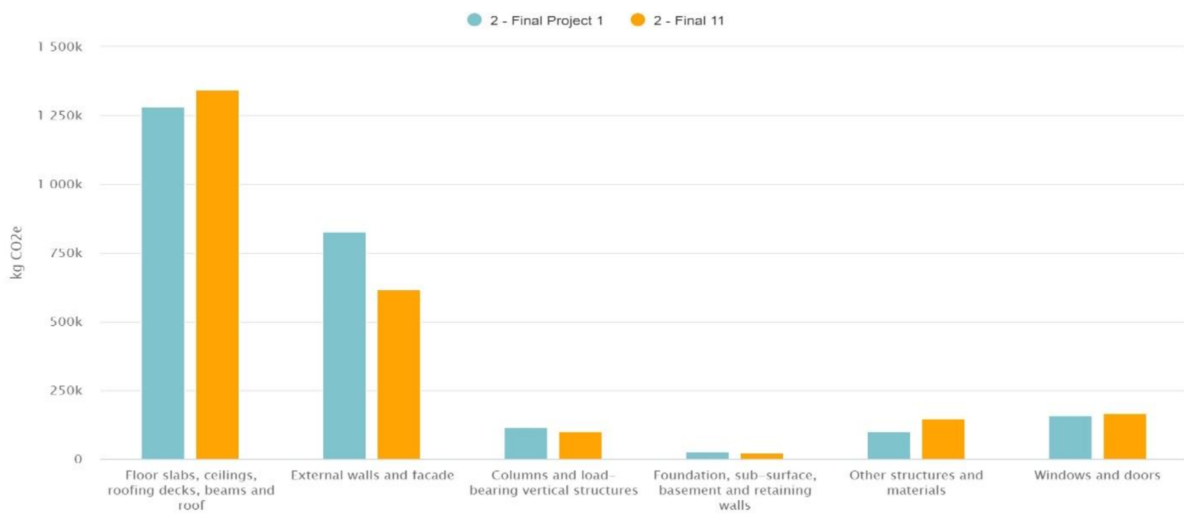


Fig. 8 Impact data analysis of two different designs as per category.

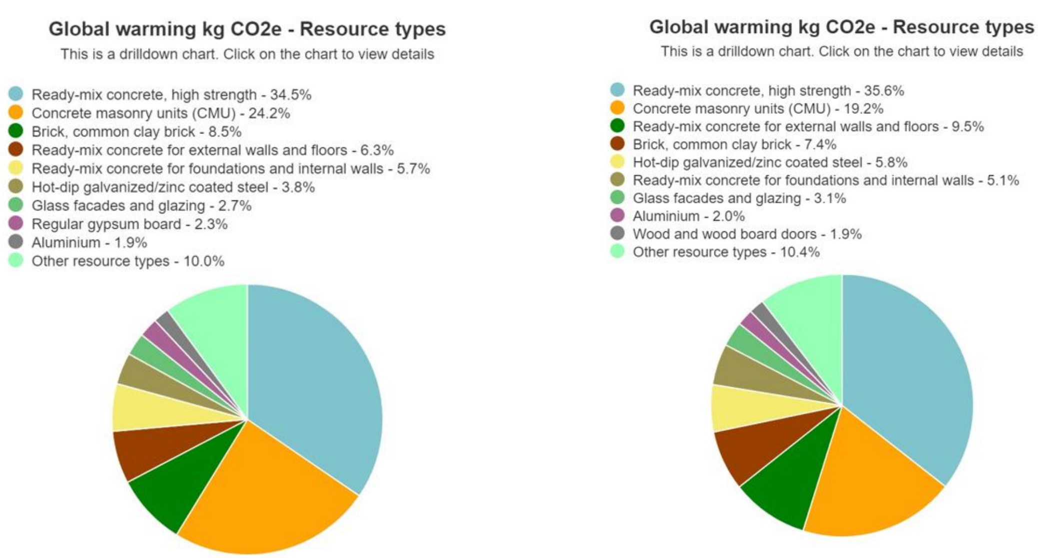


Fig. 9 Global Warming by means of different resource types.

C. A comparison of Sustainable Alternatives for the most contributing materials (Global Warming) in life cycle stages

Once the pertinent data has been imported into the cloud, the database displays the most contributing elements that increase the atmosphere's carbon emissions. The most environmentally friendly substitute materials are used in place of these ones, and the differences in emissions during the course of their life cycles are noted. For more details and an interpretation, see the data representation that follows. It is more frequently recognized that what are the emissions and what kinds of materials can be substituted when the most significant contributor to global warming is replaced with sustainable alternatives. The results is as follows

Data summary

Resource name	Quantity	A1-A3 - Materials (kg CO_2e)	A4 - Transport (kg CO_2e)	B4-B5 - Replacement (kg CO_2e)	C1-C4 - End of life (kg CO_2e)	Financial cost (€)	Financial and carbon cost (€)
Gypsum plasterboard, fire resistant, 15.4x900/1200 mm, 12.7 kg/m2, PROTECT F, GFE/GF15 (Gyproc) - 1.0 m2 ?	1.0 m2	3.2	0.03	3.2	0.07	7	7.47
High density gypsum plasterboard, fire and impact resistant, 15 mm, 15 kg/m2, 1000 kg/m3, MultiStop™ (Knauf India Private Limited) - 1.0 m2 ?	1.0 m2	3.64	0.03	3.64	0.08	6	6.37
Gypsum plasterboard, fire resistant, 15 mm, 14.4 kg/m2, 960 kg/m3, FireBloc™ (Knauf India Private Limited) - 1.0 m2 ?	1.0 m2	3.5	0.03	3.5	0.08	6	6.36

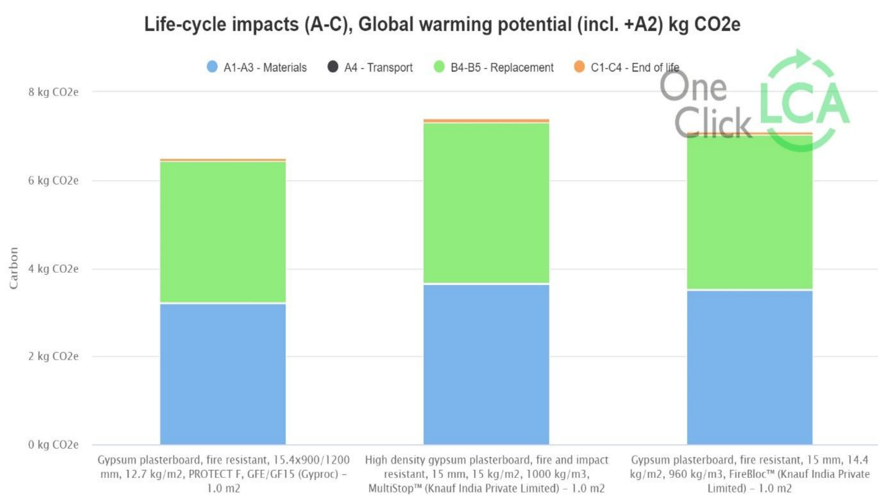


Fig. 10 The emissions in the life cycle stages of high emission contributed material – Alternatives.

D. Alternative Materials and Impact of Window and Door Panels

Data summary

Resource name	Quantity	A1-A3 - Materials (kg CO_2e)	A4 - Transport (kg CO_2e)	B4-B5 - Replacement (kg CO_2e)	C1-C4 - End of life (kg CO_2e)	Financial cost (€)	Financial and carbon cost (€)
Extruded aluminium profiles for window and door frames, generic, 10% recycled content, average world aluminium manufacturing technology (One Click LCA) - 7.8 kg ?	7.8 kg	116.8	0.14	0	0.31	22	0.0
Aluminium alloy wire rod, GRADE 1350 (APAR Industries) - 7.8 kg ?	7.8 kg	60.29	0.14	0	0.31	22	25.05
Aluminium alloy wire rod, GRADE 8176, WG22A236 (APAR Industries) - 7.8 kg ?	7.8 kg	60.92	0.14	0	0.31	22	25.08
Aluminium alloy wire rod, GRADE 6201, WG22A096 (APAR Industries) - 7.8 kg ?	7.8 kg	61.85	0.14	0	0.31	22	25.15
Aluminium conductors, SS 424 08 13, SS 424 08 14, AL59-685 SQ.MM (APAR Industries) - 7.8 kg ?	7.8 kg	63.57	0.14	0	0.31	22	25.19

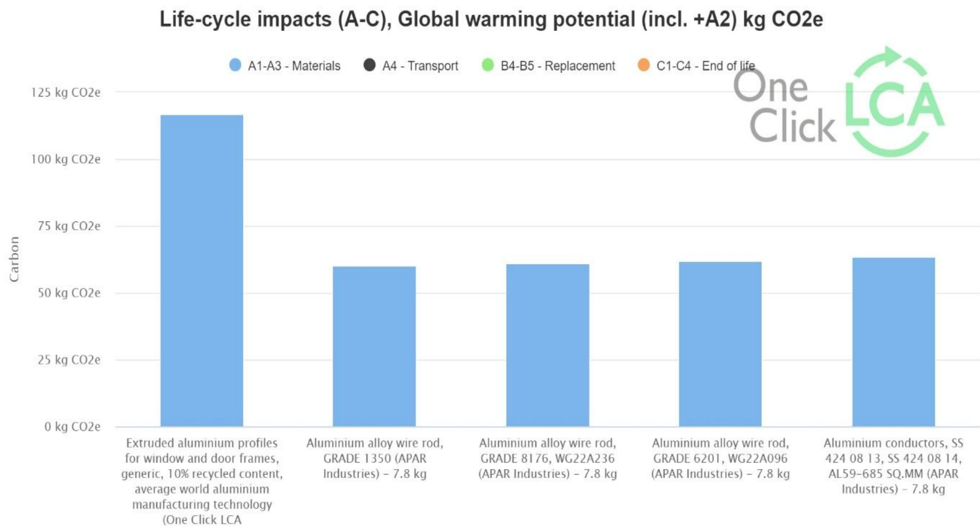


Fig. 11 The alternative materials and their impact – Sustainable alternatives.

E. *Alternative Sustainable materials for Steel*

Data summary

Resource name	Quantity	A1-A3 - Materials (kg CO_2e)	A4 - Transport (kg CO_2e)	B4-B5 - Replacement (kg CO_2e)	C1-C4 - End of life (kg CO_2e)	Financial cost (€)	Financial and carbon cost (€)
Hot dip galvanized steel, 0.73 mm, 5.72 kg/m2 - 5.7 kg ?	5.7 kg	16.3	0.08	0	0.23	7	7.85
Hot dip galvanised steel (World Steel) - 5.7 kg ?	5.7 kg	13.73	0.08	0	0.23	7	7.85

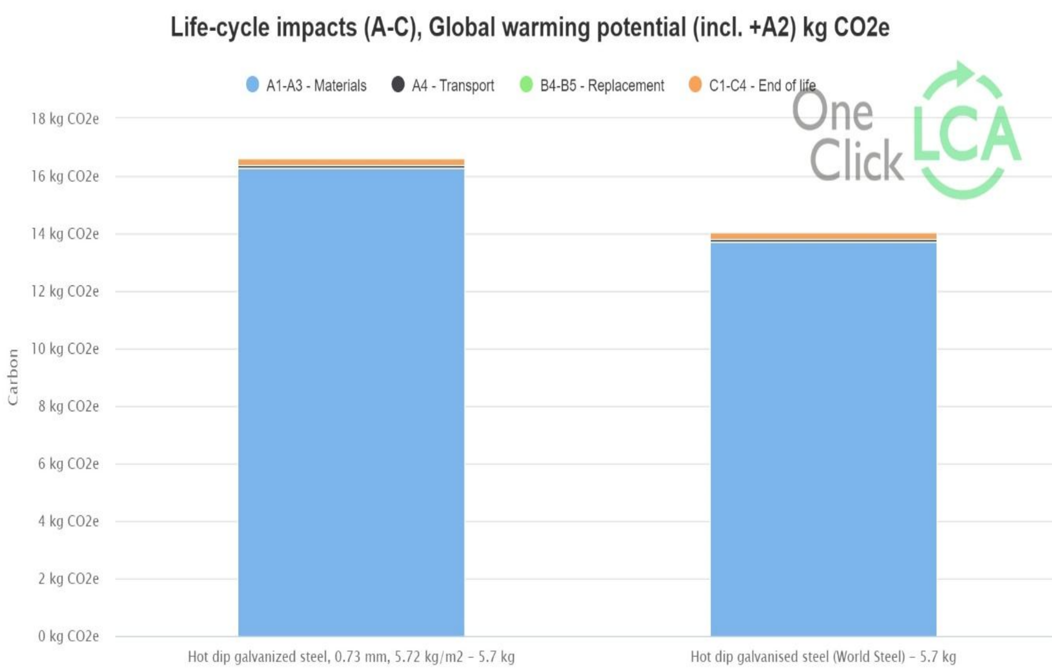


Fig. 12 A detail comparison in emission after replacing with sustainable alternative material.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
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F. Sustainable Alternatives for Insulation

Data summary

Resource name	Quantity	A1-A3 - Materials (kg CO_2e)	A4 - Transport (kg CO_2e)	B4-B5 - Replacement (kg CO_2e)	C1-C4 - End of life (kg CO_2e)	Financial cost (€)	Financial and carbon cost (€)
Rock wool insulation panels, unfaced, generic, L = 0.035 W/mK, R = 2.89 m2K/W (16 ft2°Fh/BTU), 50 kg/m3 (3.12 lbs/ft3) (applicable for densities: 25-50 kg/m3 (1.56-3.12 lbs/ft3)), Lambda=0.0346 W/(m.K) - 0.2 m2 ?	0.2 m2	1.76	0	0	0.01	1	1.09
Rock wool insulation, unfaced, L = 0.035 W/mK, 40 mm, 1.2 kg/m2, 30 kg/m3, Lambda=0.035 W/(m.K), ProRox LF 970 (ROCKWOOL) - 0.2 m2 ?	0.2 m2	0.7	0	0	0	1	1.04

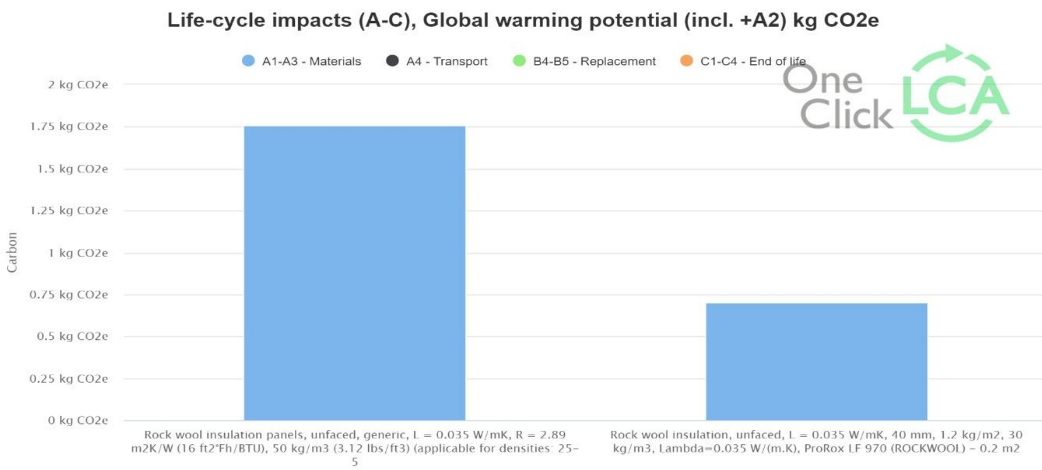

Fig. 13 Emission details after replacing with sustainable alternative material of same category.

After comparing the case studies here, we came to know that when there is an optimization in the plan there is decrease of embodied energy and carbon emissions from its life cycle stages. We can also reduce the emissions by replacing the most sustainable alternatives in the place of most contributing materials as mentioned above. The results and the differences can be observed above.

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