

CARBON-CONSCIOUS MATERIAL SELECTION IN CONSTRUCTION PROJECTS: A LIFE-CYCLE ASSESSMENT APPROACH

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Abstract

The construction sector is under growing pressure to cut greenhouse gas (GHG) emissions without compromising project cost, quality, functionality, and delivery goals. Selection of materials is an important aspect of project management decisions because of the environmental impacts that construction materials have through their extraction, manufacture, transportation, use, and end of life. The present research aims at investigating the possible role of life-cycle carbon assessment in sustainable construction project management by comparing a number of green construction materials and technologies. In consideration of the conventional construction alternatives, bamboo, recycled steel and solar photovoltaic systems are taken into account. Two case studies on the use of life-cycle carbon information in Australian construction projects, such as RMIT Design Hub and the Sydney International Regatta Centre, are explored. The results from the case-study calculations suggest significant carbon gains from recycled steel and solar PVs. The Sydney International Regatta Centre case results in a more or less 125 tCO₂ saving due to recycled steel and a more or less 951 tCO₂ benefit due to solar photovoltaic integration, while the RMIT case shows significant potential carbon benefit from using solar photovoltaic integration. It is suggested that the findings will support and facilitate the inclusion of life-cycle carbon assessment in the project planning and procurement, sustainability monitoring and material selection process. The study also makes a contribution to project management literature by recognizing LCA as a mechanism for supporting decision making in carbon-conscious construction management, rather than just an environmental assessment tool, which is the traditional approach.

Introduction

The construction sector is a big user of natural resources and energy and a contributor to greenhouse-gas emissions along the built-environment life cycle. Common materials like cement, concrete and virgin steel may have significant environmental effects associated with their extraction, processing, movement, installation, use and dismantling. Therefore,

minimizing the environmental footprint of construction projects involves more than just choosing products and materials that minimize operational impacts during the life cycle of structures.

The selection of materials is especially significant since choices made in the planning and procurement stages can embed environmental consequences throughout a

project's life cycle. Environmental project objectives, e.g. carbon reduction, resource efficiency, are becoming a key concern for project managers alongside the traditional project objectives: cost, time, scope and quality. Environmental considerations must be integrated into the decision making process for sustainable construction as an integral part of the project, and not a separate environmental initiative.

Life Cycle Assessment (LCA) is a systematic method to assess the environmental effects of products and materials over their life cycle (Ding, 2014). Unlike traditional assessments that look at manufacturing or construction, LCA takes into account various phases of the life cycle, such as raw-material acquisition, production, transportation, use and end-of-life processes. The effectiveness of LCA to compare building materials and opportunities for environmental improvement has been shown in previous studies (Bribián et al., 2011; Bruce-Hyrkäs et al., 2018).

Green Construction Materials offer the opportunity to minimize environmental impacts. For instance, bamboo has been the focus of interest due to its quick growth and utilization for construction purposes as a renewable resource (Yadav & Mathur, 2021). This means that recycled steel can decrease reliance on virgin raw materials, and decrease emissions from the production process, and PV can produce renewable electricity and reduce emissions from traditional energy production (Muteri et al., 2020). The reputation as a "green" material does not, however, decide on the environmental performance of a material. The manufacturing needs, transport, durability, maintenance, recycling and end-of-life treatment can have a significant impact on its environmental performance. Thus, project managers need a life-cycle view to make material-selection decisions.

This study accordingly examines the potential of life-cycle carbon assessment in sustainable construction project management, and makes a comparison between the carbon footprints of some green construction materials and technologies.

Research Questions

RQ1: How can life-cycle carbon assessment support material-selection decisions in construction project management?

RQ2: What potential carbon savings can be achieved through selected sustainable construction materials and renewable-energy technologies compared with conventional alternatives?

RQ3: How can LCA information be integrated into construction planning, procurement and sustainability management?

Literature Review

Life-Cycle Assessment and Construction

LCA considers the environmental effects of a product, process or system over its specified life cycle. In construction, this may include extraction of raw materials, manufacturing, transportation, construction, building operation, maintenance, demolition and end-of-life treatment. LCA use in the construction field is especially useful, as environmental effects can be spread over various steps, instead of being focused on one step. Bribián et al. (2011), for instance, showed that there is a significant variation in energy and environmental characteristics among the construction materials. Whole-building LCA has since gained more and more relevance for green building assessment and sustainable design (Bruce-Hyrkäs et al., 2018).

Project managers are not just responsible for reporting on LCA; it's crucial. The choices of materials used in the design and procurement process can impact the project's sustainability performance throughout the project. The inclusion of carbon information in these plays a role in proactive environmental management.

Green Construction Materials

Bamboo is a renewable resource that can be used for structural and architectural materials. Eco performance is dependent on cultivation, harvest, processing, transport and treatment. The production and construction approach may significantly affect LCOs (Zea Escamilla et al., 2018). Another important approach that can be taken for minimising the environmental impacts of the construction process is recycling steel. The recycling of steel reduces the need for virgin material extraction and can help achieve

circular-economy targets. Branca et al. (2020) point out the increasing role of reuse and recycling in the iron and steel industry. Unlike traditional construction materials, the main environmental contribution of solar photovoltaic (PV) systems is during operation when they generate solar power. However, the PV modules have impacts during manufacturing and at the end of their lives which should be taken into consideration in life-cycle assessment (Latunussa et al., 2016; Muteri et al., 2020).

Research Methodology

Research Design

This study adopts a quantitative comparative case-study design using life-cycle carbon assessment approach. Selected construction materials and renewable-energy technologies are analyzed based on the carbon-emission factors

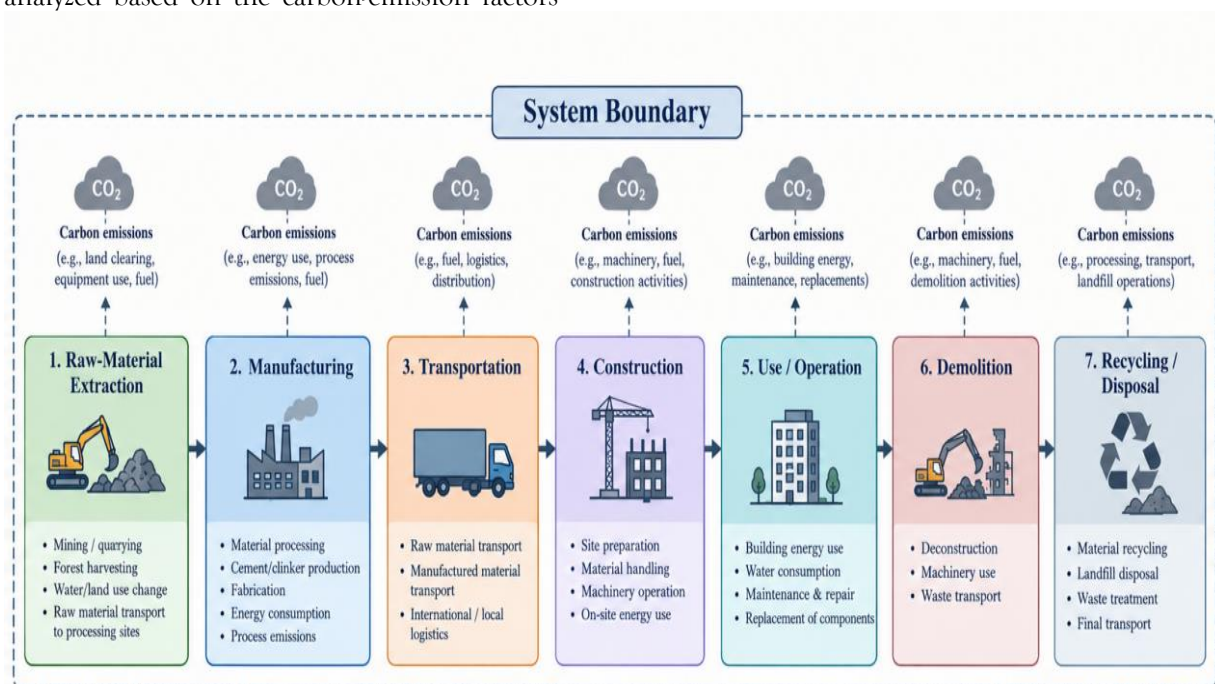
and project-level quantities obtained in the original thesis case studies.

The assessment is mainly based on the CO₂ emissions and avoided emissions, in tonnes of CO₂ equivalent (tCO₂). The analysis is designed to serve as a project management decision-support assessment and is not an ISO-compliant EPD.

System Boundary

The conceptual system boundary covers:

1. Raw-material extraction;
2. Manufacturing and processing;
3. Transportation;
4. Construction/use;
5. Operational energy effects where applicable; and
6. End-of-life treatment.



Case Studies

There are two projects in Australia which were considered: A rowing club is located at Sydney International Regatta Centre (SIRC), Penrith Lake, NSW. This study is from RMIT Design Hub, Melbourne, Victoria. The projects offer real-life scenarios for exploring the potential of sustainable materials and renewable-energy technologies to help achieve carbon reduction at the project level.

Results

Sydney International Regatta Centre: Recycled Steel

The case study reports the use of approximately 100 tonnes of recycled steel.

The assumed baseline emission factor for virgin steel is 1.8 tCO₂/t, producing:

$$100 \times 1.8 = 180 \text{ tCO}_2$$

The assumed recycled-steel emission factor is 0.6 tCO₂/t, producing:

$$100 \times 0.6 = 60 \text{ tCO}_2$$

Therefore, the estimated production-stage carbon saving is:
 $180 - 60 = 120 \text{ tCO}_2$

An additional transport-related saving of 5 tCO₂ is reported in the thesis. Accordingly, the estimated net saving is:
 $120 + 5 = 125 \text{ tCO}_2$

Table 1. Carbon assessment of recycled steel at SIRC

Indicator	Value
Recycled steel quantity	100 t
Virgin steel emission factor	1.8 tCO ₂ /t
Virgin-steel baseline emissions	180 tCO ₂
Recycled-steel emission factor	0.6 tCO ₂ /t
Recycled-steel emissions	60 tCO ₂
Production-stage saving	120 tCO ₂
Reported transport saving	5 tCO ₂
Estimated net saving	125 tCO₂

The outcome suggests that a significant reduction in embodied-carbon can be achieved by using recycled steel instead of virgin steel. From a project management point of view, the outcome clarifies the impact that procurement decisions taken during design development can have on the environment.

Sydney International Regatta Centre: Solar Photovoltaic System

The project reportedly incorporated a 40-kW photovoltaic system.

Using the stated manufacturing-emission factor of 1.2 tCO₂/kW:

$$40 \times 1.2 = 48 \text{ tCO}_2$$

The thesis estimates approximately 925,000 kWh of electricity generation over the relevant period. Using the stated avoided-emission factor of 1.08 kgCO₂/kWh:

$$925,000 \times 1.08 = 999,000 \text{ kgCO}_2$$

or approximately:

$$999 \text{ tCO}_2$$

The estimated net carbon benefit is therefore:

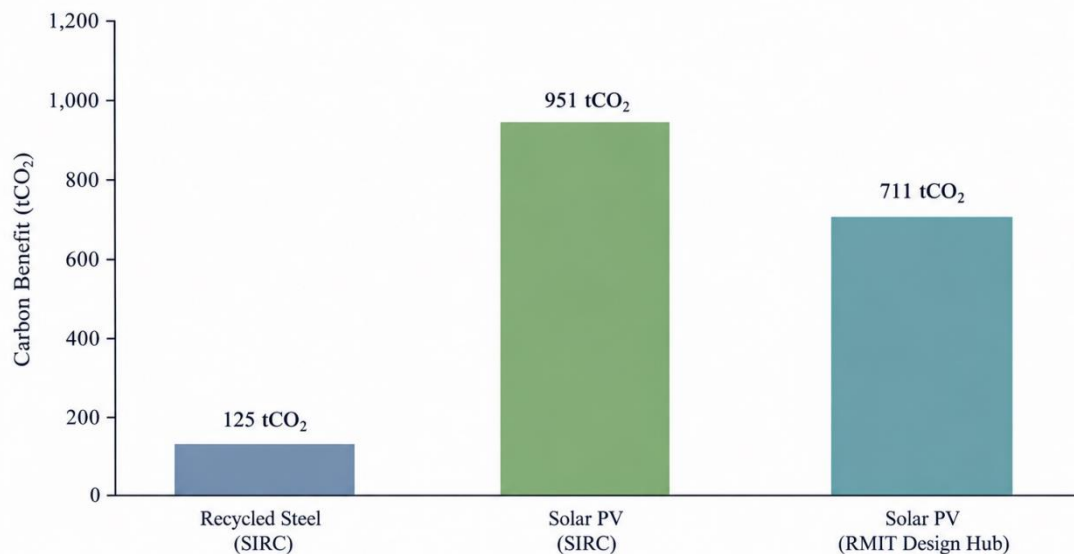
$$999 - 48 = 951 \text{ tCO}_2$$

Table 2. Solar photovoltaic carbon assessment at SIRC

Indicator	Value
Installed capacity	40 kW
Manufacturing emissions	48 tCO ₂
Estimated electricity generation	925,000 kWh
Avoided emissions	999 tCO ₂
Estimated net carbon benefit	951 tCO₂

The result suggests that the operational carbon benefit of renewable-energy generation can substantially exceed the initial manufacturing emissions under the assumptions applied.

Estimated Carbon Benefits from Selected Sustainable Initiatives



RMIT Design Hub

The second case study considers a photovoltaic installation associated with the RMIT Design Hub. The thesis reports an installed capacity of approximately 150 kW and a potential photovoltaic area of approximately 1,200 m². Using the stated manufacturing factor:

$$150 \times 1.2 = 180 \text{ tCO}_2$$

The estimated electricity-generation offset is:
 $825,000 \times 1.08 \text{ kgCO}_2/\text{kWh} = 891,000 \text{ kgCO}_2$
 or approximately 891 tCO₂.

The resulting estimated net benefit is:
 $891 - 180 = 711 \text{ tCO}_2$

Table 3. RMIT Design Hub photovoltaic assessment

Indicator	Value
Potential photovoltaic area	1,200 m ²
Installed capacity	150 kW
Manufacturing emissions	180 tCO ₂
Estimated electricity generation	825,000 kWh
Avoided emissions	891 tCO ₂
Estimated net carbon benefit	711 tCO₂

The results indicate that photovoltaic integration can contribute significantly to project-level carbon management, particularly when projects have suitable roof or façade areas for renewable-energy generation.

Comparative Analysis

The case studies demonstrate different mechanisms through which sustainable technologies influence carbon performance. Recycled steel primarily reduces **embodied carbon**, while photovoltaic systems generate carbon benefits through **avoided operational emissions**.

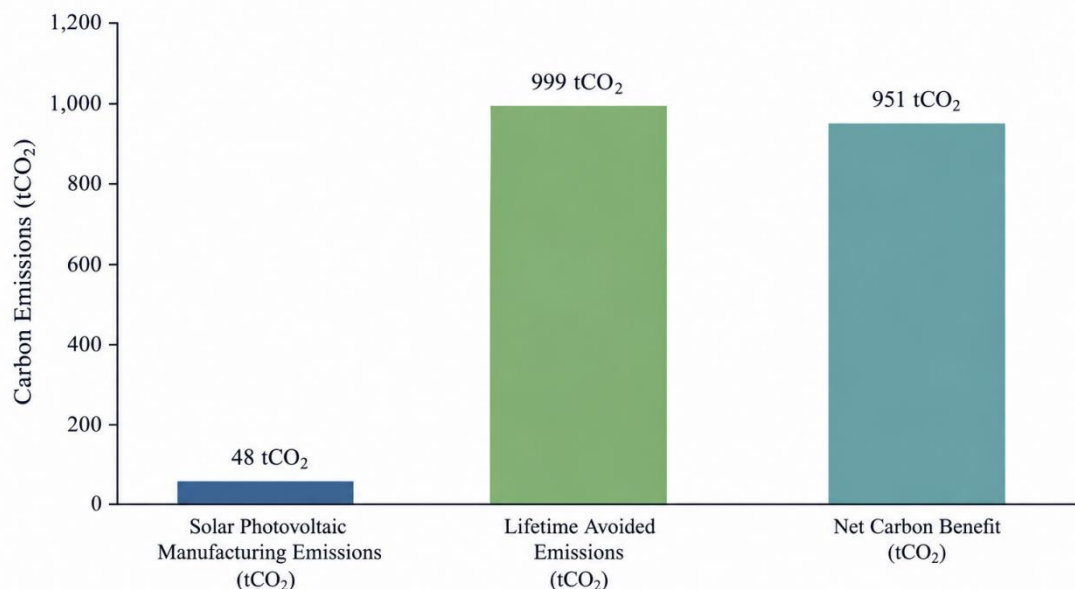
Table 4. Comparative carbon benefits

Sustainable intervention	Project	Estimated carbon benefit
Recycled steel	SIRC	125 tCO ₂
Solar photovoltaic system	SIRC	951 tCO ₂
Solar photovoltaic system	RMIT Design Hub	711 tCO ₂
Total reported case-study	—	1,787 tCO₂

benefit

The thesis originally reported a total of 2,107 tCO₂ because it included additional entries, including a reported concrete saving and solar-façade saving. However, the supporting calculations supplied in the thesis are insufficient to independently reproduce those

figures. Therefore, the present article limits the main comparative calculation to the three interventions for which numerical calculations are explicitly available and internally reproducible.



Discussion: Project Management Implications

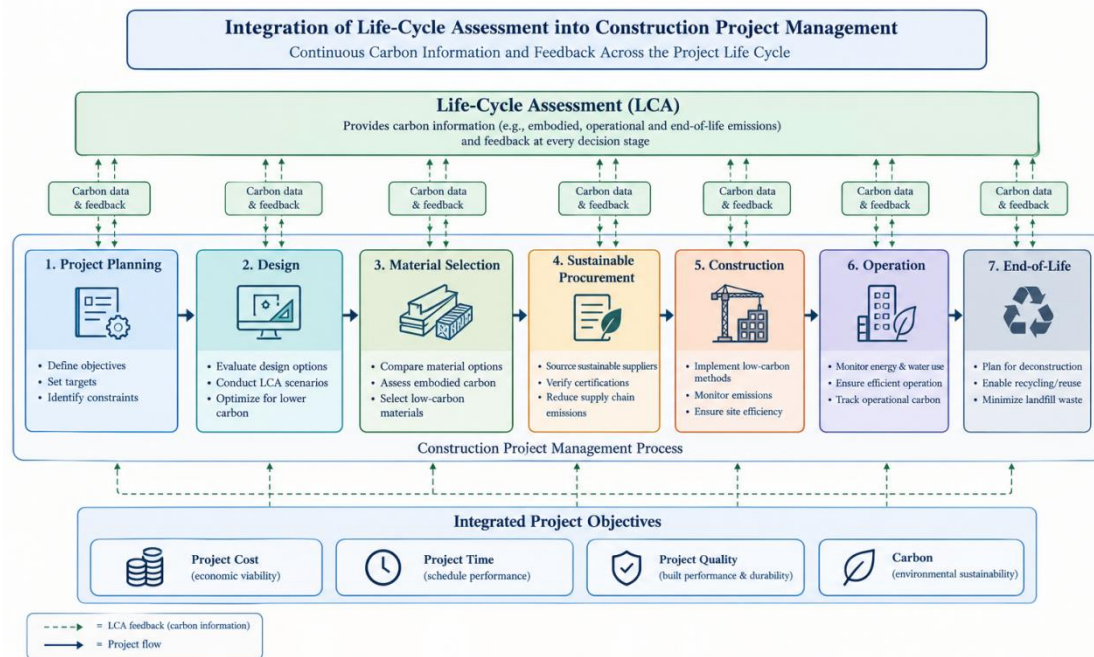
The results of the study have a number of implications in project management of construction work. First, assessments of carbon should be made at the planning stage, not in post-construction. Typical times for making decisions on material selection are conceptual design, detailed design and procurement. Embedding LCA can help project teams uncover opportunities for carbon reduction at these phases, before decisions are made that are hard to change or costly.

Secondly, LCA can enhance sustainable procurement. Project managers have the opportunity to include carbon requirements in material specifications and supplier assessment. Project teams do not have to only choose materials based on cost of purchase, but can also look at a wider decision making framework that includes cost, carbon, durability, availability and end-of-life recovery.

Third, the results highlight the need to differentiate between embodied and operational carbon. Emissions from the use of recycled steel are less than those from producing material, while the electricity generated by a PV system can be used to cut future operational emissions. It is important for project managers to not compare these interventions with any one undifferentiated indicator.

Fourth, LCA can provide support for sustainability monitoring of a project. Carbon targets can be integrated with traditional project performance metrics like cost variance, schedule variance and quality performance.

Finally, results provide a basis for decision-making processes for carbon awareness. The benefits of LCA for project managers are that they can share environmental trade-offs with clients, design teams, contractors and procurement staff.



Conclusion

In this study, life cycle carbon assessment for a sustainable construction project management was studied by selected green construction materials and renewable energy technologies. The analysis shows that there can be significant differences in environmental performance among materials and life-cycle stages, and that material selection for sustainability can yield meaningful carbon benefits. According to the SIRC case study, an estimated 125 tCO₂ saving can be achieved from recycling steel and about 951 tCO₂ net carbon benefit can be achieved from the PV system, based on the assumptions above. In the case of the RMIT Design Hub, the carbon benefits of using PV are estimated at 711 tCO₂ net PV DC carbon benefit. The results show the added value of LCA over the environmental assessment. If it is incorporated at the project planning, design and procurement stage, it can be a realistic decision support tool for helping to meet carbon-reduction goals.

The results should, however, be interpreted with caution as the case-study emission factors and quantities are based on the results of the thesis calculation and do not have a full independently verified LCA inventory. Future studies should use standardized LCA databases and ISO 14040/14044 procedures, sensitivity analysis and project specific primary data. Further studies are also needed that

incorporate cost, carbon, schedule, risk and quality in a multi-criteria decision-making process. In general, the study proposes a shift from the traditional project management to the „carbon conscious construction project management“, in which environmental performance becomes part of the „mainstream project decision making process“.

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