DEVELOPING A CONCEPTUAL FRAMEWORK TO EMBED THE SOCIAL COST OF CARBON IN COST ESTIMATION FOR COMMERCIAL BUILDINGS

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Cost estimation for commercial buildings predominantly focuses on financial metrics, neglecting societal impacts of carbon emissions. The Social Cost of Carbon (SCC), monetising long-term damage of carbon dioxides, offers a mechanism to integrate environmental and social externalities. This study develops a conceptual framework for embedding SCC into building cost estimation. A critical review of 23 academic studies and 8 semi-structured interviews with sustainability consultants, cost managers, policymakers are conducted. Findings reveal 3 primary carbon cost drivers from literature and 4 key integration themes from industry, the need for granular carbon data, stakeholder interest alignment, supportive policy incentives, and tools compatible with existing cost software. The proposed framework integrates SCC throughout the building lifecycle, from feasibility and design to procurement and operation, expanding Whole Life Costing to incorporate societal costs. This enables cost professionals to account for long-term climate and social impacts alongside traditional expenditure. Future research should pilot the framework and develop digital tools (e.g., BIM-based platforms) For SCC-informed decision-making.

Keywords: social cost of carbon; cost estimation; commercial buildings; sustainability; whole life costing

INTRODUCTION

The commercial building sector is under growing pressure to address not only the environmental consequences of construction (e.g., greenhouse gas emissions) But also the social impacts of buildings on communities and public well-being. Buildings are responsible for nearly 40% of global energy-related carbon dioxide emissions (Gao *et al.,* 2023; Myint *et al.,* 2025), contributing significantly to climate change. At the same time, construction activities and building operations affect public health, safety, and social equity - for instance through air pollution, resource depletion, and community disruption (Lu *et al.,* 2020). These externalities impose monetised societal damage that is usually borne by society at large rather than by project proponents. The Social Cost of Carbon is a financial estimate of the long-term harm caused by emitting one extra tonne of carbon dioxide into the atmosphere. It represents the monetary value of future damages to society, such as negative impacts on public health, farming, and infrastructure, for every additional tonne of CO_2 released. Unlike

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conventional market-based carbon prices, e.g., carbon taxes or emission trading permit prices, SCC attempts to quantify all externalities borne by society, such as the cost of climate-related disasters or health care burdens from pollution (Rennert *et al.,* 2022). Department for Energy Security and Net Zero publish carbon valuation guidelines for UK government policy appraisal that SCC is used in cost-benefit analyses to inform regulations (Rennert *et al.,* 2022); however, it remains contentious due to uncertainties in climate-economic models, e.g., discount rates, damage functions, and ethical debates about intergenerational impacts (Khabarov *et al.,* 2020; Dong *et al.,* 2024). Notwithstanding these debates, SCC provides a useful framework to evaluate the broader societal costs of emissions in monetary terms, effectively translating environmental and social harm into project-relevant cost figures.

Traditionally, cost estimation in commercial building projects has focused on capital expenditure and straightforward lifecycle costs including maintenance, operation, disposal, emphasising the financial viability of projects. Standards like Publicly Available Specification (PAS) 2080 and International Organisation for Standardisation (ISO) 14000 promote sustainability considerations, but their influence on everyday cost planning has been fragmented and indirect (Huang *et al.,* 2018; Cui *et al.,* 2019). As a result, early project decisions often omit the full spectrum of carbon costs, leading to suboptimal choices that perpetuate environmental damage and social harm (Othman and Mohamed, 2016). For example, a design alternative with lower upfront cost may incur higher emissions and future societal costs yet be favoured if those external costs are invisible in the budget. This gap between sustainability goals and cost methods means that the true societal impact of design and material choices is rarely factored into business cases. Even Whole Life Costing (WLC) Frameworks, which attempt to account for costs over a building's life, seldom quantify societal externalities like public health effects or climate damages (Wong, 2010; Tokede *et al.,* 2013). There is a clear need to bridge conventional cost estimation with sustainability metrics so that decisions at the planning and design stages internalise carbon emission costs (Wu *et al.,* 2021). In other words, cost models must evolve to explicitly include the SCC, effectively embedding monetised environmental and social impacts into project appraisal.

This paper addresses the above gap by developing a conceptual framework that embeds the SCC into cost estimation practices for commercial buildings. The research is guided by the following objectives: (1) Identify key cost drivers across a building's lifecycle that significantly contribute to carbon-related societal costs; (2) Explore industry perspectives on the challenges and enablers of integrating SCC into current cost estimation through expert interviews; and (3) Formulate a practical framework that links these cost drivers and industry insights, operationalising SCC inclusion at each project stage. By clearly defining these objectives, we focus the study on both the technical factors from literature and the stakeholder/context factors from practice needed to incorporate SCC. In pursuing these objectives, the study aims to demonstrate how expanding cost estimation to include monetised societal damage can encourage more sustainable decision-making in building projects.

LITERATURE REVIEW

Efforts to integrate sustainability into construction cost management reveal limitations in existing approaches, particularly the neglect of broader societal costs like carbon emissions. Traditional cost estimation focuses on direct financial costs, overlooking environmental degradation and social impacts (Sadliwala and Gogate, 2022;

Samarasekara *et al.,* 2024). Although frameworks like Whole Life Costing and Lifecycle Costing extend beyond initial capital expenditure, they rarely monetise societal externalities such as climate damage or public health effects (Wong, 2010; Tokede *et al.,* 2013).

Consequently, sustainable initiatives struggle to justify green choices economically. SCC, originating from environmental economics, addresses this by assigning monetary value to comprehensive carbon damage, encompassing infrastructure risks, agricultural losses, ecosystem degradation, and health impacts (Ackerman and Stanton, 2010; Livermore, 2016). Despite its policy use, SCC adoption in construction faces challenges: complex valuation debates, e.g., discount rates, climate sensitivity; Khabarov *et al.,* 2020, lack of sector-specific data (Wu *et al.,* 2021), and stakeholder misalignment favouring short-term budgets over long-term liabilities (Kamaruddin *et al.,* 2024; Kolk and Pinkse, 2006). Practitioners often perceive SCC as an added complication without mandates (Kita, 2017).

Nevertheless, integrating SCC holds promise for driving low-carbon innovation, offering holistic externality valuation beyond direct carbon pricing. Recent advances, such as OpenBIM tools for monetary carbon assessment (Lu and Deng, 2023) And multi-stakeholder frameworks (Wu *et al.,* 2021), demonstrate growing efforts to quantify sustainability within cost models. The literature thus identifies a clear gap between conventional cost estimation and carbon accountability, motivating this research to bridge financial metrics with societal impacts through a unified SCC framework.

METHODS

This study employed a qualitative mixed-methods approach, combining a critical review with thematic analysis of expert interviews, to triangulate theoretical and practical insights for robust framework development. A critical review of 23 academic publications (2010-2024) Sourced from Scopus and Web of Science identified key carbon cost drivers and SCC integration methods. Selection criteria prioritised studies on lifecycle carbon accounting, SCC valuation, sustainable cost methods, and building WLC. Publications like Wong (2010) And Plebankiewicz *et al. (*2019) Provided foundational concepts, with analysis synthesising insights across construction management, environmental economics, and sustainability science. This yielded initial cost drivers for framework development.

Complementing this, semi-structured interviews were conducted with eight UK-based professionals, e.g., sustainability consultants, cost managers, policymakers, selected via purposive sampling to capture diverse stakeholder perspectives in commercial building projects. Interviews, lasting 45-60 minutes, explored current cost practices, SCC awareness, and integration barriers. Saturation was achieved by the eighth interview. To transform this rich interview data into substantive findings, the verbatim transcripts were subjected to a rigorous thematic analysis using NVivo software. The process began with open coding, where foundational concepts were identified directly from the practitioners' narratives, such as the recurring challenge of "data availability." Through an iterative analytical process, these initial concepts were then compared and grouped to build robust, higher-order themes. For example, concepts like "data availability" and "data security" were consolidated into the overarching theme of " data granularity". This systematic approach ensured that the core findings presented in this study are directly and demonstrably grounded in the expressed experiences and perspectives of the participants. Trustworthiness was ensured through researcher cross-checking and disconfirming evidence consideration. Integrating literature-derived drivers and interview themes enabled the development of a theoretically grounded, practically relevant SCC integration framework.

RESULTS

Key Carbon Cost Drivers from Literature

The critical review identified three primary cost drivers significantly determining a commercial building's carbon footprint and associated societal costs over its lifecycle: (1) Embodied carbon in materials production, (2) Operational energy consumption, and (3) End-of-life decommissioning emissions. These drivers represent the largest contributors to a building's total carbon emissions and thus its monetised societal impact, making their integration crucial for effective SCC application in cost estimation (Lu *et al.,* 2023; Plebankiewicz *et al.,* 2019). The proposed framework explicitly centres on these drivers, mapping each to relevant project lifecycle stages and specific cost-estimating relationships (CERs) That incorporate SCC to translate carbon impacts into monetary terms. Figure 1 presents a novel conceptual framework designed to embed carbon cost considerations directly into the building lifecycle. It aligns with Royal Institute of British Architects (RIBA) Plan of Work, a definitive model for the design and construction process of buildings. It illustrates how three principal carbon cost drivers intersect with critical project stages, including Feasibility (RIBA 1-2), Design Development (RIBA 3-4), Procurement (RIBA 4-5), and Operational Planning (RIBA 6-7). However, cross-cutting dimensions of Data Transparency and Stakeholder Engagement are essential supports for successfully managing a project's whole-life carbon impact.

Figure 1: Main structure of the SCC-integrated cost estimation framework

In detail, Feasibility (RIBA 1-2) Establishes a project's viability and strategic brief, setting the foundational carbon footprint for the building's entire lifecycle. Design Development (RIBA 3-4) Refines the concept into a detailed technical design, making critical decisions on materials and systems that determine the building's final embodied and operational carbon performance. Procurement (RIBA 4-5) Involves appointing a contractor to construct the building, providing a crucial opportunity to enforce carbon reduction targets through contractual agreements and partner selection. Operational Planning (RIBA 6-7) Prepares for the building's handover and long-term use, establishing the management and monitoring strategies essential for achieving its designed energy performance throughout its life.

Table 1 details the framework for embedding the Social Cost of Carbon (SCC) At each lifecycle stage, augmenting traditional cost processes with specific actions or cost-estimating relationships (CERs).

Table 1: Breakdown of SCC integration across lifecycle stages in the conceptual framework

Project Stage	SCC Component	Further Task
Feasibility	Carbon Scenario Analysis	Estimate emissions for various site/design options; monetise using SCC values (Wu *et al.*, 2021).
	Site and Typology Comparison	Compare alternative locations and typologies with embodied emissions impact (Wu *et al.*, 2021).
	Carbon-Adjusted Financial Appraisal	Include SCC in financial appraisals and NPV modelling of lifetime project costs (Wu *et al.*, 2021).
Design Development	Material and Component Evaluation	Evaluate low-carbon material choices using embodied carbon and SCC metrics (Lu and Deng, 2023).
	Systems and Operational Strategy Analysis	Assess systems based on carbon-cost trade-offs; simulate energy performance (Lu and Deng, 2023).
	Iterative Design Feedback	Use SCC feedback to guide design decisions during early development stages (Wolf *et al.*, 2016).
Procurement	SCC-Integrated Tender Criteria	Integrate SCC into contractor selection and bid evaluation criteria (Xue *et al.*, 2018).
	Supplier and Manufacturer Declarations	Require EPDs and carbon costing from suppliers and manufacturers (Xue *et al.*, 2018).
	Contractual Mechanisms	Implement incentives or penalties tied to construction-phase emissions (Xue *et al.*, 2018).
Operational Planning	Long-Term Emissions Forecasting	Forecast emissions across asset life; inform energy and capital planning (Wolf *et al.*, 2016).
	Maintenance and Retrofit Planning	Plan for upgrades or replacements with SCC-informed decision tools (Wolf *et al.*, 2016).
	End-of-Life Emissions and Circularity	Include carbon value of demolition and promote reuse and recycling (Wolf *et al.*, 2016).
All Stages	Data Transparency and Documentation	Maintain traceability of SCC inputs via digital tools and documentation (Lu and Deng, 2023).
	Stakeholder Engagement	Align stakeholders on SCC importance through engagement and training (Kamaruddin *et al.*, 2024).
	Policy and Regulatory Integration	Integrate SCC with carbon pricing policies and building regulations (Kolk and Pinkse, 2006).

During the Feasibility (RIBA 1-2) Stage, carbon scenario analysis is used to estimate and monetise projected emissions from early design or site options, enabling comparisons based on societal carbon costs (Wu *et al.,* 2021). This includes evaluating the embodied carbon impacts of different sites or building typologies. Concurrently, carbon-adjusted financial appraisals integrate SCC into metrics like Net Present Value (NPV), explicitly factoring future carbon liabilities into investment evaluations (Wu *et al.,* 2021).

In the Design Development (RIBA 3-4) Stage, SCC is incorporated into material selection by adjusting purchase prices based on embodied carbon, facilitating comparisons between alternatives as formalised in Equation (1):

$$\text{Adjusted Unit Rate} = \text{Material Cost (£)} + (\text{Embodied Carbon (tonnes)} \times \text{SCC (£/tonne)}) \quad (1)$$

Analyses of systems and operational strategies also use SCC to assess long-term emissions from design options, guiding choices towards energy-efficient solutions.

This involves iterative feedback loops where designs are recalculated for lifecycle carbon impacts to ensure alignment with targets (Wolf *et al.,* 2016).

At the Procurement (RIBA 4-5) Stage, SCC is integrated into tender evaluation criteria, where proposals are assessed on both financial cost and anticipated construction-phase emissions (Xue *et al.,* 2018; Sloan *et al.,* 2014). Bids are evaluated to include societal carbon costs, calculated as a carbon liability using Equation (2):

$$\text{Carbon liability} = \text{SCC (£/tonne)} \times \text{Projected operational emissions (tonnes)} \quad (2)$$

Supply-chain transparency, through mandatory Environmental Product Declarations (EPDs), and contractual clauses with carbon-related incentives or penalties ensure robust data and accountability (Xue *et al.,* 2018).

During Operational Planning (RIBA 6-7), long-term operational emissions forecasts are informed by SCC to guide maintenance and retrofitting decisions, monetising the avoided societal costs of efficiency improvements (Wolf *et al.,* 2016). The end-of-life strategy also monetises the carbon implications of demolition and disposal. Factoring SCC into these decisions encourages designs that support material reuse and circular economy principles, with the end-of-life liability evaluated using Equation (3):

$$\text{End-of-life liability} = \text{SCC (£/tonne)} \times \text{Estimated end-of-life emissions (tonnes)} \quad (3)$$

Finally, two universal elements are critical. First, data transparency and documentation, requiring consistent carbon data and SCC values, often facilitated by digital platforms and robust local datasets. Second, stakeholder engagement and policy integration are essential to foster alignment among clients, contractors, and regulators. Communicating SCC's necessity, reinforced by mandates or policies, is crucial for effective adoption (Kamaruddin *et al.,* 2024; Kolk and Pinkse, 2006).

Themes from Expert Interviews

The expert interviews substantiated and enriched the framework by highlighting four key themes essential to effectively embedding SCC into cost estimation practices. These themes represent practical considerations crucial for the framework's successful implementation. The first theme identified was data granularity, emphasising the need for detailed, region-specific carbon data to reliably integrate SCC into cost estimation. Industry practitioners across sustainability consultancy and cost management roles highlighted the critical importance of accurate, localised datasets. For instance, a costing manager in the energy sector explained: "Developing the carbon cost estimation, you need to have a good database. If you don't have a good database, the indicators you use in the planning phase could be different from the reality in execution". This underscores the necessity of high-quality local carbon data as the foundation for credible SCC integration.

The second prominent theme, stakeholder alignment, pointed to the prevalent challenge of short-term financial considerations overshadowing long-term carbon liabilities. A professional in project controls within the infrastructure sector highlighted this tension, noting: "Most companies…look at it short term - what's this going to cost to build - and disregard the OpEx costs. Looking at whole life cycle costs is quite unusual". This observation illustrates a significant barrier: organisations' predominant short-term outlook conflicts with the long-term perspective required to effectively integrate SCC. Achieving stakeholder alignment thus requires clearly communicating the value of incorporating SCC into long-term decision-making and proactively educating stakeholders on its benefits.

Regulatory drivers emerged as the third key theme, with interviewees stressing the crucial role external mandates or incentives play in facilitating SCC adoption. Interviewees from cost consultancy and project management backgrounds agreed that clear regulatory requirements or strong client-driven mandates are essential. A cost consultant emphasized their role's limitations, stating: "All we can do is price what we're asked to price… If we want to price in additional scope to make social value gains, we will do it because we are told to". Similarly, a project management expert pointed to the effectiveness of mandatory procurement requirements for carbon reporting: "In the bid process, you must provide [carbon impact] information. Then they have to do it... people who don't provide it will not be considered". These statements illustrate that explicit regulatory expectations are powerful motivators for incorporating carbon accountability into industry practices.

The final theme, tool interoperability, highlighted the necessity for integrating SCC calculations seamlessly into existing cost estimation tools and workflows. Cost consultants and sustainability professionals emphasized that effective implementation requires minimal disruption to established estimation practices. One expert, experienced in sustainability-focused cost planning, noted ongoing industry efforts to enhance compatibility with widely used estimation software: "We're working with [software] companies that have tried-and-tested systems and advising them on what we need… to move those systems forward". Another professional specialising in aviation cost planning described the technical feasibility enabled by structured data systems: "If the data's structured correctly, you can easily apply the carbon factor… a lot of it comes down to the structure of your data". These insights confirm that integrating carbon-cost calculation modules into familiar cost-estimation tools significantly enhances practicality and likelihood of adoption.

Collectively, these four themes, including granular data, stakeholder alignment, regulatory support, and tool compatibility, highlight critical factors determining the successful adoption of SCC methodologies. Addressing these aspects ensures the practical relevance and feasibility of the proposed SCC-integrated framework, bridging the gap between theoretical sustainability objectives and real-world cost management practices in construction.

DISCUSSION

Integrating SCC into building cost estimation bridges the critical gap between financial planning and environmental accountability. The framework quantitatively monetises carbon externalities within standard cost analysis, moving beyond traditional Whole Life Costing's qualitative treatment of environmental factors (Huang *et al.,* 2018; Wu *et al.,* 2021). This operationalises SCC into specific cost-estimating relationships, incentivising socially optimal choices alongside cost-effectiveness. Findings align with stakeholder and policy realities: cost professionals operate within client directives and market norms, perceiving SCC integration as a potential complication unless mandated or value-adding (Kita, 2017). The framework's success thus hinges on demonstrating value (e.g., life-cycle savings, risk reduction) And aligning with regulatory drivers. Policy mandates, such as emerging climate disclosure rules, are pivotal catalysts for adoption (Kamaruddin *et al.,* 2024;

Kolk and Pinkse, 2006). Robust methods like this framework can, in turn, support policymakers by demonstrating industry capability.

Data quality and tool interoperability are key implementation bottlenecks. While digital innovations like BIM facilitate embedding carbon values (Lu and Deng, 2023), data uncertainty, e.g., SCC value ranges, emission factors, remains a challenge. Transparency in reporting ranges and using uncertainty buffers is advocated to manage this (Dong *et al.,* 2024). Seamless integration with existing cost software and workflows is essential for practitioner uptake. Potential benefits include improved decision-making accounting for long-term risks and externalities, potentially revealing win-win scenarios where carbon efficiency aligns with cost efficiency (Porter's hypothesis). However, limitations exist: The framework's conceptual nature requires empirical validation; SCC values and impact factors evolve with science and policy (Rennert *et al.,* 2022); and it specifically targets carbon externalities, acknowledging that monetising other social impacts, e.g., community cohesion remains complex and outside its scope. Future research should pilot the framework in real projects, develop interoperable digital tools, explore sensitivity to SCC values, and consider integrating other environmental indicators.

CONCLUSIONS

This research developed a conceptual framework embedding the SCC into commercial building cost estimation across the lifecycle. It addresses the disconnect between financial decisions and the societal costs of carbon by monetising emissions. Key findings underpinning the framework are three primary carbon cost drivers including embodied emissions, operational energy, end-of-life emissions and four cross-cutting themes containing data granularity, stakeholder alignment, regulatory drivers, and tool interoperability. Expert interviews highlighted both challenges, e.g., prevalent short-termism and opportunities, e.g., data-driven win-wins (Kolk and Pinkse, 2006).

For practice, the framework provides cost consultants and project managers a structured method to quantify carbon impacts monetarily, enabling more sustainable decisions and clearer societal cost pictures. For policy and standards, it offers a template for operationalising carbon reporting or pricing within projects, potentially accelerating compliance with standards like PAS 2080. Limitations include the framework's conceptual stage, reliance on evolving SCC/data, its specific focus on carbon externalities and UK-centric interview insights. Future work must prioritise testing and refining the framework in real projects through pilot studies, developing user-friendly digital tools or plugins for seamless implementation, and maintaining updated regional carbon cost databases. Collaborating on standard SCC values for construction could enhance consistency. This framework provides a foundational step towards holistic cost models that integrate environmental and societal accountability into construction economics.

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