engineering proceedings

Proceeding Paper

Capturing the Decarbonization Opportunity in Construction Industry: Emission-Free, Effective, and Resilient †

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† Presented at the 1st International Online Conference on Buildings, 24–26 October 2023; Available online: https://iocbd2023.sciforum.net/.

Abstract: The global economy's most significant sector, the construction sector is key to accomplishing sustainability objectives. The building and infrastructure business is not typically thought of as being environmentally friendly, but this is likely to change as the ecosystem (the whole life cycle of all structures and infrastructure, from design and material manufacture to construction, use, and destruction) develops. Participants in the building sector cannot afford to ignore the worldwide trend of decarbonization. As the sector is responsible for more than 20% of all greenhouse gas emissions worldwide, construction companies have the opportunity to reduce their climate impact by decarbonizing their building operations. Participants in the construction sector must prioritise a strategic goal and collaborate with other ecosystem players, such as clients, architects, engineers, manufacturers, and financiers, in order to realise this potential. Here, we show what the industry can do right now and how stakeholders from all points along the value chain may work together to succeed. It's also important to keep in mind that if the low-interest rate environment lasts and sizable stimulus packages are implemented, these developments may help deploy new sustainable infrastructure as well as infrastructure for adaptation and resilience, investments that would support the creation of jobs in the near future. In the meanwhile, it's possible that the need for international collaboration on this matter will increase in clarity and acceptance. This research study focuses on how construction affects greenhouse gas (GHG) emissions in the context of buildings, how the sector may decarbonize, and how businesses might profit from this process.

Keywords: infrastructure; decarbonizing; stakeholders; sustainability; greenhouse gas

Citation: Jaglan, A.K.; Korde, N. Capturing the Decarbonization Opportunity in Construction Industry: Emission-Free, Effective, and Resilient. *Eng. Proc.* **2023**, *53*, x. https://doi.org/10.3390/xxxxx

Academic Editor(s): Name

Published: 24 October 2023

1. Introduction

Given that cities account for 70% of carbon emissions, they are essential in the fight against climate change. 38% of worldwide emissions are caused by the building industry's construction and operation (Ali et al., 2020). To speed up the decarbonization process and keep the increase in global temperature to below 1.5 °C, solutions are required (Fawzy et al., 2020). In 2021, buildings will account for around one-third of all global final energy consumption (FEC) and CO_2 emissions, and they will probably be crucial to the transition to a low-carbon world (Camarasa et al., 2022). In contrast, without more climate policy, the amount of energy consumed in buildings might rise by 46–73% in 2050 from 128 EJ in 2019, as a result of population expansion, a higher spread and usage of energy-consuming technologies, and rising living standards in emerging nations (Pablo-Romero et al., 2022). The shift to a low-carbon economy is anticipated to be considerably aided by buildings, which are responsible for one-third of worldwide FEC and CO_2 emissions. Due to population expansion, higher energy consumption, and growing living standards in emerging nations, without climate legislation, building energy demand may increase by 46–73% by 2050 (Santamouris & Vasilakopoulou, 2021). According to the scenario and model, CO_2

emissions must be reduced between 50% and 90% by 2050 in order to keep the increase in world temperature to 1.5 to 2 °C. Depending on the decarbonization scenario, these reductions can be realized with changes in energy consumption between −3% and +50% (Shimoda et al., 2021). Since its consequences, such as tsunamis, wildfires, and droughts, are getting worse, climate change is a significant problem for humanity. As a result, sustainable techniques, including green building, have been used to slow down climate change. The real estate market in India is changing, despite its large population of nearly 1.3 billion people and scarce resources. With energy consumption expected to hit $4 trillion and water shortages in 21 Indian cities, the real estate industry has come to understand the need of combating climate change via green building.

Reduced carbon footprint, improved indoor air quality, and resource conservation are all benefits of green building. Better health and higher productivity at work are the results of using environmentally friendly products. Additionally, the societal advantages of this strategy include improved productivity and wellness. In India, green structures that have been certified by the Indian Green Building Council (IGBC) provide notable water and energy savings of 20–30% and 40–50%, respectively. Additionally, these structures raise property values and save down on construction expenses. The asset value of green buildings is 7% higher than that of conventional structures, according to a 2016 analysis by Dodge Data & Analytics. Ecological support, effective resource utilization, and economic and social advantages are all provided by green building. To meet these goals, the building industry has to put energy-efficient building technologies, net-zero carbon construction, energy rehabilitation, low-energy consumption behavior's, centralized and decentralized renewable energy sources, and widespread electrification into practice.

Where We Are Today

Embodied carbon emissions from construction represent 16% of the world's total CO_2 emissions in 2020, making construction a substantial contributor to carbon emissions (Sizirici et al., 2021); (Röck et al., 2020). Beyond 2050, these emissions are anticipated to continue to be substantial assuming business as usual. To decarbonize at scale, the industry has to move quickly. 92% of the embodied carbon emissions in the construction value chain are attributable to the sourcing and production of cement and steel (Miller et al., 2021). While decarbonization is important, there are obstacles to overcome, such as high energy intensity, a finite source of renewable energy, process emissions, and lengthy asset lives. Emissions from shipping, road freight, and site equipment make up the majority of the 8% of emissions caused by construction operations and logistics (Sezer & Fredriksson, 2021). In the areas of transportation, power, commerce, and housing, fossil fuel consumption significantly increases greenhouse gas emissions. Buildings, infrastructure, and industrial developments all decarbonize at varied speeds in the construction sector. Due to their public ownership and centralized funding, infrastructure building projects are anticipated to decarbonize the quickest. These projects' size makes it simpler to bear the greater expenses of low-carbon solutions. Large organizations with net-zero emissions goals, as well as the general public and home purchasers, are likely to lead the end market for buildings in a similar direction. The industrial end market is anticipated to shift the least quickly due to its significant carbon emission footprint. But other industrial end industries, including those in the technology sector, are shown signs of being early adopters in the decarbonization process.

This article does not address the difficulty of reducing these emissions by switching to renewable, low-carbon energy sources. CO_2 emissions from the processing of raw materials provide a difficulty for the industrial sector. As an illustration, the calcination of limestone to produce lime during the production of cement produces CO_2 emissions. These emissions need finding decarbonization solutions for basic commodities like cement, lime, glass, and steel, which are necessary for a decarbonized economy. By emphasizing qualitative advantages and including holistic investment value in decision-making, the Net-Zero Carbon Cities Building Value Framework seeks to speed the transformation of the urban built environment. With this strategy, more money will be directed towards initiatives and solutions that reduce carbon emissions. Asset owners and investors who are making capital investment choices can benefit from the framework and its suggestions. Rapid transitions are necessary to achieve a 45% decrease in global emissions by 2030 and carbon neutrality by 2050 if we want to keep global warming to 1.5 °C (Huang & Zhai, 2021). These lofty goals, which are higher than those set for climate action to date, call for radical change. The requirement for net-zero GHG emissions is finally being acknowledged by local governments, who are pushing comprehensive decarbonization. The requirement for net-zero GHG emissions is being acknowledged by local governments, who are undertaking comprehensive decarbonization. With elaborate plans to do so, they have promised to achieve an 80% decrease in overall GHG emissions in the neighborhood by 2050 (Rissman et al., 2020). Governments throughout the world are committed to aggressive GHG reduction targets, but there is a lack of information regarding local strategies and measures enable varied cities to meet these objectives.

Leading cities are now considering emissions, embodied carbon, and carbon sinks, as well as activities outside the city boundary. This approach aims to reduce greenhouse gas emissions and promote sustainable development. The paper "Capturing the decarbonization opportunity in Construction Industry: Emission-Free, Effective, and Resilient" examines the sector's present issues and potential approaches to promoting decarbonization. It offers a detailed plan for getting to net zero, concentrating on expanding low-carbon solutions, creating substitute materials and technologies, enacting helpful laws, and working closely with others. There is general agreement that attaining net zero is feasible via greater usage of low-carbon solutions, encouraging legislation, and substantial collaboration.

2. Barriers to Decarbonization

Geology, climate, consumer preferences, project size, and technology all have an impact on barriers, which have an impact on end markets.

- Customer demand is impacted by procurement practices in a fragmented market that put cost and speed ahead of embodied carbon reduction.
- Infrastructure development and the manufacture of cement and steel are hampered by insufficient regulatory incentives for construction sub-sectors and end markets.
- For decarbonization technologies to develop and scale, considerable financial expenditure is needed because steel and cement are big emitters.
- The inability of market players to assert findings consistently is caused by the lack of unified standards and a single regulating agency for carbon accounting.

2.1. Potential Solutions for Decarbonizing Construction

Customers want more low-emission projects, so governments and lenders are giving it priority. As a response, construction firms are taking pledges and investigating novel technologies. Decarbonization was cited as one of the top three corporate priorities by more than 80% of those surveyed (Johnson et al., 2023). Despite the fact that major construction companies have made commitments to cut emissions, net zero requires firm action. Executives in the construction industry must establish and implement precise decarbonization policies, but the path ahead is still uncertain. Uncertainty surrounds current approaches and how they will affect decarbonization. Instead of only emphasizing operational efficiency, businesses should concentrate on fostering a decarbonization attitude.

2.2. Demand, Regulations and Technology

By aggregating demand and promoting embodied carbon awareness, joint sourcing and coalitions can promote investment in low-carbon goods. By recognizing embodied carbon and expanding financing options, financiers may promote low-carbon building. The ability to scale client demand through alliances and partnerships offers investors and building businesses the assurance they need to make investments while also assisting institutions in managing risk and releasing previous investments. To speed up the development of low-carbon buildings, policies must address both supply and demand. The use of low-carbon assets must be encouraged, and coercive measures must be supported, in order to encourage investment in additional low-carbon building methods and technologies. Reducing embedded carbon emissions requires coercive measures as well as incentives. Technologies like renewable energy, energy efficiency, and alternative materials are being used by the construction industry. Investing in low-carbon cement and concrete routes can lower emissions by using renewable energy sources, creating cleaner clinker manufacturing techniques, and lowering cement clinker consumption. Technology utilizing carbon capture, utilization, and storage (CCUS) is required to fulfil the industry's net-zero objective. This objective may be further advanced by the further development and application of CCUS technology. In order to minimize emissions, new materials like low-carbon asphalt are being developed. The use of bio-based binder in the manufacturing of asphalt is one of the key technologies, along with low-carbon energy and warm-mix asphalt. These innovations assist in heating mixes, reducing the carbon footprint of asphalt, and assisting power plants. Through R&D efforts, the industry should utilize alternate and circular resources like modernized wood and recycled asphalt. Although low-carbon energy is in short supply, low-emission technology is already in use. Careful planning is needed to provide high-capacity grid connections and make it possible for building contractors to connect to energy infrastructure on-site.

2.3. Role and Implementation

New abilities like carbon data analysis and the creation of low-carbon materials are required to progress decarbonization technology. The value chain for cooperation, information exchange, and talent development in the construction industry must be expanded. Sharing of information and risks will be facilitated via public-private partnerships. Through the use of standardized and repeatable building techniques, modular design may save waste by over 80% (Baldwin et al., 2009); (Ferdous et al., 2019). To make sure that carbon savings are achieved, construction companies may keep an eye on the progress of their projects. Modernizing design and materials standards would free the sector from ingrained habits, allowing it to accept new breakthroughs more quickly and incorporate low-carbon practices. Power purchase agreements or joint investment in new projects are necessary for the sector to guarantee a sufficient supply of renewable energy. Infrastructure for the transmission, delivery, and storage of energy must be created, and the location of manufacturing facilities and building sites should be based on the accessibility of low-carbon energy. In order to reduce demand for virgin materials, the industry should promote systems thinking, which takes into account emissions, cost, operations, maintenance, and demolition.

3. The Roadmap: Accelerating Decarbonization in Construction

Research offers 15 decarbonization options for the construction sector, all of which call for a gradual, stepwise approach.

- Rapid adoption and expansion of ready-now solutions with the aim of fostering long-term low-carbon investment are the short-term objectives (2023–2030).
- To achieve a significant shift in the industry in the medium term (2030–2040), commercial uses of cement and steel should be used.
- Long-term objective: Sector quickly adopts solutions, scaling to net zero by 2040+.

Different links in the value chain need to lead to various solutions in order for the chain to advance as a whole. While manufacturers can make low-carbon materials and equipment available, construction businesses may drive improvements in efficiency, skill sets, and contract models. The recommendations in this paper can facilitate an immediate drop in emissions and hasten the process of decarbonization. Although the speed at which this plan is being implemented may vary by location, the sector may learn from Western Europe's stringent legislation and investments in low-carbon materials to quicken the pace of change in certain areas. Despite the difficulties and complexity, research participants were optimistic about a net-zero future for the building industry. They recognized the necessity, opportunity, and urgency of cross-value chain collaboration.

4. Innovation Ecosystem

They recognized the necessity, opportunity, and urgency of cross-value chain collabo-ration. By 2030, the Indian green building sector is predicted to be worth $30–40 billion, representing a $1.4T investment potential. Startups are attempting to lessen the carbon impact of the building sector and advance sustainability. The AGNIi Mission, a centerpiece project of the Office of the Principal Scientific Adviser, provides funding to companies offering green building solutions that are both affordable and sustainable. Agrocrete, a carbon-negative construction material manufactured from agricultural waste and industry byproducts like steel, paper and power plants, is one example of an innovative solution. It is formed of lignifying thoughts. Buildings, landscaping, container yards, pathways, and parking lots may all benefit from the ecologically friendly, cost-effective Geopolymer Concrete Block technology, which provides an alternative to traditional walling materials. Textile Reinforced Concrete Prototyping Technology (TRCPT), a cutting-edge green building technique without moulds, is offered by AGNIi (Igniting Ideas). With the help of this technique, textile/fabric reinforced composite sheets in a variety of shapes and sizes may be produced for both structural and non-structural purposes. Through their Minion Energy Management Solution, Minion Labs provides real-time device-level electricity usage insights. This solution uses data and 5 AI practices to save electricity expenses, increase productivity, and lower climate risk, assuring energy efficiency and sustainability. By incorporating pollutants into the carbon tile, Carbon Craft Tile, an upcycled product manufactured from recycled materials, reduces air pollution. With less need for cement kilns and a less environmental effect, this unique tile is manufactured from recycled materials. Building materials like Paver Blocks, Tiles and Kerbstone may be made from 100% recycled materials thanks to RecycleX, which lowers construction's carbon footprint. To ensure a carbon-negative construction process, these elements include sand, aggregate, industrial waste, fly ash, and plastic. For consumers in both urban and rural areas, AVATAR compact wind turbines provide a distributed, decentralized renewable energy option. These turbines, which use multi-award-winning technology, make wind energy available and cheap for the average person, turning it into a vital and sustainable energy source.

5. Global Blueprint for Carbon-Reducing Construction

Urban Planning: Urban planning decisions and strategies not integrated across themes: Integration of priorities in urban planning: Place an emphasis on energy efficiency, create local and national plans, and make sure there is cooperation between the national and subnational levels.

For New Buildings: Most construction occurring in places with no codes for mandatory minimum energy performance: Put a strong priority on efficiency requirements through reducing carbon emissions, enforcing construction rules, and rewarding success.

For Existing Building: Performance of existing buildings generally unknown, few energy driven retrofits: Increase renovation rates, promote investment, and implement decarbonization measures for building retrofits.

For Building operations: Minimal use of tools for energy performance, disclosure and management: Adopt energy efficiency measures for building management, maintenance, and enhanced operations.

For Appliances and Systems: Average efficiency of appliance and systems much lower than best available technology: Develop and enforce minimum energy performance requirements, prioritize energy efficiency in public procurement.

For Materials: High embodied carbon of materials, low awareness of impact and options, little data and information: To lower embodied carbon throughout the whole production life cycle, create databases on embodied carbon, increase awareness, and encourage material efficiency.

For Resilience's: Some planning strategies for natural disasters but not widespread: By adopting integrated risk assessments, techniques for building adaptation, and resilience-incorporating new design, the initiative seeks to improve resilience in both communities and structures.

For Clean Energy: Significant use of fossil fuels; 39% population no access to clean cooking: 11% no access to electricity: The goal is to expedite the decarbonization of electricity and heat by implementing clear regulatory frameworks, financial incentives, promoting renewable energy, green power procurement, and clean cooking.

6. Conclusions

Improving energy and climate models and analytical tools for companies with high energy demands is essential to achieving the Paris Agreement commitments. Understanding changes requires looking at decarbonization pathways. It takes ground-breaking technology to address CO_2 emissions in steel and concrete, but these technologies may be combined to do so. Despite the creation of new technologies aimed at decarbonizing the energy-intensive construction sector, these technologies are not completely taken into account in the present modelling frameworks and policy discussions. Through cover strategies from market adoption and innovation policies through ultimate consumption, an all-encompassing industrial policy framework is required. In order to assure economic viability and achieve the aims of the Paris Agreement, it is essential to priorities research initiatives to support entities, organizational structures, and business models that encourage technology implementation.

Recommendations and Future Roadmap:

- Promoting sustainable manufacturing practices and policies in the construction sectors is the aim.
- The goal of the programme is to keep up research and development work to find and improve CO_2-emitting materials substitutes.
- By avoiding over-specification, encouraging component reuse, and encouraging the use of substitute materials with lower CO_2 emissions, the project strives to reduce the amount of construction materials used.
- Promoting the development of novel methods for decarbonizing the production of certain materials is the objective.
- To execute thorough decarbonization techniques in the building materials business, it is the objective to foster collaboration among researchers, industry stakeholders, and policymakers.
- The objective is to continually evaluate the environmental effect of building materials and to encourage the adoption of sustainable practices within the construction sector.

Author Contributions: Conceptualization, A.K.J. and N.K.; methodology, A.K.J. and N.K.; software, A.K.J. and N.K.; validation, A.K.J. and N.D.; formal analysis, A.K.J. and N.K.; investigation, A.K.J.; resources, A.K.J.; data curation, A.K.J.; writing—original draft preparation, A.K.J.; writing—review and editing, A.K.J. and N.K.; supervision, A.K.J. and N.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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