Current Status and Future Exploration of Methodologies for Voluntary Greenhouse Gas Emission Reduction Projects in the Building and Construction Sector

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Abstract. The building and construction sector is a significant contributor to global energy demand and greenhouse gas emissions, with carbon dioxide emissions accounting for 36% of global total emissions, making it a crucial component of the voluntary carbon reduction market. However, the existing methodologies in the building and construction sector are not match with the implementation of carbon neutrality targets, adjustments in industrial policies, and advancements in technology empowerment. Therefore, this paper aims to align with global carbon neutrality goals and promote comprehensive participation of the building and construction sector in carbon emission trading markets. First, it reviews the current development status of methodologies in the building and construction sector under seven widely used voluntary carbon reduction market systems. Second, it analyzes the differences between the methodologies focusing on carbon reduction perspectives and the carbon reduction potential of different application technologies. Based on this analysis, the paper provides relevant suggestions and actionable steps for the development of new methodologies for building and construction sector, including the selection of green building materials and the management of carbon emissions throughout the entire life-cycle of buildings.

Keywords: Voluntary carbon offset trading market; Methodology; Building and Construction Sector; Carbon reduction perspective in construction

1 Introduction

The building and construction sector is one of the three major industries worldwide with high energy consumption and emissions[1]. As shown in Figure 1, the current energy consumption related to buildings accounts for approximately one-third of the global total energy consumption, contributing to 36% of the global carbon emissions directly and indirectly, representing a significant proportion with substantial potential

© The Author(s) 2024
G. Zhao et al. (eds.), *Proceedings of the 2024 7th International Symposium on Traffic Transportation and Civil Architecture (ISTTCA 2024)*, Advances in Engineering Research 241,
https://doi.org/10.2991/978-94-6463-514-0_58

for energy-saving and carbon reduction[2]. Therefore, this industry faces immense pressure to reduce carbon emissions and requires significant adjustments to its current state in order to align with global efforts in combating climate change.

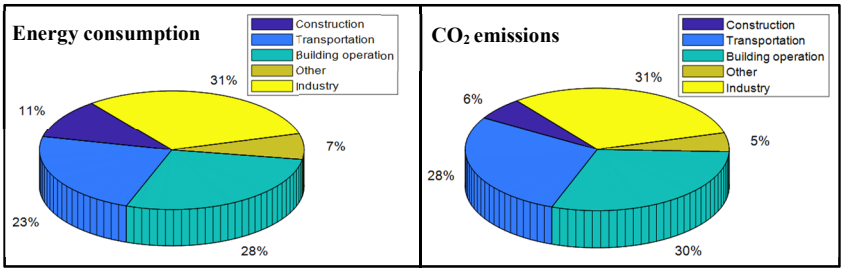

Fig. 1. Global construction industry energy consumption and CO_2 terminal share in 2021

The emergence of greenhouse gas emission trading markets has provided a new direction for the building and construction sector to reduce carbon emissions from both policy and market perspectives. Since the Kyoto Protocol proposed the establishment of greenhouse gas emission trading markets based on international law in 2005, the global carbon trading market has experienced explosive growth[3]. The carbon trading market consists of two main parts: the mandatory market for quota trading and the voluntary market for greenhouse gas emission reductions, as illustrated in Figure 2[4]. In the mandatory market, a quota allocation system is implemented for key enterprises, requiring high-emission companies to participate in carbon reduction and efficiency improvement[5]. In contrast to the mandatory market's quota system, enterprises and projects with emission reduction demands can participate flexibly in the voluntary market for greenhouse gas emission reductions. Currently, the building and construction sector mainly participates in the voluntary market for emission reductions[6].

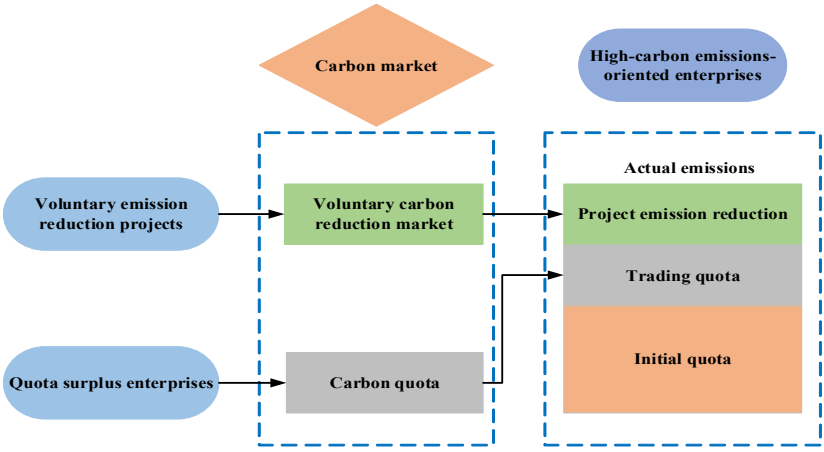

Fig. 2. Carbon market trading mechanism diagram

However, most emission reduction projects in the building and construction sector primarily focus on reducing the operational energy demand of buildings and the associated greenhouse gas emissions, while overlooking the greenhouse gas emissions associated with different stages of the building's lifecycle. The current participation in carbon emission trading markets does not effectively facilitate comprehensive energy saving and carbon reduction in the construction industry from both policy-driven and market-driven perspectives[7].

To demonstrate compliance with the rules of voluntary emission reduction and accurately quantify emission reduction volumes, it is crucial to develop methodologies for greenhouse gas voluntary emission reduction projects that are tailored to the characteristics and logic of the projects[8]. To comprehensively integrate the building and construction sector into the voluntary market for greenhouse gas emission reductions, it is essential to enhance and upgrade the project methodologies specific to the building and construction sector. These methodologies should be more adaptable to absorbing different decarbonization technology projects in the construction sector for participation in the voluntary market for greenhouse gas emission reductions. Therefore, this paper first introduces the current status of the development of project methodologies in the construction industry across seven global voluntary carbon markets, including international carbon reduction mechanisms, domestic voluntary mechanisms in various countries, and third-party independent voluntary reduction mechanisms. Subsequently, an analysis and overview of the differences between existing construction-related methodologies and the decarbonization potential of different applied technologies in the construction sector are developed. Based on this analysis, targeted recommendations and actionable steps are developed for the development of new methodologies for construction projects.

2 Current Development Status of Methodology in the Construction Industry

2.1 Overview of the Development of Construction-Related Methodologies across Different Market Systems

The building and construction sector, as a major global emitter of carbon, is a crucial component of the voluntary emission reduction market[9]. As shown in Table 1, various voluntary carbon market methodologies worldwide, including international carbon reduction market systems, domestic voluntary carbon reduction market systems in different countries, and third-party independent voluntary reduction mechanisms, all involve the construction industry. Among them, the Global Carbon Council (GCC)[16] has the highest number of methodologies related to the construction sector, with a total of 22 methodologies. Established in 2016 by the Gulf Research and Development Organization, GCC has received funding support from government organizations and the highest heritage committee. Its registered methodologies include all methodologies registered under the Clean Development Mechanism (CDM)[10]and three self-developed method-

ologies, totaling 227 registered methodologies, with the construction-related methodologies accounting for 9.69%. The Climate Action Reserve (CAR)[13] and American Carbon Registry (ACR)[12] have a relatively smaller number of registered methodologies, with 22 and 14 methodologies respectively, and the construction-related methodologies account for 13.64% and 21.43% respectively.

Further analysis reveals that although GCC has the highest number of construction-related methodologies and ACR has the highest proportion of construction-related methodologies, both fall far below the 36% global carbon emissions contributed by the construction sector. Therefore, from the current overview of the development of construction-related methodologies, it can be concluded that in order to incentivize comprehensive decarbonization of the building and construction sector through carbon markets, existing construction-related methodologies are in need of updates and expansion.

Table 1. Development of building methodologies under different carbon market systems

Market positioning	Voluntary carbon reduction market system	Methodology Total	Building and construction sector	Percentage
International carbon reduction market	Clean Development Mechanism (CDM) [10]	224	21	9.38%
	Verified Carbon Standard (VCS) [11]	49	7	14.29%
domestic voluntary carbon reduction market	American Carbon Registry (ACR) [12]	14	3	21.43%
	Climate Action Reserve (CAR) [13]	22	3	13.64%
	Chinese Certified Emission Reduction(CCER) [14]	279	13	4.66%
third-party independent voluntary reduction market	Gold Standard (GS) [15]	39	8	20.51%
	Global Carbon Council (GCC) [16]	227	22	9.69%

2.2 Common Features of Construction-Related Methodologies across Different Market Systems

Currently, these construction-related methodologies primarily focus on reducing carbon emissions generated during the operational phase of buildings, particularly in relation to energy supply and demand aspects. These methodologies can be classified into three main categories: reducing carbon emissions resulting from the interaction between buildings and public energy networks, reducing carbon emissions from the demand side energy requirements of buildings, and reducing carbon emissions from the supply side energy provision for buildings.

The first category is to reduce the carbon emissions generated by the interaction between buildings and public energy networks. The methodologies in this category focus on projects that involve equipment upgrades and technological advancements to minimize greenhouse gas emissions during the distribution of electricity and heat from public grids to buildings. Typical project methodologies include supplying power to communities through grid expansion and the establishment of micro-grids (CMS-070-V01) [14], providing electricity to rural communities through grid extension (CMS-020-V01) [14], and implementing low-carbon district heating through heat network renovation.

The second category is to reduce carbon emissions generated by energy demand on the demand side of buildings. The methodologies in this category involve projects that improve energy efficiency and reduce energy demand in buildings through equipment upgrades and technological advancements. Typical project methodologies include boiler retrofit or replacement (AM0044)[10], implementation of energy-efficient lighting technologies (AM0046)[10], and enhancing the energy efficiency of water pumping systems (AM0022)[10].

The third category is to reduce carbon emissions generated by energy supply on the supply side of buildings. The methodologies in this category involve projects within the construction industry that focus on improving building energy efficiency and implementing fuel conversion to reduce greenhouse gas emissions. Typical project methodologies include supplying energy to commercial buildings through combined heat and power(CHP)or trigeneration systems (VM0002)[11] and incorporating renewable energy in new residential buildings (CMS-041-V01)[14].

2.3 Differences of Construction-Related Methodologies across Different Market Systems

Currently, the potential differences in methodologies related to the construction industry within the international seven voluntary carbon reduction market systems can be summarized in four aspects: the definition and scope of the construction industry, carbon reduction calculation methods, project data standards, and market system interoperability[17].

Different methodologies within carbon reduction market systems have different definitions and scopes for the construction industry. Most carbon trading market methodologies focus on the operational phase of buildings, with only a few methodologies including building-related activities. For example, the VCS system includes methodologies for utilizing CO2 in concrete production (VM0043)[11]. Additionally, some methodologies within market systems limit the construction industry to specific types of buildings, such as commercial buildings and residential buildings. Examples include energy efficiency and renewable energy measures in new residential buildings and combined heat and power (CHP) or trigeneration systems supplying energy to commercial buildings within the CCER system, as well as energy-saving refrigerators and air conditioners (AM120)[10] in the CDM system as replacement or new sales projects for residential installations.

Different methodologies within carbon reduction market systems employ different carbon reduction calculation methods for building emission reduction projects. Currently, different carbon reduction market systems adopt different carbon reduction calculation methods for building emission reduction projects. Market systems such as CDM, CCER, and GS calculate the carbon emission reductions of building projects based on building energy efficiency standards and energy consumption data. In contrast, the VCS system utilizes more complex building and energy consumption models to obtain more accurate estimates of carbon emission reductions, with stricter baseline settings.

3) Different methodologies within carbon reduction market systems have different

data standards for building emission reduction projects. Besides carbon reduction calculation methods, another key factor in calculating emission reductions for building projects is the acquisition of baseline data. Different carbon trading market methodologies have varying requirements for data collection and reporting for building projects. For example, VCS-related methodologies require detailed energy consumption data and building material information to be collected and reported. On the other hand, other market systems such as ACR, CAR, and CCER have more flexible data requirements, allowing building projects to estimate and report data based on actual circumstances.

Differences exist in the interoperability of different market systems. The aforementioned points primarily highlight the differences in the internal structures of carbon reduction market systems. However, there are also external differences among different market systems, particularly in terms of their interoperability. Methodologies supporting carbon reduction projects within different market systems can be certified and traded not only within their respective markets but also in other markets. For example, ACR[12], CAR[13], and CDM10 projects can be traded not only within their own systems but also in the CBL market. GS[15], VCS [11], and CDM projects can be traded not only within their own systems but also in the CTX market. Meanwhile, GCC[16] and CCER[14] can only be traded within their respective platforms.

3 The Current Methodologies Related to the Building and Construction Sector have Shortcomings

Based on the analysis and comparison of methodologies related to the building and construction sector within different systems, it is evident that the existing methodologies primarily focus on different application scenarios of carbon reduction technologies in buildings. These methodologies support projects aimed at reducing carbon emissions during the operational phase of buildings, providing effective methodological guidance for low-carbon building operations. However, at the same time, carbon reduction in the construction industry is a systemic issue that lacks methodologies related to green material selection, low-carbon construction, and comprehensive management of carbon emissions throughout the entire lifecycle of buildings, including design, construction, operation, and demolition. This hinders the participation of emission reduction projects and technologies in the voluntary carbon reduction market.

3.1 Lack of Methodologies for Green Building Material Selection and Low-Carbon Construction

The design and construction stages are crucial components of the entire building life cycle, as they directly impact the energy demand over the building's lifespan of 50-60 years and have a direct influence on the overall carbon emissions of the building [18]. Researchers have conducted assessments based on building type, location, and material usage, and the evaluation results, as shown in Figure 3, reveal that the embodied carbon emissions during the design and construction stages can account for as much as 26% for traditional buildings and nearly 100% for zero-energy buildings[19]. However, the

current methodologies in the construction industry have not taken this into consideration.

From the perspective of architectural design, different types of building materials have different levels of carbon emissions, as shown in Table 2. At the same time, the quality of these materials also affects the energy efficiency and energy utilization of the building, directly determining the "green" level of the building. Green building materials, as a type of building material, stand out from traditional materials due to their advantages such as energy saving, emission reduction, safety, convenience, and recyclability. They can significantly reduce the consumption of natural resources and the impact on the ecological environment throughout their lifecycle. Therefore, if safe and durable green building materials are used in the production stage of a building, it can not only greatly extend the service life of the building but also directly reduce the carbon emissions in the material production and construction processes.

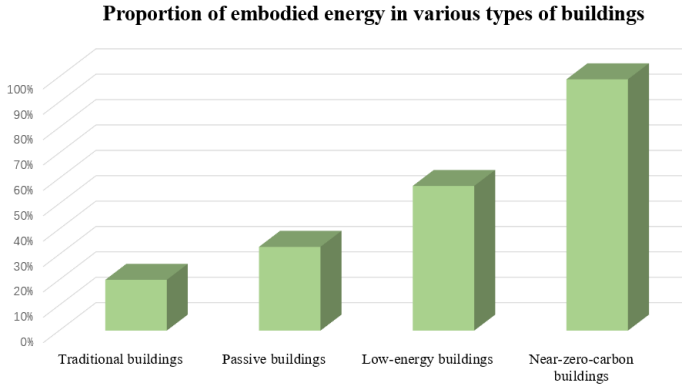

Fig. 3. Proportion of Embodied Carbon in Buildings

Table 2. Comparison of Unit Carbon Emissions for Different Building Materials

Material	Thermal conductivity (w/kg·K)	Price (RMB/m^3)	Carbon emissions per unit (kgco2e/m^3)
Molded Polystyrene	0.04	312	502
Polyurethane	0.024	457	627
Polyvinyl chloride	0.048	302	796
Rock wool board	0.036	780	1010
Perlite	0.175	175	328

3.2 Lack of Methodologies for Building Carbon Emission Management throughout the Life Cycle

The entire lifecycle of a building encompasses various stages, including design, construction, operation, and ultimate demolition[20-22]. Each stage contributes to varying

levels of carbon emissions, and the emissions generated in one stage can mutually influence emissions in other stages. For instance, the choice of green building materials during the design phase directly impacts carbon emissions during construction, operation, and demolition[23]. However, current methodologies in the construction field solely focus on carbon emissions during the operational phase of buildings, disregarding the carbon emissions and their interdependencies in the remaining stages.

Taking the Chinese construction industry as an example, as shown in Figure 4, the total energy consumption throughout the entire construction process reached 2.27 billion tons of coal equivalent (tce) in 2020, accounting for 45.5% of the national energy consumption[24]. The total carbon emissions throughout the entire construction process amounted to 5.08 tCO2, representing 50.9% of the national carbon emissions. Notably, carbon emissions in the production phase of building materials hold the largest share in the entire construction process. Therefore, to achieve effective carbon emission management, solely focusing on carbon emissions during the operational phase of buildings is far from sufficient. It is crucial to encompass all stages of the building lifecycle and ensure precise measurement and control of carbon emissions throughout the entire construction chain[25].

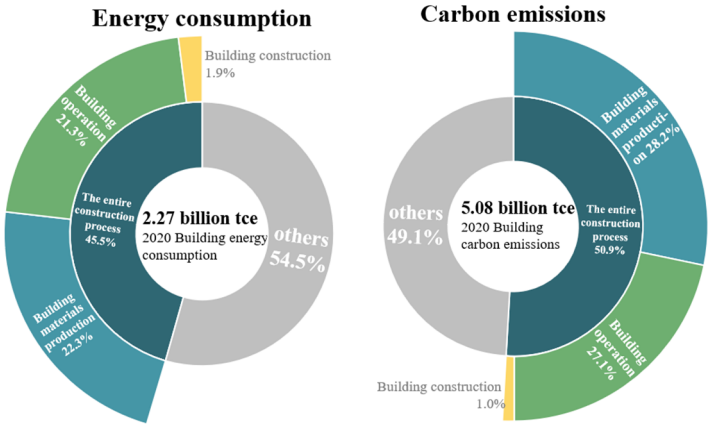

Fig. 4. The proportion of carbon emissions from the entire construction process in China

And current methodologies, in disregard of the fundamental impact of design decisions on carbon emissions. Secondly, existing methodologies often focus on a single carbon reduction measure, neglecting the synergistic effects as a whole. Although it may reduce carbon emissions to some extent, the actual effectiveness could be significantly compromised due to the failure to consider the impacts across all stages of the building. Therefore, systematic carbon management becomes crucial, as it is only through this approach that different decarbonization measures can be effectively coordinated and their effectiveness throughout the entire lifecycle ensured. Such limitations make it challenging for existing methodologies to comprehensively and effectively address the issue of carbon emissions in the construction sector.

4 Discussions for the Development of Methodologies in the Building and Construction Sector

With the implementation of carbon neutrality targets, adjustments in industrial policies, and the development of technology-enabled solutions, the existing methodologies in the construction industry are now at a crucial stage for renewal and expansion. Simultaneously, the purpose of methodology documentation is to provide technical frameworks and relevant standards for carbon reduction projects participating in carbon market transactions. To address these challenges, this paper based on the previous analysis of existing methodologies in the construction industry, provides recommendations and actionable steps for the development of methodologies in the construction sector. These recommendations and actions focus on the selection of green building materials, the adoption of emerging energy sources like hydrogen, carbon emissions management throughout the entire lifecycle of buildings, and the assessment of building carbon footprints.

4.1 Comprehensively Integrate Methodologies Related to Green Building Materials and Low-Carbon Construction

The use of green building materials and low-carbon construction are crucial aspects of energy conservation and emissions reduction in the construction industry. Green building materials, which significantly reduce resource consumption and environmental impact throughout their lifecycle, are becoming the "main battlefield" for achieving carbon-neutral transformation in the construction sector. Low-carbon construction, through the application of scientifically sound construction techniques and methods to minimize carbon emissions during the construction process, is an essential means of implementing green development in urban and rural construction.

From the perspective of selecting green building materials, the applicants of methodologies can consider incorporating intelligent selection of energy-saving glass, door and window systems, high-performance concrete, and low-carbon cement into relevant methodologies in the construction field. This can establish a unified standard system for the selection, production, design, construction, evaluation, and supervision of green building materials, actively promoting new types of environmentally friendly and energy-saving building materials. This will guide the transformation of buildings towards "high-end, green, and intelligent" green construction.

4.2 Establishing Methodologies for Carbon Emission Management throughout the Building Life Cycle

Methodologies for managing carbon emissions throughout the entire life cycle of buildings should encompass the entire process from design, construction, operation, to demolition[28]. It should not only consider the carbon emissions of the building itself but also take into account other factors such as the production, transportation, and disposal of building materials, as well as energy consumption during the building's use[26,27].

Emphasizing coordination and integration across all stages, this comprehensive management approach can provide a better understanding of the building's environmental impact, enabling more effective carbon emission management and optimization.

When considering the establishment of methodologies for managing carbon emissions throughout the building life cycle, applicants can consider developing a baseline methodology for assessing carbon emissions. This methodology should quantify the environmental impact of products and services over their entire life cycle, helping to identify and quantify carbon emissions throughout the entire process from design, construction, operation, to demolition. This provides a basis for developing effective decarbonization strategies for buildings.

4.3 Developing Methodologies for Building Carbon Footprint Assessment System

Accurate characterization of the carbon footprint of buildings and providing a clear answer to the question of "where carbon comes from" enables the transmission of micro-level to macro-level insights. It reveals the transfer and transference logic of "carbon" in the building industry under the backdrop of regional socio-economic development. From a long-term perspective, building carbon footprint analysis differs from managing carbon emissions throughout the building lifecycle. It effectively connects the upstream production process of building materials to the downstream carbon emissions of the building itself, breaking the lifecycle boundary for different product types. The establishment of methodologies related to building carbon footprint can provide technical support for achieving carbon neutrality goals in the building and construction sector. The methodologies for building carbon footprints can provide theoretical references for the building and construction sector's comprehensive participation in the carbon trading market, covering everything from the extraction and transportation of building materials to the final demolition of buildings. They also support the precise decision-making for carbon reduction projects at different stages.

5 Conclusion

In the context of achieving carbon neutrality goals, the development and improvement of methodologies are beneficial for the building and construction sector to pursue low-carbon development in a market-oriented manner. To promote the active participation of the building and construction sector in carbon reduction trading markets, this article reviews the current status of methodological development in the building and construction sector under seven commonly used voluntary carbon reduction market systems, including global international carbon reduction mechanisms, national voluntary mechanisms, and third-party independent voluntary reduction mechanisms. The results indicate that the current methodologies in the construction industry account for only 13.64%-21.43% of the methodologies in different market systems, which is significantly lower than the proportion of the building and construction sector's carbon emis-

sions in total emissions. Moreover, these methodologies primarily focus on the operational phase of buildings, which hinders the comprehensive participation of the building and construction industry in voluntary carbon reduction markets. Subsequently, the article summarizes the shortcomings of existing methodologies in the construction industry. Lastly, it provides development suggestions and actionable measures for the implementation of new methodologies in construction projects, including the selection of green building materials, the utilization of new energy types such as hydrogen energy, comprehensive management of building carbon emissions throughout their life cycle, and the establishment of building carbon footprint systems.

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