

Article

Transition from Technological Dominance to Total Management in Future Low-Carbon Building Industry

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Abstract

The room for reducing carbon emissions and improving low-carbon practices in the building industry is significant. In this study, a bibliometric analysis shows that technology is the primary mechanism adopted for driving carbon reduction in the existing practices building industry, which is conducted by using the CiteSpace 6.2.R4 tool. It is considered that there is a limitation in promoting further low-carbon practices by technological dominance without a proper management paradigm. This paper, therefore, aims to search for a new management paradigm in order to help further reduce emissions in the building industry. This study adopts an innovative synergy theory to explain the mechanism by which the efforts of all management dimensions can be synergized to promote low-carbon practices in the building sector. Consequently, the outcome of this paper is the introduction of a total low-carbon management (TLCM) paradigm. Synergy theory supports our assertion that a joint force can be formed within the building industry system to drive TLCM practice, as all building-related elements (government departments, building organizations, building personnel, building activities, and building processes) in the system will have to follow the government's actions towards low-carbon practices. The TLCM paradigm is integrated by five components: whole regulation, whole industry, whole enterprise, whole staff, and whole process. The new paradigm should be promoted to replace the existing technology-dominated paradigm in order to achieve low-carbon practices in the building industry. The TLCM paradigm will guide low-carbon management decisions and practices across all phases of the building project's lifecycle, together with integrating quality and risk management.

Keywords: building industry; low-carbon practice; management paradigm; synergy theory; systems approach



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1. Introduction

The International Energy Agency (IEA, 2024) recently issued the “CO₂ Emissions in 2023” report, indicating that global emissions continued to increase in 2023, with

global energy-related carbon dioxide emissions reaching 37.4 billion tons. The report also states that the global temperature has been changing every year, and the last eight years (2015–2022) have been the warmest on record. One of the major topics that the United Nations General Assembly (UNGA) has been addressing over the past years is climate change. The 2022 report by the World Wide Fund (WWF) for Nature International identifies a triple planetary crisis, which includes climate change, biodiversity loss, and air pollution [1]. The Copernicus Climate Change Service (C3S), which is the EU's Climate Monitoring Agency, released a report on the 9th of January 2024, indicating that 2023 was the hottest year on record in numerous countries worldwide. The global average temperature for 2023 was recorded at a staggering 14.98 °C, which surpassed the previous record set in 2016 by 0.17 °C. It was reported that the year 2024 has surpassed again the unprecedented temperature recorded in 2023 [2].

Faced with the global challenge of climate change, various responsive measures and a wide range of technologies have been introduced and implemented to address this issue both locally and internationally. Many countries have specified their dual carbon targets as governmental strategies to promote low-carbon development. For example, the Chinese government has set its dual carbon targets of peaking carbon emissions by 2030 and achieving carbon neutrality by 2060. The US government has set the carbon peaking and neutrality targets for 2007 and 2050, respectively, the Japanese government set them for 2020 and 2050, and both the UK and French governments set them for 1991 and 2020 [3]. The public has also been becoming increasingly aware of the responsibility to take all possible actions to reduce carbon emissions, such as using public transportation and using solar energy for living.

In the context of the building industry, it is widely appreciated that the industry is a major emitter globally, and it has a major responsibility to address the challenge of climate change by promoting low-carbon practices [4]. Various measures have been introduced in the technological domain to combat carbon emissions in the building industry [5–12]. These typical technologies include building-integrated photovoltaics (BIPVs), recycled concrete, passive house design, and smart-energy management systems [13–16]. Over the past several decades, governments around the world have introduced many regulations and measures to encourage the practice of a green low-carbon building industry. Two typical green building systems are BREEAM (Building Research Establishment Environmental Assessment Method), introduced in the UK in 1990, and LEED (Leadership in Energy and Environmental Design), introduced in the USA in 1998. BREEAM is one of the world's most popular environmental assessment methods for buildings. And LEED is a worldwide recognized green building rating system that promotes the sustainability of buildings by looking at the performance in the aspects of spatial development, water-saving schemes, material selection, indoor air quality, and innovation. Following the implementation of BREEAM and LEED, other green building systems have also been introduced globally, typically including HQE (High-Quality Environmental Standard), introduced in 1996 in France, HKBEAM (Hong Kong Building Environmental Assessment Method), introduced in 1996 in Hong Kong, Green Star introduced in Australia in 2003, Green Mark in Singapore in 2005, GB/T50378 [17] (Green Building Appraisal Standard) in China in 2006, and DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen) by the German Sustainable Building Council in Germany in 2007.

However, the challenge remains that the emissions from the building industry have been showing increasing trends. According to the report "Research Report of China Building Energy Consumption and Carbon Emissions (2022)", the total energy consumption of the entire construction process in China increased from 950 million tons of coal equivalent (tce) in 2005 to 2.27 billion tons of coal equivalent (tce) in 2020, a 2.4-fold increase,

with an average annual growth rate of 6.0%. And the life cycle carbon emissions in the construction sector in China in 2020 were 5.08 billion tons, accounting for 50.9% of the total national carbon emissions, and this figure is expected to grow much higher in the near future. According to Deo Prasad [18], the carbon emissions in the Australian building industry are one-fifth of the national emissions, and this may increase further as Australia's building stock is estimated to double by 2050 based on the 2019 level [19]. The Hong Kong Construction Industry Council (2020) reported that the built environment accounts for 71% of Hong Kong's territorial carbon emissions. These facts show that limited effectiveness has been gained in promoting low-carbon practices in the building industry.

The above discussions demonstrate that the efforts devoted to date for addressing the challenges of climate change are largely in the technological domain. The existing research mainly focuses on the technological field to promote carbon reduction in the building industry. However, relying solely on technological advancements is insufficient to control the increasing trend of carbon emissions in the building industry [20,21]. While innovations like BIPV, recycled concrete, and smart energy management systems offer considerable potential, their widespread adoption and maximal efficacy are frequently constrained by the absence of a total management framework. Consequently, this technology-centric approach often encounters practical limitations in achieving transformative reductions, largely due to its tendency to overlook the intricate interplay of human behavior, systemic inefficiencies, and fragmented management practices throughout the building lifecycle. There is less effort devoted to exploring new management paradigms for further promoting low-carbon practices in the building industry, which aims not only to embrace technologies but also to request cohesion between different management dimensions. The attainment of a low-carbon building future would continue to remain elusive if the technology-dominant practice remains unchanged. Therefore, this paper aims to search for a new management paradigm in order to help further reduce emissions in the building sector. This paradigm significantly improves current technology-centric models by advocating a synergistic theory. It aims not only to effectively adopt technologies but also to ensure robust control over the whole process of emissions generated within the built environment. And the application of the new management paradigm is expected to help reduce carbon emissions to a new level by not only using technology effectively but also controlling the whole process where emissions are generated in the building sector.

The novelty of this study includes: (1) revealing three main domains for promoting low-carbon buildings through a bibliometric literature analysis: technology domain (TD), management domain (MD), and application domain (AD), and finding that TD has been adopted as the main mechanism for reducing building carbon emissions; (2) demonstrating the limitations of the existing technology-dominant pattern in promoting low-carbon practices in the building industry; (3) introducing a total low-carbon management paradigm (TLCM) based on synergy theory to facilitate further emission reduction in the building sector. The new management paradigm is expected to drive the building industry to effectively reduce carbon emissions. The rest of the paper is structured as follows: Section 2 will present the research methods. The total low-carbon management (TLCM) paradigm will be proposed in Section 3. Section 4 will present component specifications in the context of TLCM. Section 5 will present the discussions. Section 6 will conclude the study.

2. Research Methods

A research roadmap was designed to conduct this study, as shown in Figure 1.

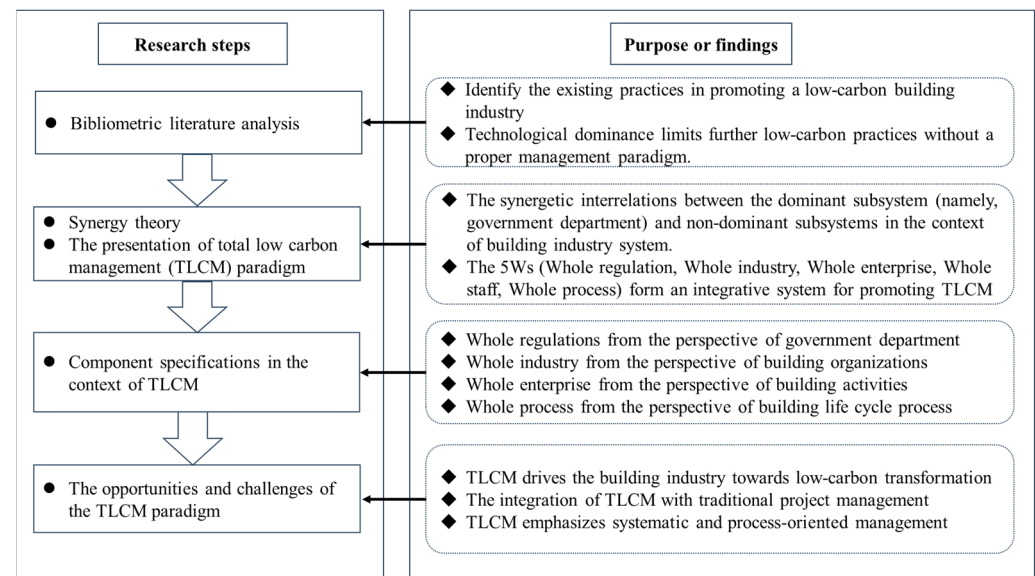


Figure 1. Research roadmap.

According to the research roadmap, the methodology of this study consists of two parts. The first part is a bibliometric literature analysis, which is a proven effective tool to systematically review existing literature. The adoption of this analysis tool will help reveal the research performance and development in the field of low-carbon buildings and identify the current shortcomings in carbon reduction within the building industry. This analysis will then form the rationale for the need to seek a new paradigm in order to further reduce emissions in the building sector. The second part of this study will apply synergy theory to develop the total low-carbon management (TLCM) paradigm, enabling the coordination between various elements within the building sector with the aim of practicing effectively low-carbon buildings. Therefore, the TLCM framework proposed in this paper is both innovative and promising. Its development was a rigorous process, built upon a comprehensive literature review and identifying critical gaps in current approaches. This foundational research was then critically validated through a series of expert workshops. Furthermore, a comprehensive TLCM framework, comprising its TLCM paradigm and the components, was proposed through expert workshops.

2.1. Bibliometric Literature Analysis

Existing research works on low-carbon development in the building industry primarily focus comprehensively on technological issues such as low-carbon technology innovation, low-carbon building materials, building energy efficiency, low-carbon design and practices, and the assessment of building carbon emissions. It appears, nevertheless, that little research effort was devoted to examining management modes for promoting low-carbon practices across the building industry.

We have conducted a comprehensive bibliometric literature analysis by using the data analysis tool CiteSpace 6.2.R4 to review existing literature relevant to low-carbon practices in the building industry. CiteSpace 6.2.R4 is an effective method to examine the co-occurrence of keywords embodied in the literature and conduct the keyword burst analysis using a word frequency algorithm [22]. Through co-occurrence analysis, the keywords that frequently appear within a large number of literature documents can be identified. According to the results of bibliometric literature analysis, important research areas about low-carbon practices in the existing studies can be understood.

Web of Science (WOS) was selected in this paper as the literature search engine, and the data were collected from the Web of Science Core Collection. This database is authoritative

in terms of journals, publications and the classifications of research fields, which ensures the sufficiency for carrying out a literature visualization analysis [23]. There are other databases available for retrieving literature, such as Scopus and Google; however, it has been found that the data in Scopus and Google have a lot of duplications with the data included in WOS. Furthermore, some information in Scopus and Google databases is rather informal, which may lead to inappropriate conclusions [24].

Data used in this study were collected in December 2024 from the Web of Science (WOS) Core Collection (SCI and SSCI). The search parameters were designed as “TS= (“building industry” OR “building sector” OR “construction industry” OR “construction sector”) AND TS= (“carbon reduction” OR low-carbon OR “reduce carbon emission*” OR “carbon emission* reduction” OR “carbon abatement”)”. The search time span was set before 24 December 2024. The search specifications are further refined by document types “Article” and “Review Article”, and the language “English” was chosen. Based on these defined search parameters, a total of 1070 literature papers were retrieved. To ensure the quality and accuracy of the literature analysis, the abstracts of all retrieved papers were examined by the authors to weed out irrelevant ones. Finally, 1062 papers were selected for bibliometric analysis and further discussions.

According to the literature articles retrieved, it was observed that literature relevant to the field of the low-carbon building industry was largely absent before 2000. Then, there was a steady increase in publications in this field since 2010. Co-occurrence analysis results were obtained by using the CiteSpace 6.2.R4 tool, as shown in Figure 2. The size of the nodes in Figure 2 represents the frequency level of keywords, where the larger the nodes, the more frequently the keywords appear in the literature. High-frequency keywords reflect the hotspots in the research discipline of the low-carbon building industry. The lines between the nodes in the figure represent the co-occurrence relationships among the keywords, and the width of the lines indicates the intensity of the co-occurrence of different keywords; the wider the lines, the more intense the co-occurrence between the corresponding keywords.

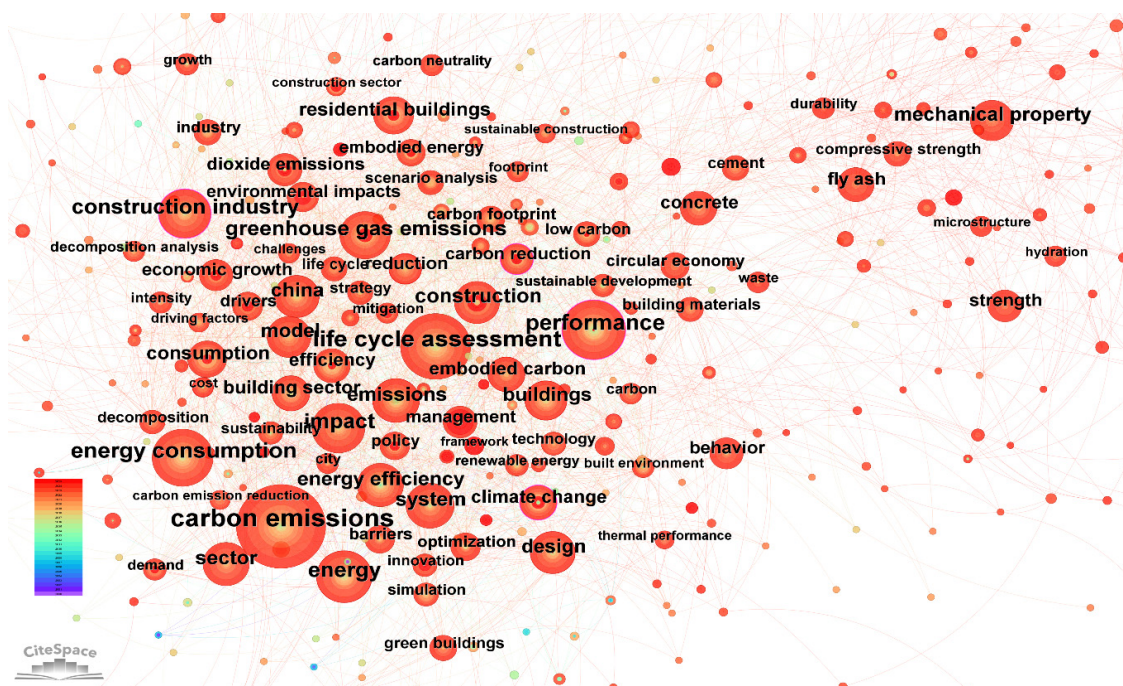


Figure 2. Co-occurrence analysis on research keywords in relation to the low-carbon building industry.

As can be seen from Figure 2, the most frequent research keywords include “carbon emissions”, “life cycle assessment”, “performance”, “energy consumption”, which reflect the focus of research on low-carbon development in the building industry. Based on the co-occurrence network map (Figure 2), the relevance between keywords was identified by calculating the frequency of their co-occurrence in the same document. Table 1 lists the keywords that have a high frequency of occurrences of appearing more than 20 times. These keywords can be broadly classified into three domains: technology domain (TD), management domain (MD) and application domain (AD). These domains were derived from a systematic review of the existing literature and informed by previous research [25–27]. The research keywords in the technology domain (TD) are mainly related to green building materials, energy and emission measurements, technological standards of green buildings, and technological innovations. The research keywords in management domain (MD) are mainly related to life cycle assessment, behavioral management and supply chain management. And the research keywords in the application domain (AD) are mainly related to specific application contexts such as China, the construction industry, the building sector, etc.

Table 1. High-frequency keywords.

Keywords	Occurrence	Domain	Keywords	Occurrence	Domain
carbon emissions	285	TD	carbon reduction	41	MD
life cycle assessment	179	MD	management	41	MD
performance	142	MD	environmental impacts	39	TD
energy consumption	135	TD	embodied energy	38	TD
energy	118	TD	barriers	35	TD
impact	109	MD	drivers	35	TD
construction industry	107	AD	policy	34	MD
GHG emissions	97	TD	optimization	33	MD
construction	87	TD	carbon footprint	32	TM
system	79	TD	circular economy	32	MD
emissions	77	TD	industry	30	AD
energy efficiency	76	MD	building materials	28	TD
sector	76	AD	cement	28	TD
china	74	AD	green buildings	28	TD
design	72	TD	low carbon	28	MD
model	70	TD	life cycle	26	MD
mechanical property	68	TD	compressive strength	25	TD
buildings	67	TD	scenario analysis	25	TD
residential buildings	61	TD	strategy	25	MD
consumption	60	MD	decomposition	24	TD
building sector	56	AD	simulation	24	TD
efficiency	54	MD	sustainability	24	TD
embodied carbon	54	TD	technology	24	TD
climate change	53	TD	innovation	23	TD
concrete	51	TD	carbon	22	TD
fly ash	50	TD	city	21	AD
dioxide emissions	47	TD	decomposition analysis	21	TD
reduction	44	MD	durability	21	TD
strength	43	TD	intensity	21	TD
behavior	42	MD	mitigation	21	MD
economic growth	42	MD	sustainable development	20	MD

In Table 1, there are 62 keywords in total; among them, 2031 are in technology domain (TD) (accounting for 58.97%), 1049 in the management domain (MD) (accounting for 30.46%), and 364 in the application domain (AD) (accounting for 10.57%). These data can be

further presented in Figure 3. Figure 3a shows the distribution of the number of keywords and Figure 3b presents the distribution of the keyword frequency.

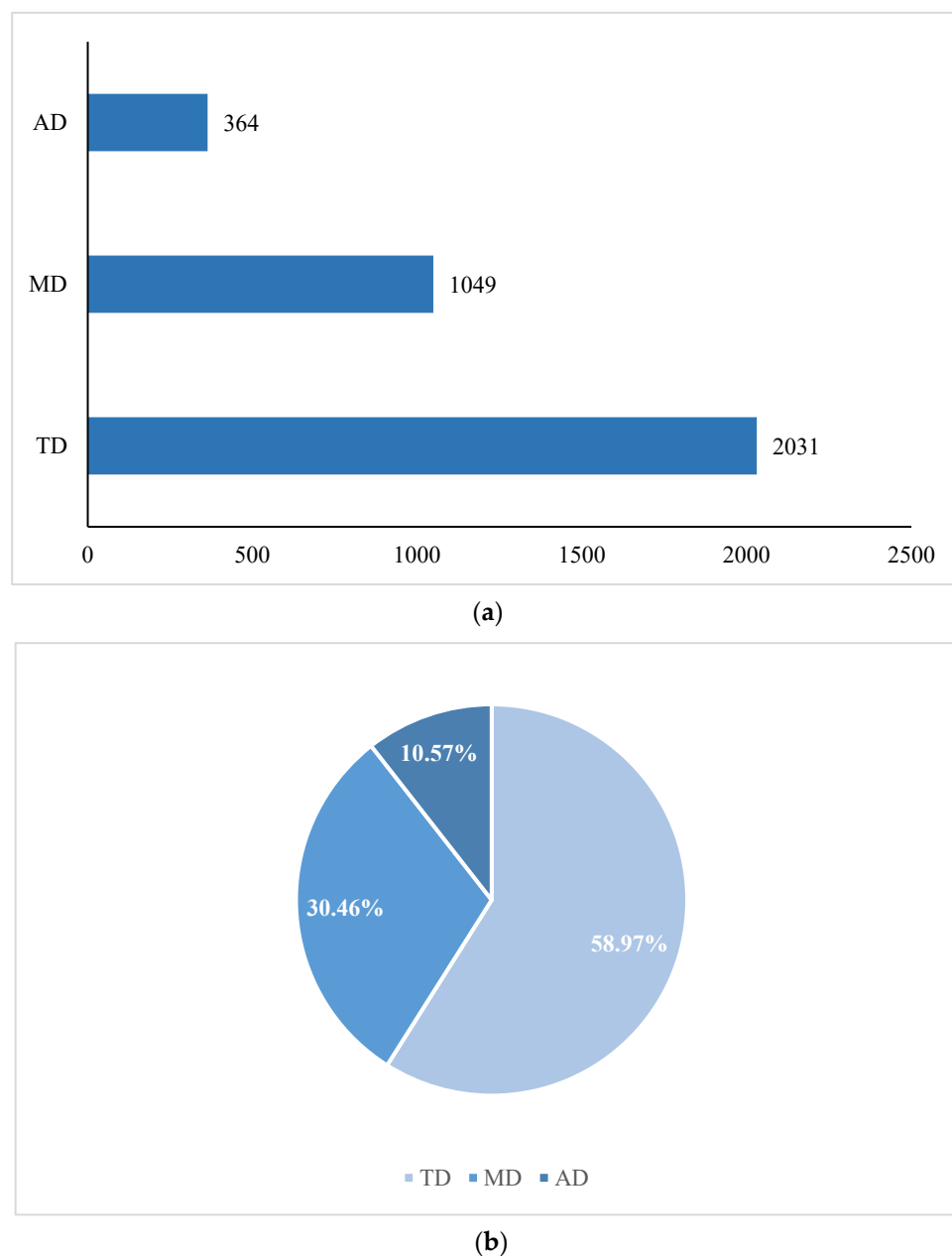


Figure 3. Distribution of research keywords in the discipline of low-carbon building industry. (a) Distribution of the number of keywords. (b) Distribution of the keyword frequency.

Table 1 and Figure 3 show that the most frequently occurring keywords are within the technology domain, which encompasses methods for effectively applying advanced technologies and materials for promoting low-carbon practices in the building industry. It can be noted that fewer keywords are within the management domain, suggesting that less research effort was devoted to addressing the roles of management modes for promoting low-carbon practices in the building industry. In other words, the existing practice in promoting a low-carbon building industry is technology-dominated. The reason for this is in multiple aspects. (1) The outcomes from applying technologies for emission reduction are typically measurable; (2) technological advancements can bring immediate and visible effects of emission reductions, making them highly attractive to policymakers and busi-

nesses; (3) there is a lack of a systemic perspective on carbon reduction challenges, which is not only a technical issue but also an issue relating to legal, process, stakeholder and other aspects. It is therefore considered that the technological dominance paradigm has limitations in further promoting low-carbon practices. Although other management paradigms, such as Total Quality Management (TQM), are available, they focus on improving overall organizational efficiency and customer satisfaction through quality enhancement. However, reducing carbon emissions is an issue of more than quality control. It is, therefore, necessary to investigate an innovative management paradigm to further promote the reduction in emissions in the future building industry.

2.2. Synergy Theory

Synergy theory is used in this study to investigate the innovative management paradigm in order to further promote low-carbon practices in the future building industry. Synergy theory is a development from the application of the systems approach. The theory explores how components within complex systems collaborate to produce effects that exceed the capabilities of individual parts [28]. According to the principle of Synergetics [29], the state of an open system is governed by one or a few dominant subsystems, which are called the order parameters in synergy terms. In other words, the dominant element or order parameter in an open system determines the development of the whole system. Other non-dominant elements in the system are called slaving elements or subsystems. The effective operation of an open system will be guaranteed by the fact that the slaving subsystems work according to the order imposed by the order parameter.

In applying synergy theory in this study, it is necessary to consider the building industry as a system and define the order parameter or dominant element in this system. Nevertheless, it is widely appreciated that the building industry is a complex and open system that is composed of many parts across building participants, building activities and building processes [30]. The key participants in the industry include government departments, building organizations, and the people working in the industry [31]. Therefore, in broad terms, the complex system of the building industry includes five subsystems or elements: government, building organization, building personnel, building activity, and building process, as shown in Figure 4. Referring to Figure 4, the way the five subsystems within the building industry system work in synergy can be examined by applying the synergy theory.

In referring to the system of the building industry in Figure 4, the subsystem of the government department is the dominant subsystem (order parameter). The government department introduces laws, designating regulations and codes of practice for the development and operation of building activities. According to the principle “law is above all”, regulation is therefore the order parameter in the system of the building industry [32]. The regulations implemented by the government department are used to oversee the life cycle process of a building across planning, design, construction, and operation stages, and to coordinate the interactions and collaborations between different types of building companies. Figure 5 presents graphically the synergetic interrelations between the dominant subsystem (namely, the government department) and non-dominant subsystems in the context of the building industry system.

The above discussions show the rationality of using synergy theory to investigate an innovative paradigm for the building industry.

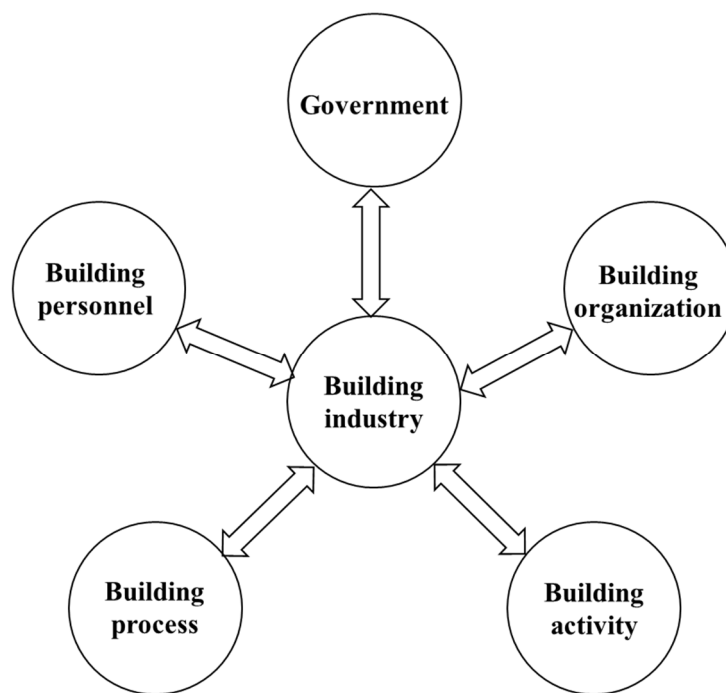


Figure 4. The composition of a typical building industry system.

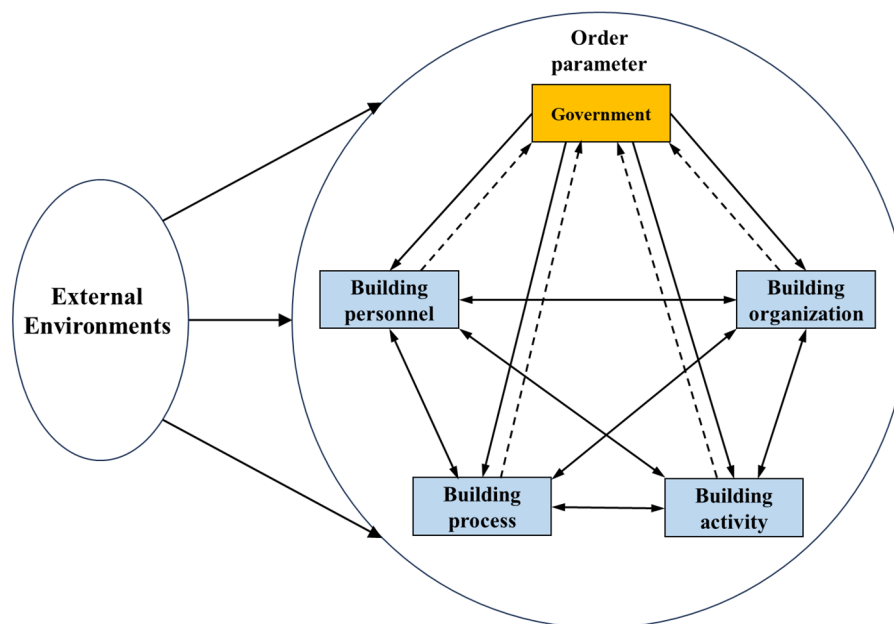


Figure 5. Building industry system from a synergetic perspective.

3. Total Low-Carbon Management (TLCM) Paradigm

As an open system, the building industry is interactive with its external environment and conditions, and all its subsystems will be affected by the changes in the external environment. According to synergy theory, when the external influence or turbulence forces are sufficiently strong, the dominant subsystem (or order parameter in synergy terms) will change its specifications and lead the system to a new state or new development direction. In this case, other subsystems will follow the suit of the order parameter to change to new specifications or states.

On the other hand, according to the discussions presented in the introduction section, the external environment for the practices of the building industry has changed funda-

mentally in recent years in order to address the global challenges of climate change [33,34]. Building industries throughout the world are under great pressure to take action and engage in low-carbon practices [35]. Therefore, the building industry has to respond to these external changes by producing green and low-carbon buildings. For example, the government sector will change building codes and standards to meet the requirements of green and low-carbon buildings. Building clients choose energy-efficient and environmentally friendly buildings. Material suppliers offer green and low-carbon materials and invest in technological innovation. Designers, in turn, will consider the environmental impact of buildings, particularly in terms of energy consumption, carbon emissions, and resource utilization efficiency. To facilitate the effective response from the building industry to external changes, the management paradigm for the industry has to shift to one that can effectively take up the challenges. The government, as the order parameter in the building industry system, has to change the mindset and transfer the management paradigm of the industry from a traditional technological low-carbon paradigm to a total low-carbon management paradigm.

In fact, governments in many countries have been shifting their management approach for overseeing the building industry by introducing measures such as green building laws and regulations to reduce building carbon emissions [36–38]. For example, the government in China introduced policies in 2013 to promote the development of green and low-carbon buildings, such as the “Green Building Action Plan” [39]. The European Union launched the “Energy Performance of Buildings Directive (EPBD),” in 2024, which mandates member states to achieve “nearly zero-energy buildings” by 2050 [40]. The United States has set energy efficiency requirements through codes such as the “International Energy Conservation Code (IECC)” launched in 2024, covering areas like heating, ventilation, and air conditioning (HVAC), lighting, and building envelope [41]. Japan promotes green building development through the “Building Energy Efficiency Regulation,” which mandates energy-saving standards, and encourages the adoption of green building certifications like the Comprehensive Assessment System for Built Environment Efficiency (CASBEE) through its “Green Building Design Standards” [42].

However, according to the synergy theory, as discussed earlier in this paper, all other elements within the building industry system have to follow the order of the order parameter (government) to transition to low-carbon practices. In other words, all subsystems, including building organizations, building personnel, building activities and building processes, must respond synergically to external change and engage in low-carbon practices. When all the subsystems engage in carbon practice, a total low-carbon management (TLCM) paradigm is presented. TLCM, therefore, is a new and innovative management paradigm that is sustainability-oriented and pursues contributing to further reducing carbon emissions in the building industry. In the technological domain, the new management paradigm prioritizes the promotion of low-carbon practices along the chain of all types of building organizations across all types of construction activities in the whole building life cycle process.

In referring to Figure 5 presented in the previous section, each subsystem has a specific role in engaging low-carbon practices: whole regulations from the perspective of government department; whole industry from the perspective of building organization; whole staff from the perspective of building personnel; whole enterprise from the perspective of building activities; and whole process from the perspective of building life cycle process. The 5Ws (Whole regulation, Whole industry, Whole enterprise, Whole staff, Whole process) form an integrative system for promoting TLCM, as shown in Figure 6. The 5Ws work in synergy towards the low-carbon building industry, in which the element “whole regulation” assumes the role of the dominant element (the order parameter).

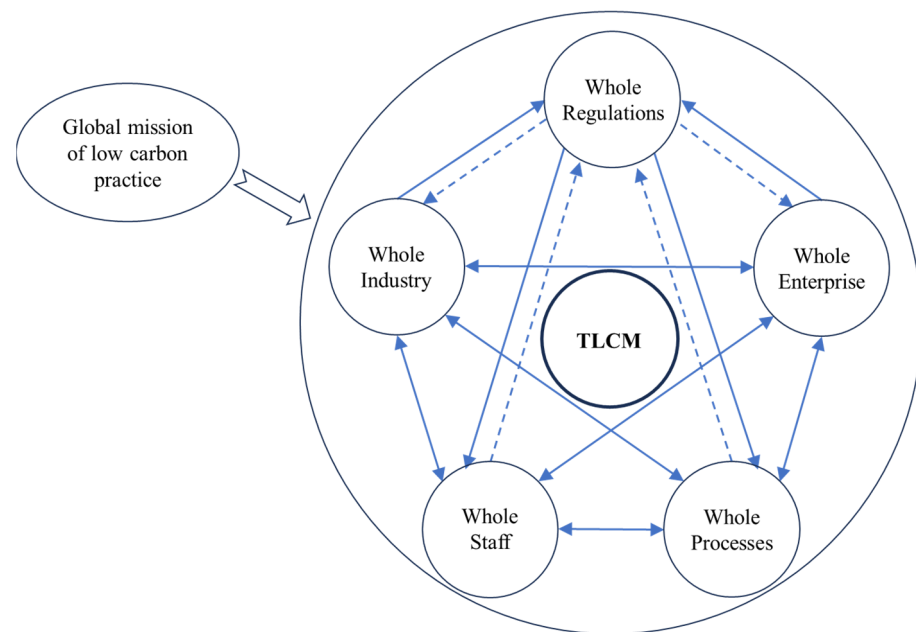


Figure 6. The 5Ws for promoting the TLMC paradigm in the building industry.

Figure 6 depicts the management paradigm in the future building industry, a mode of total management integrated by five components. The detailed specifications of each component will be discussed in the following section.

4. Component Specifications in the Context of TLMC

The analysis in the above section presents a total low-carbon management (TLMC) paradigm for the future building industry that will be transitioned to practice. This management paradigm transition will have fundamental impacts on the specifications of all the components within the building industry system.

4.1. Whole Regulations from the Perspective of Government Department

In promoting the TLMC paradigm in the building industry, the government department, as the dominant element, needs to design and implement regulations for guiding the whole building industry towards low-carbon practice, specified as whole regulations [43–48]. The government department has the authority and responsibility to modify existing regulations and introduce new regulations in order to guide and supervise the building industry's transition to low-carbon practices. For example, codes, norms and standards should be revised or updated to shift to using renewable energy, contributing more investments to projects that apply clean energy, reducing finance for projects applying fossil fuel energy, changing contract terms in favor of those low-carbon businesses, etc. In a typical case, the government should consider imposing the provision of an Environment, Social and Governance (ESG) report as part of tendering documents in the process of recruiting participants in the building industry, including construction clients, contractors, and consultants [49].

4.2. Whole Industry from the Perspective of Building Organizations

Low-carbon actions should be implemented across all types of building organizations in the whole industry, along the chain of developers, clients, contractors, materials producers and suppliers, designers, contractors and consultants. All these organizations are engaged with the building industry in different business contexts, and they have to follow the lead of the government department and promote low-carbon development in their own

domains. For example, contractors should use advanced construction techniques, such as prefabricated components and BIM technology, reduce the use of carbon-intensive materials, minimize energy consumption, optimize construction schedules to improve efficiency, and properly dispose of construction wastes to promote the recycling of materials [50–53]. Designers should comply with green building codes, select materials and equipment that have lower carbon emissions, adopt passive design strategies to reduce the building's energy consumption, and integrate renewable energy solutions, such as solar and wind power [54–56]. Moreover, building design should focus on improving space utilization efficiency and adopting multifunctional space designs, which can help reduce material waste and energy consumption, thus leading to a reduction in carbon emissions [57].

Developers should adhere to green building certifications such as LEED to ensure that building design and construction processes can meet high environmental and energy efficiency standards [58]. On the other hand, in the context of building design, we need to answer some fundamental questions, such as do we need to design large-size residential apartments? Do we need to design luxury buildings where large volumes of fossil energy are embedded in building materials and various appliances? Developers and clients should prioritize the development and purchase of low-carbon buildings [59]. Suppliers should supply low-carbon products and promote a green supply chain to ensure the sustainability of material sourcing [60–62].

Those organizations that have advantages and experiences in promoting low-carbon practices shall be exemplified in taking actions to implement low-carbon practices. They should be encouraged through incentive mechanisms to share their best low-carbon practices and promote a low-carbon chain among all types of building organizations in the building industry.

4.3. Whole Enterprise from the Perspective of Building Activities

Building activities involve the collaboration among various departments within a building enterprise, such as planning, procurement, project management, construction management, finance, logistics, and sales and marketing departments. Along with the transition to the TLM paradigm in the building industry, all departments in any type of building enterprise have to cultivate a green and low-carbon working culture within their functional areas. TLM requires close collaboration among various organizational departments to adopt low-carbon practices in different building activities. Emission reduction efforts should be particularly given to densely emitted activities such as on-site construction, materials delivery, material purchasing, machine operations, etc. Project planning activities play pivotal roles in reducing emissions as they will affect what building materials and construction methods are to be applied, although they do not directly generate emissions.

In specific terms, the procurement department should prioritize recruiting low-carbon contracting firms, selecting green material suppliers and purchasing products that have environmental certifications; establishing a comprehensive low-carbon supplier assessment and management system; and adopting electronic procurement systems to facilitate paperless transactions [63,64]. Other researchers also pointed out that low-carbon procurement should seek to reduce carbon in the supply chain, ensuring environmental sustainability by selecting materials and services that minimize environmental impacts at the source [56,65].

The project management department, which is responsible for implementing specific building projects, should consider reducing wasted resources and non-essential works through accurate project planning and scheduling; allocate low-carbon objectives into different project phases; and monitor and assess carbon emissions during project implementation [66–70]. Furthermore, some preconstruction activities must be carried out by

the project management department, such as environmental impact assessment, which can tell beforehand the environmental consequences of the construction and ensure that fewer carbon emissions and environmental impacts are generated during the construction stage [63].

The construction management in a building organization is typically responsible for on-site construction works. This department should employ energy-efficient equipment, implement waste recycling and resource reuse programs, and enforce strict environmental standards at the construction site in order to reduce carbon emissions [50,71–73]. Other environmentally friendly construction methods, such as using trucks that operate on renewable energy fuels, should also be adopted on-site [74,75].

The finance department in a building business should prioritize financial support for low-carbon projects and seek the return on low-carbon investments; review and track environmentally related costs and savings to provide data support for low-carbon decision-making; and set up financial incentives to encourage low-carbon activities and behaviors [76,77].

The logistics department should implement efficient inventory management systems to reduce over-storage and over-transportation of building materials [78]. Previous studies also suggested that energy consumption during transportation accounts for about 20% of the total energy consumption in the construction industry [79]. Logistics activities should be planned to reduce the number and distance of material and equipment shipments.

The sales and marketing department should shift towards digital marketing; strengthen the promotions of low-carbon products; conduct market research to understand consumer demand and preferences for low-carbon buildings or products; and develop marketing strategies targeted at environmentally conscious consumers and partners [80–82].

4.4. Whole Process from the Perspective of Building Life Cycle Process

Each process in the building life cycle will have environmental impacts in terms of energy consumption and carbon emissions. TLMCM requests the application of low-carbon measures for the whole process across the building life cycle, including a low-carbon feasibility study; low-carbon design; low-carbon procurement, which requires an ESG report; low-carbon construction; low-carbon operation; and low-carbon demolition [83]. The implications of low-carbon procurement and low-carbon construction have been addressed in the above section.

A low-carbon feasibility study for a building project aims to assess the viability of implementing low-carbon strategies and provide references for subsequent low-carbon design and decision-making [63,84]. The principles and requirements of low-carbon practices should be incorporated as evaluation criteria for conducting a feasibility study of a building project. Following low-carbon feasibility, low-carbon design establishes specific specifications for reducing carbon emissions throughout the building life cycle process, mainly by adopting energy-saving layouts and low embodied energy materials [56]. Building design must be thoroughly evaluated to ensure that it serves as the benchmark for low-carbon practices across all building activities [15].

As addressed in the previous section, low-carbon construction is a crucial component in promoting low-carbon practices during the building life cycle process, as the construction process is the most emission-intensive [65]. Low-carbon construction methods and energy-efficient construction equipment should be employed. Following the construction stage is a building's operational phase, which is recognized as the largest carbon emission contributor in a building's life cycle, accounting for 60–80% of the total emissions generated throughout the lifecycle [85,86]. It is therefore essential to promote low-carbon practices at the operation stage, which typically involves using high-efficiency and energy-saving

devices and systems to reduce energy consumption, such as Light Emitting Diode (LED) lighting and high-efficient HVAC (heating, ventilation and air conditioning) [87]. Chua, et al. [88] also pointed out that typical measures of reducing emissions in building operations include using renewable energy technologies such as solar panels, wind turbines, and geothermal systems, and reducing the dependence on fossil fuels, etc. Employing building automation systems (BASs) is also appreciated as an effective emission reduction measure in a building's operation process [89].

Furthermore, at the stage of demolition in a building's life cycle, low-carbon demolition practices emphasize the reduction in demolition waste generation and carbon emissions through the adoption of environmentally friendly demolition methods and material recycling strategies [90]. The construction industry's low-carbon demolition methods include a series of innovative demolition technologies, such as Soundless Chemical Demolition (SCD) and Induction Heating Demolition (IHD) [91].

4.5. Whole Staff from the Perspective of Building Personnel

The TLCM paradigm requests the practice of low-carbon behavior among the whole staff. All people or members in the building sector have the responsibility of promoting low-carbon behaviors. Building personnel engage in different activities at different building life cycle stages, and they can promote effective implementation of low-carbon measures across all building stages. Managerial staff positions are at the core of the organization, and they should set examples in practicing low-carbon behaviors [56]. On the other hand, managers can introduce incentive programs to promote low-carbon behaviors among all staff. Cao, et al. [92] opined that the incentive mechanism can effectively encourage employees to practice low-carbon activities. Furthermore, organizations should provide staff with education and training programs on low-carbon knowledge, which contributes to empowering staff to practice low-carbon behaviors and cultivating a low-carbon culture among all staff [93,94].

5. Discussions

Although there are no empirical findings from previous sections, as this is not an empirical study, the outcome of the analysis is a new management paradigm, namely the total low-carbon management (TLCM) paradigm, which enables further emission reduction in the building industry. It is believed that the international promotion of green development and dual carbon targets designated by governments will lead to shifting the management paradigm for the building industry to a total low-carbon management (TLCM) paradigm. As it is well appreciated that the building industry is a major emitter, this shift to TLCM is essential for the building industry internationally in order to assume the responsibility of addressing the challenge of emission-induced climate change. This means that the technologies, the human skills, and the norms and standards needed for the future building industry will change. In line with this management paradigm development, all the stakeholders in the building industry have to take measures to prepare themselves for adapting to this management transaction, as specified in the above section.

The TLCM paradigm will drive the building industry to transition to a low-carbon construction pattern. That will present opportunities for regenerating building products, improving the quality of the working environment in the industry, and building up a better and greener image of the industry. On the other hand, in the era of promoting TLCM in the future building industry, the demand for low-carbon construction products from the whole public will increase substantially, which presents a great new business opportunity to all types of building enterprises along the supply chain, both upstream and

downstream businesses of the building industry, such as low-carbon supply, low-carbon design, low-carbon consultancy, etc.

The introduction of TLM is an extension of traditional project management processes. The principles of project management are the fundamental basis for developing TLM. The TLM paradigm will guide management decisions and practices across all phases of the building project's lifecycle, integrating quality and risk management. In practicing TLM, the risks of carbon emissions will be identified across the lifecycle, thus measures can be designed for reducing emissions risks at all building phases. The application of TLM needs the establishment of regulations by the government. Areas such as codes of practice in the building industry, norms and standards for building quality and specifications, and procurement and contract laws need to be reviewed and updated by incorporating the principles of TLM. TLM encourages collaboration among all parties, ensuring that low-carbon objectives are integrated throughout all phases of the building project. Different stakeholders in the building industry, including building clients, contractors, designers, building materials suppliers, building users, and all other types of consultants, all need to transition their conventional practices to low-carbon practices by updating their business plans and strategies in reference to the principles of TLM. For example, in procurement and quality control, TLM requires the use of low-carbon materials and technologies, ensuring that the project adheres to low-carbon principles throughout its whole lifecycle. Stakeholders should realize that the adoption of the TLM will help enhance their competitiveness. Those that continue to follow their conventional management practices will sooner or later be eliminated by the future building market. Furthermore, individual members associated with the building industry must build up low-carbon awareness and empower their career capability by acquiring low-carbon knowledge. Multiple "wins" can be obtained between the government, building industry, organizations and individuals through the practice of the new management paradigm.

Nevertheless, it can be perceived that challenges exist in applying the TLM paradigm. At the organizational level, for example, the question of how to obtain a balance between economic growth and low-carbon social responsibility is difficult to answer in building practice. In particular, low-carbon practices in the building industry may confront the riches and powers that are used to fuel a carbon-intensive life. There could be a misunderstanding about the relationship between economic benefits and low-carbon practices. There are some voices arguing that low-carbon practices would be at the expense of economic growth. Nevertheless, this is indeed a misconception. In fact, low-carbon practices promote the development of renewable energy (such as solar, wind, hydropower, etc.), energy-efficient technologies and green industries. These practices can create new jobs and can actually stimulate economic growth. By contributing to economic growth, low-carbon practices have become a new type of economic development mode, namely, the low-carbon economy.

On the other hand, the TLM paradigm emphasizes the pattern of systematic and process-oriented management. It is, of course, a challenge to change the traditionally unsystematic and outcome-oriented management mentality to the new management pattern. There is a need, particularly for managerial professionals, to understand the benefits of having a process-oriented mentality in promoting low-carbon practices. Emphasizing the process will allow for identifying good experiences gained, lessons and mistakes crossed among all types of activities in the building process, which is essential for designating further corrective actions for improving low-carbon practices. Furthermore, the process-oriented management mentality in practicing TLM will allow for the participation of everyone and all stakeholders involved in the building process to contribute to problem-solving and performance improvement of low-carbon practices.

Another typical challenge in applying the TLMC paradigm in the building industry is the barrier to reaching a consensus among these stakeholders about standards and forms of low-carbon practice. There have been many emerging business firms labeled as low-carbon in the building industry internationally in recent years, such as low-carbon suppliers, low-carbon designers, low-carbon consultants, low-carbon contractors, etc. There is a need to establish a mechanism at the international level to encourage collaboration between all types of businesses engaging in low-carbon practices in the building industry.

6. Conclusions

As a major carbon emissions emitter, the building industry has to transition towards a low-carbon development mode by appreciating the limitations of the technology domain in promoting low-carbon practices in the building sector. It is considered important to transition the management practices within the building industry to a total low-carbon management paradigm (TLMC). This transition is essential for the industry as governments globally have shifted their mentality to low-carbon development patterns. The process-oriented paradigm (TLMC) can ensure more effective promotion of low-carbon practices in the building sector. Furthermore, according to the synergy theory, this study reveals that a collaborative relationship can be formed between the dominant subsystem (government) and those non-dominant subsystems, including building organization, building personnel, building activity, and building process. Accordingly, it is expected that the TLMC paradigm will be in effect in the future building industry, composed of whole regulation, whole industry, whole enterprise, whole staff, and whole process.

This paper presents a proposal for transferring the existing technological dominance paradigm to a new paradigm of TLMC in the building industry for the mission of further reducing carbon emissions. The argument on this new management paradigm sheds light on the low-carbon development pattern in the future building industry, although its effective application may not happen in the short term. The introduction of the TLMC paradigm contributes to advancing knowledge and enriching the literature in the discipline of low-carbon practices and sustainable development. It provides an alternative theoretical perspective in studying solutions for further promoting low-carbon practices in the building industry. Practically, this paper also demonstrates typical measures of culture and mentality transition to low-carbon practices among all types of building organizations and the personnel working in the industry.

The typical limitation of this study is that the theoretical model of the TLMC paradigm has not been given an in-depth discussion on its application mechanisms. The specifications on the roles of the government sector, building organizations and building personnel in applying the TLMC paradigm should also be further evaluated in future studies by conducting effective surveys and using certain empirical data. Therefore, further empirical research is needed to validate the practical applicability and effectiveness of the TLMC framework. Future research could explore integrating the TLMC framework with advanced digital technologies like digital twins and BIM-based carbon tracking for real-time monitoring and precise management. Furthermore, agent-based simulations could model behavioral aspects and interactions, validating the framework's effectiveness in diverse scenarios.

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Abbreviations

The following abbreviations are used in this manuscript:

TLCM total low-carbon management

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