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Driving forces for low carbon technology innovation in the building industry: A critical review

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ABSTRACT

As a response to climate change, low carbon development has attracted a growing public attention. It is urgent to implement low carbon economy through technological innovation so that carbon emissions can be reduced effectively. The synergy and cooperation amongst the participants is required due to various challenges such as: multi-participants, multi-objectives and multi-technologies. These present significant challenges to the low carbon technology (LCT) innovation development. The objective of this study is to identify the relevant driving forces of LCT innovation and their interaction in the construction industry. This paper firstly analyzes the interrelationships of the participants via a methodology of system dynamics (SD) and questionnaire survey. The main driving forces and related influential factors are highlighted by means of a deductive method. Moreover, a SD model is established to examine the driving forces where government and private firms all play a role. The results show that LCT integration driving forces are significantly influenced by the continuous changes of a particular low carbon project as well as the number of participating enterprises. All the driving forces reflect an increasingly level of effectiveness. According to the model simulation, it will take a long period of time to transform traditional projects to low carbon projects. China needs at least 21 years that the quantity of low carbon buildings exceeds that of traditional ones. As a result, the building and construction industry is facing a significant challenge in terms of carbon emissions reduction. The numbers of enterprises participating in LCT innovation will not always increase with the enhancement of driving forces. Rather, it will keep at a stable level after a certain growth. A particular one single driving force has limited impact on the growth of low carbon projects and participating enterprises. System integration plays a crucial role to achieve the low carbon development.

1. Introduction

Conventional projects are featured with excessive energy consumption and low-added value [1]. Currently, the construction industry is responsible for about 1/3 of the total energy consumption in China. This proportion is even increasing due to the rapid urbanization [2]. The low-carbon development has attracted a growing level of attention as a response to the global warming, the energy crisis and the constantly increasing energy consumption in China. Residential and commercial buildings accounted for approximately forty percent of the total energy consumption and carbon dioxide emissions in the United States [3]. China is now the largest emitter of CO2 in the world, having contributed to nearly half of the global increase in carbon emissions between 1980 and 2010 [4]. Hong et al. employed a multi-regional input–output model to investigate the energy use embodied in the consumption and interregional trade of China's construction industry. Their study found that as a typical demand-driven sector, the construction industry consumed 793.74 million tons of coal equivalent in 2007, which is equal to 29.6% of China's total national energy consumption [5]. Last decades have witnessed growing public awareness of sustainable development in China arguably due to the social and environmental issues associated with the rapid urbanization [6], while the economic growth has been recognized as a decisive factor for PM2.5 emissions [7].

International policies indicate the building sector plays a critical role for sustainable development. According to the Intergovernmental

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Panel on Climate Change (IPCC), the building sector has the greatest and cheapest potential for delivering significant greenhouse gas emission reduction [8].

As one of the industries with the highest energy consumption, construction has become a key area to promote low carbon emission projects. It has been recognized as a critical sector to define and realize a roadmap for the carbon emissions reduction at the national level. For instance, in UK, the tariff-based domestic Renewable Heat Incentive (RHI) is introduced to encourage the deployment of renewable heat technologies as a key component of its carbon reduction policy [9]. However, it presents a significant challenge to the transform the conventional building processes towards low carbon ones. The essence of the low carbon development lies in the systematic project management processes and technological innovation. The low carbon development depends on the optimization of energy demand/supply management technologies and carbon emission reduction at various levels of the building lifecycle. The low carbon transformation is subject to the effective implementation of LCT innovation. Due to various economic, social, and environmental challenges, the Chinese construction industry is under tremendous pressure to transit to a sustainability orientation [10].

Wang, Kuang and Huang [11] suggested that the main driving and impeding factor to energy-related carbon emissions is economic output and energy intensity respectively. Their study also showed that the contributions of energy mix, industrial structures, population size and living standards are not significant. Shao, Chen and Zhu examined innovative and sustainable residential construction methods for rural areas in western China, particularly the integration of solar energy technology with modern prefabricated building techniques. However, their study did not attempt to investigate the triggers on developing solar energy in Western of China [12].

Sustainability is one of the most contested ideologies because there is lack of consensus on what needs to be changed as a response [13]. As part of multi-level technologies integration, single technological adoption or innovation cannot satisfy the economic transformation requirement of the modern construction industries. CO2 emission is mainly derived from energy production for all sorts of industries, throughout the entire lifecycle. Therefore, the essence of carbon emission reduction in buildings lies in the rational management of energy production/consumption during their construction, operation and reuse/recycling. Reduction of energy consumption and carbon emission will inevitably involve the improved systematic management and the technological system integration. The management of LCT innovation covers a series of carbon control technology management issues, e.g. the social, economic, technological and other aspects. Therefore, it calls for a timely study to critically review the studies related to critical factors for LCT innovation.

This paper aims to identify the driving forces for LCT innovation and their impacts on the LCT innovation performance. Similarly, this paper examines how LCT management in the construction industry can support the low carbon transformation in China.

2. Literature review

The construction industry is facing various economic, social, and environmental challenges which facilitate a sustainability transition [14]. It is imperative to examine the driving factors and contributions of carbon emissions peak volume for reducing the cumulative carbon emissions in developing countries [15]. As reported in Section 1, LCT integration innovation involves various technologies and participants due to the complexity of a common engineering system. A number of obstacles or uncertainties exist during the implementation of LCT innovation. This determines driving factors amongst the enterprises participating in a particular LCT innovation integration project and/or process. Therefore, an appropriate understanding and identification of LCT integration innovation of the driving factors is needed. It plays a critical role in promoting LCT in the building industry. The existing studies on low carbon innovation can be classified as the following categories: methods or mechanisms for carbon emission analysis, driving forces for technological innovation, impacts of driving factors on carbon emission.

2.1. Methods or mechanisms for carbon emission analysis

Integrated assessment models (IAMs) are increasingly used to evaluate impacts of carbon policy on energy structure, however results vary according to models [16]. A rigorous understanding of energy systems plays a crucial role in developing strategies to mitigate impacts associated with climate change. Agent-based modelling (ABM) is a powerful tool for representing the complexities of energy demand, such as social interactions and spatial constraints [17]. [18,19] employed a structural decomposition method to analyze the influencing factors and influencing mechanisms of carbon emissions [20,21]. discussed the technology application and policy simulation for carbon emission reduction and mitigation potentials. An extended STIRPAT model based on the classical IPAT identity was used to determine the main driving factors for energy related carbon emissions in Xinjiang [22]. Logarithmic Mean Divisia Index (LMDI) method is also a common approach to identify the driving factors for the sustainable development level and technology carbon emission [23,24]. [25] pointed out that the levels of priorities and awareness of sustainable practices vary according to stakeholders in the architecture, engineering and construction industry. This shapes the adoption of green technology, and the rate at which the industry is shifting towards more sustainable practices.

2.2. Driving forces for general technological innovation

An and Zhang argued that the driving forces for enterprise's technological innovation are profit, achievement and social value [26]. Both Xiang and Duan argued that the driving factors of green technology innovation should be studied from the perspectives of regulation standard, government enforcement, economic interests, social requirement, technological progress and the improvement of working conditions, etc. [27,28].

Xiang pointed out that the main driving factors for enterprises to implement technological innovation can be classified into three aspects: the enterprise's internal demand, technological progress and external incentives [29]. Feng suggested that the enterprises' technological innovation is mainly driven by the internal and external environment forces. The internal driving forces mainly include: innovation goal, innovation consciousness, innovation ability and internal regulations. The external driving forces include: scientific and technological development, technology innovation policy, technology innovation system and other external factors [30]. Yang argued that the internal driving forces of enterprise's technological innovation are: the entrepreneurial spirit, entrepreneurial profits, internal incentive and corporate culture. Similarly, the external driving forces include: the science and technology progress, market demand, competition and governmental support [31].

From the circular economy perspective, Pang suggested that the enterprise's technological innovation is driven by the promotion of enterprise's technological progress and risk investment, the pull of the consumption demand, the pressure from the industry competition, and the relevant incentive policies [32].