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Effectiveness of Facility Management in Achieving Carbon Neutrality in the Green Building Industry Supply Chain

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Greenhouse gas emissions is harmful to the global climate, carbon neutrality has been an important topic gaining attention worldwide. Carbon emissions from the construction industry are significant, including those generated by facility management during the operation of buildings. This study analysed the lifecycle and supply chain of the materials required for the disinfection process in the CITIC Tower (Beijing) facility management, alcohol disinfectant, through qualitative and quantitative methods. The study also explored possible means of reducing carbon emissions in the production and supply of alcohol disinfectants. This paper will classify the selection criteria for facility managers to choose sustainable products in the context of carbon neutrality. The findings should that in the context of COVID-19, facility management has been extended to include daily disinfection to maintain the health of employees. For large office buildings, facility management requires a large number of materials on a daily basis, and there is scope for reducing carbon emissions through the supply and production of these materials. There is also the specific process of distillation, which requires heat, and the fact that the contribution to carbon emissions varies according to the type of heat used. The use of burnt maize straw would be the best option, which makes maximum use of every growing part of the maize. In summary, the proposed research model and findings of this study are applicable to the calculation of carbon emissions from the supply of facility management materials for all office buildings in China and provide a reference for the calculation of carbon emissions from the wider facility management material supplying process.

Keywords: green space; sustainable building; facility management

I. INTRODUCTION

Facilities management integrates management science, building science, behavioural science and engineering technology to combine people, space and process to effectively plan and control the human work and living environment, maintain high-quality activity spaces, improve investment efficiency and meet the requirements of strategic objectives and business plans of enterprises, institutions and government departments. Specifically in the construction industry, facilities management is responsible for the ancillary services of building facilities, including activities such as building maintenance, utility management, gardening, supervision, and cleaning (Ancarani & Capaldo, 2005).

All human activities, especially industrial activities, generate greenhouse gases (GHG) and carbon emissions. The carbon emissions as an activity of the construction industry occur in all aspects of facility management. Excessive carbon emissions contribute to global warming.

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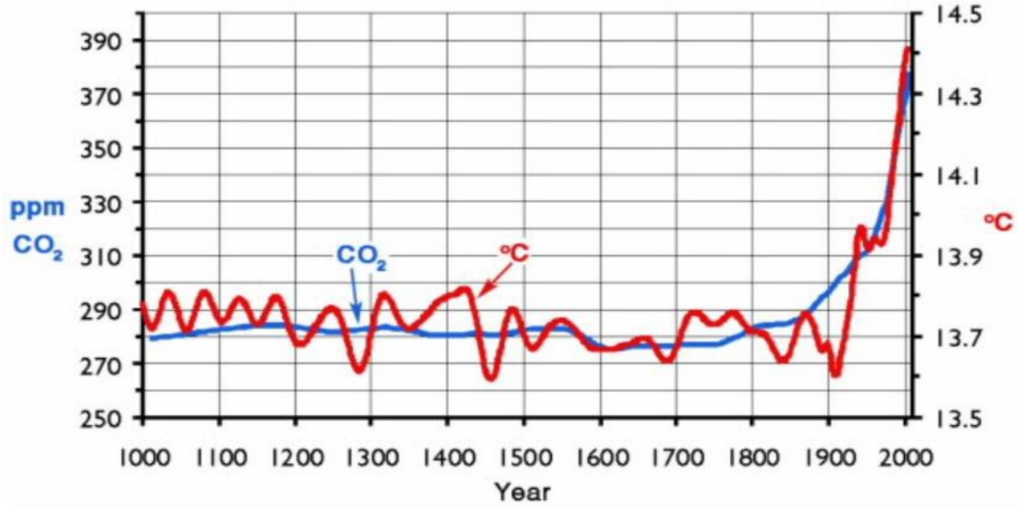

Figure 1. Earth's atmospheric CO2 concentration and temperature from 1000 to 2000
(Source: Climate Has Changed Before – American Chemical Society, 2022)

Global warming is a consequence of human actions causing climate change on the planet. With the rapid development of industry and human activity, global warming is affecting people's lifestyles and causing problems. In 2002, a 3,250 square kilometre ice shelf in Antarctica fell off and melted away within 35 days. According to the data from National Aeronautics and Space Administration (NASA, 2002), Greenland melt an average of 221 cubic kilometres of ice sheet per year, twice the amount of ice melted in 1996 (Change, 2022).

Since the impact of GHG emissions on rising temperatures and global ecology has been minimising, United Nations has decided to take measures to reduce global greenhouse gas emissions in order to protect ecosystems and halt the rise in sea levels in order to avoid the inevitable consequences that could occur. In 2015, 195 countries and regions have signed the Paris Agreement (United Nations, 2015) to combat potential global climate change from greenhouse gas emissions. The main objective of the Paris Agreement is to limit global temperature increases to less than 2°C above pre-industrial levels by 2050, preferably to 1.5°C, through national efforts.

China, as one of the parties to the Paris Agreement, plans to gradually complete a low-carbon transition over the next few decades, with the goal of reaching peak carbon by 2030 and carbon neutrality by 2060 (ICCSD, 2022).

The construction industry is a major energy consumption industry (Leong, 2023a; Leong, 2023b). Types of buildings are divided into residential buildings, public buildings and commercial buildings. As of 2018, the total construction area in China was 60.1 billion square metres, of which 12.8 billion square metres were commercial and public buildings, accounting for approximately one-fifth of the total construction area. Carbon emissions from the construction processes are not considered when calculating carbon emissions from the construction sector. The amount of energy consumed in public and commercial buildings refers to the energy consumed by the building during its operational phase to provide the functions for which it was designed. Currently, the building sector consumes approximately one-third of the total energy worldwide (IEA & UNEP, 2019).

In China, statistics for 2018 show that the final commercial energy consumption of the building sector was 690 million tonnes equivalent, of which 1.7 trillion kWh was used (RCBEC, 2020). From these, facilities management is one of the main components of the carbon emissions generated by the operation of the building.

Based on historical data from various developed countries, building energy consumption will continue to grow as countries become more economically developed. Although per capita building energy consumption is still relatively low compared to other developed countries (Data tables – Data & Statistics – IEA, 2022), given that China is at a critical stage of economic development, building energy consumption is likely to increase significantly in the future.

With over 6,000 office buildings in China today (Wu *et al*., 2012), carbon emissions from their operation and facility management will be a carbon-neutral challenge for the construction industry to watch in the future.

In the context of the current COVID-19, facility management in buildings has been given a new meaning (Stride *et al*., 2021). In addition to maintaining the normal functioning of the building and the functional integrity of the building modules, maintaining the health of the building occupants through continuous disinfection is also an important task of facility management. As disinfection becomes more frequent, the use and purchase of disinfection supplies is becoming an increasingly large proportion of the consumables required for facility management.

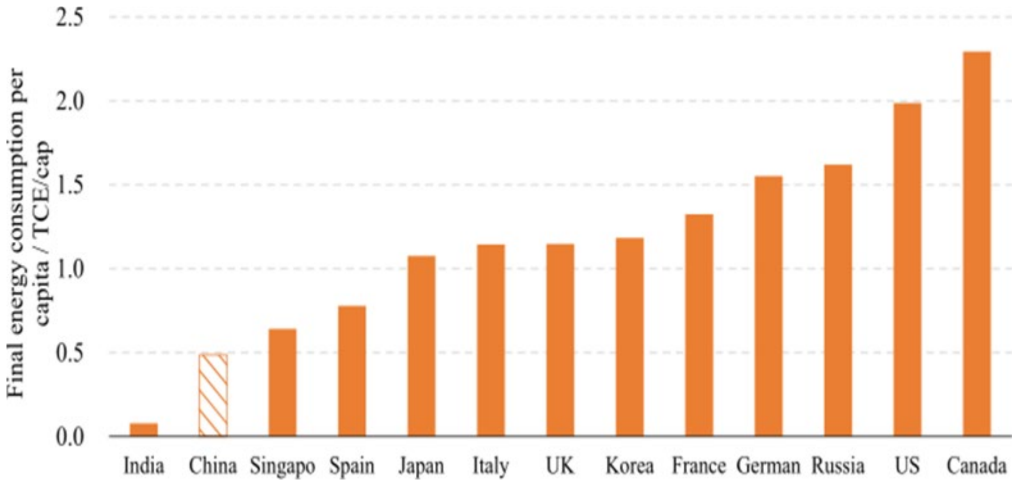

Figure 2. Comparison of energy use in buildings per capita between China and other countries (2017) (Source: Data tables – Data & Statistics – IEA, 2022)

The supply chain is an important part of a product's life cycle (Tan & Khoo, 2005), and studies on life cycle have been widely used in the assessment of a product's carbon footprint and emissions compared to supply chain research (Zhang *et al*., 2019). Therefore, Life Cycle Assessment (LCA) is an important reference method for this study.

Therefore, China is now at a critical stage in deciding on the approach to building energy efficiency, and the study of emission reductions in representative buildings will have a direct bearing on whether China's total energy consumption and carbon peak and carbon neutral targets can be met on time, or even ahead of schedule, in the coming decades. The supply of consumables required for facility management is an important component of the carbon footprint of building operations. As a new demand for alcohol disinfection products in the context of COVID-19, the consumption and supply of alcohol disinfection products are in a growth phase and are of great research value.

For a large building, the amount of facility management materials is hundreds or even thousands of times greater than a small building. With thousands of bottles of various chemical products consumed every day, the supply chain of raw materials required for facility management should be paid a lot attention (Araszkiewicz, 2017).

All products and their supply chains generate carbon emissions throughout the life cycle of a product. Since disinfectants are an increasingly large part of the consumption and procurement of utility management, the carbon emissions generated by the production and supply of disinfectants should be considered.

However, there are no clear studies in the literature on carbon emissions from the life cycle of disinfections required for facility management. In this study, the carbon emissions caused by facility management materials' supplying are calculated to justify the impact that caused to Chinese carbon neutrality aim in 2060. The carbon emissions from the supply chain of alcohol disinfection required for a green building facility management was properly calculated and a judgement made as to whether this will make a significant contribution to China's carbon neutrality targets.

This project is targeting the future large commercial buildings in China. As the future is unpredictable, this study is based on CITIC Tower, a large office building that has been constructed in the last few years. Therefore, the focus is on the supply chain of possible facility management materials used in CITIC Tower. The carbon emission of specific materials in facility management is the concern of this study. In this study, Alcohol disinfectants, as a commonly used surface disinfectant, were analysed.

Carbon emissions from the construction industry are one of the most significant sources of carbon emissions worldwide. This study will show the potential carbon emission in facility management and point to a better supply chain approach. In the long term, this will be of great value to China's facilities management approach in the construction industry, as a good supply chain approach can help China reach its carbon neutrality targets faster at the macro level and help companies achieve better economic results at the micro level.

II. LITERATURE REVIEW

Facilities management market has become more sophisticated, facilities management groups have started to emerge in the market and competition has become increasingly fierce. To increase their competitiveness, many facility management groups have started to introduce key performance indicators (KPI) to demonstrate their superiority over their competitors (Dasandara *et al*., 2022).

In recent years, KPIs commonly used in facilities management have included business loss due to service failure, customer satisfaction, environmental safety, responsiveness to problems, effectiveness of services, and professional approach of staff (Meng & Minogue, 2011). However, traditional supply chain design models focus on minimising fixed and operational costs, while carbon emissions are not usually a cost considered in supply chains. With the development of corresponding policies for carbon neutrality and the increased emphasis on carbon neutrality by the government, carbon emissions should be included in the judging criteria of the supply chain in addition to KPIs.

A. Current Situation of Carbon Emissions Worldwide

Carbon dioxide (CO_2) is an important component of greenhouse gases (GHG). GHGs include greenhouse gases that are produced as a result of human activities or naturally occurring, such as: water vapour (H_2O), Freon, carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), ozone (O_3), hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride, etc. Once greenhouse gas emissions exceed atmospheric standards, they will cause the greenhouse effect, which will increase global temperatures and threaten the survival of mankind. Therefore, the control of greenhouse gas emissions has become a major issue for all mankind.

According to the United Nations Intergovernmental Panel on Climate Change (IPCC, 2020), the global chemical industry uses about 115 million tonnes of CO_2 per year, using it as the original for various synthetic processes.

The level of CO_2 in the atmosphere today is 27% higher than it has been for the past 650,000 years. CO_2 began to rise in the era of the Industrial Revolution when large amounts of coal were burned. With more countries going industrial in recent decades and more cars on the roads, it has taken much less time for humans to cause climate change than the natural cycle of change in the climate system. Although volcanic eruptions release CO_2 and other gases, and small changes in the Earth's rotation axis and orbit can have a significant impact on the Earth's surface temperature, they are still not comparable to the human activities that are now continuing to accelerate (Lal, 2004).

CO_2 contributes up to 60% to the greenhouse effect. From 1750 to 1994, the volume fraction of CO_2 in the atmosphere has increased from 2.80×10-4 (280 ppm) to 3.58×10- 4 (358 ppm), reaching 3.68×10-4 (368 ppm) in 2000. As CO_2 has a lifetime of 50-200 years in the atmosphere, even if CO_2 emissions are maintained at current levels, its concentration will still double in the 22nd century. Therefore, the Kyoto Protocol to the United Nations

Framework Convention on Climate Change, adopted in 1997, requires that: developed countries reduce their emissions of the six greenhouse gases by 5.2 per cent compared to 1990; and by 2008-2012, their emissions of the six greenhouse gases will be reduced by 5.2 per cent compared to 1990. In the period 2008-2012, compared to

1990, the EU will reduce its emissions by 8% on average, the US by 7%, Japan and Canada by 6%, Eastern European countries by 5% to 8%, New Zealand, Russia, and Ukraine by 0%, Australia by 8% and Iceland by 10%.

Of the six greenhouse gases, CO_2 is the most abundant in the atmosphere, so it has become the focus of reduction and control.

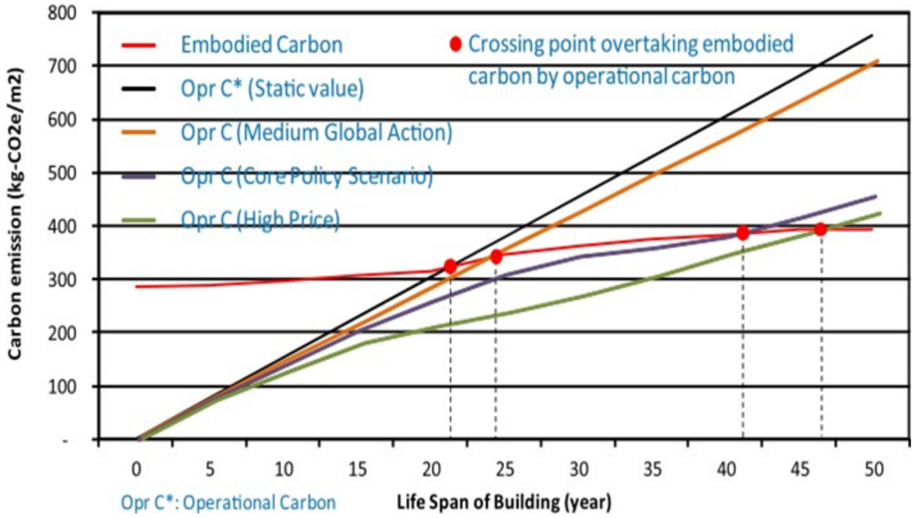

Figure 3. Life cycle carbon emission intensities of a building in Australia (Source: Seo *et al.*, 2015)

B. Carbon Control Methods to Help Achieve Carbon Neutrality

This can be done in parallel through carbon capture, utilisation and storage (CCUS). Carbon capture is the direct absorption of CO_2 from industrial flue gases using appropriate flue gas treatment technologies, either man-made or natural materials, to reduce CO_2 emissions. In general, this type of carbon capture device removes CO_2 from the plant flue gas but also has the function of denitrification, dust removal, and desulphurisation. Carbon utilisation refers to the use of carbon in various forms, including direct use, and the use of the absorbed CO_2 product to make substances such as building materials or fuels.

Carbon sequestration, on the other hand, refers to the capture and safe storage of carbon as an alternative to the direct emission of CO_2 into the atmosphere (Rubin *et al.*, 2012). All three of these technologies can significantly reduce the amount of CO_2 already emitted. However, managing emissions after they have been emitted is never a sensible solution. New sustainable technologies in industrial production and transportation could be a better resolution for achieving carbon neutrality.

In supply chain, there have been a number of approaches that have demonstrated that appropriate approaches can be taken in the supply chain to achieve carbon emission reductions. Among them, Zhang *et al.* (2015) measured energy and CO_2 emissions performance through an analysis of transport technologies in China, measured energy efficiency by province through a data envelopment analysis (DEA) approach, and suggested possible influences on carbon reduction in the transport and corresponding supply sectors. The study shows that the mandatory national policy target of a 40%-45% reduction in carbon intensity from 2015 to 2020 compared to 2005 has facilitated the development of carbon reduction technologies in China's transport sector and has effectively reduced CO_2 emissions per unit of GDP.

In addition, Koehler and Wildbolz (2009) found that while the manufacturing of the product itself is the main cause of carbon emissions, the production and use of plastic packaging is also a significant cause of carbon emissions.

Therefore, in order to analyse possible product carbon reduction measures in the supply chain, it is feasible and proven to be reliable to explore possible CCUS approaches in terms of product manufacturing, transportation and packaging manufacturing.

1. Buildings' carbon emission

For buildings, many studies have also demonstrated that energy and carbon growth has had a significant impact on the life cycle of buildings (Hammond & Jones, 2008). Operational carbon and embodied carbon together make up the carbon emissions in the supply chain. The embodied carbon generated throughout the life cycle of a building product can be divided into initial implicit carbon, construction carbon and recycled embodied carbon, which represent the pre-construction product-based carbon emissions, i.e. the carbon emissions generated during the life cycle of the building pre-product, respectively.

Building carbon is the carbon emissions generated during the construction phase of a building. Cyclic embodied carbon is the carbon emissions generated during the maintenance, renewal, demolition and recycling of the building. Together, these three types of implicit carbon make up the total embodied carbon of a building (Alshboul & Alzoubi, 2008). In this study, although the study phase is cyclic embodied carbon, the causes and processes of generation are similar to those of initial embodied carbon. Therefore, both initial embodied carbon and cyclic embodied carbon calculation methods should be paid attention on in this study.

Following the principle of adapting to local conditions and taking into account the characteristics of the climate, environment, resources, economy and culture of the region where the building is located, the performance of the building is evaluated comprehensively in five categories of indicators, including safety and durability, health and comfort, convenience of living, resource conservation and environmental liability, over the whole life of the building (Lee, 2009). Although green building evaluation should normally be conducted after the completion of the building project, pre-evaluation can be conducted after the construction drawings of the building project are completed.

2. LCA used in supply chain analyses

Sustainability assessment of products or technologies is often seen as covering three dimensions of impact - social, environmental and economic (Elkington, 1998). In practice, LCA is often used to assess the potential impact that something may have on the environment.

Generally speaking, the core of the supply chain is a functional chain of companies that provide production and transport services, starting with the components, making intermediate and final products and finally delivering them to the consumer through the sales network, linking suppliers, manufacturers, distributors to the end user as a whole. Harrison *et al.* (2005) defined the supply chain as "the functional chain that performs the procurement of raw materials, converts them into intermediate and finished products, and sells the finished products to users to users". Another more authoritative definition of the supply chain comes from Stevens, who argues that controlling the flow from suppliers to users through value-added processes and distribution channels is the supply chain, which begins at the point of supply and ends at the point of consumption (Stevens, 1989). In the facilities management section of construction management, this study will discuss the material supply process that needs to be used in facilities management.

Seo *et al.* (2015) conducted a carbon emissions study in Australia on the supply chain of an important building product, aluminium windows. This study used a method of calculating embodied carbon to investigate the difference in carbon emissions between different brands of aluminium windows.

It is suggested that the carbon emissions resulting from energy consumption during building operation, known as operational carbon, are a significant contributor to the life-cycle carbon emissions of a building. The other part, known as embodied carbon, is mainly generated from the extraction of raw materials and processes (as kg CO_2eq).

The transport process is not a major contributor, accounting for only 0.45% of embodied carbon production, which is almost negligible. Similarly, Browne *et al.* in 2005 looked at the total energy use in the production process and supply chain of jeans in France and found that the energy consumed in the transportation process was very small, even less than the energy consumed by consumers driving their jeans home. They also identified LCA as a structured and quantitative means of exploring the impact of changes in logistics operations and supply chain management strategies (Browne *et al.*, 2005).

The life cycle of a supply chain consists of the following main steps.

① Acquisition of raw materials, which refers to the acquisition of energy resources and raw materials used in production from the natural environment, such as mining, cutting down trees for timber, etc.

② Manufacturing and processing, which refers to the input of raw materials and energy to transform the raw materials into the target product. This is not usually done in a single location and factory but requires several different factories and processes. These processes can occur in the same location or in different locations in the supply chain, but most likely in different locations.

③ Warehousing, material handling and logistics, which encompasses all the warehousing and inventory management of raw materials, processed goods and finished goods at all stages of the supply chain.

④ Freight, which contains all the transport elements of the supply chain, can be summarised primarily as the transport of raw materials to production, manufacturing and processing locations, the transport of manufacturers to storage locations, the transport of storage locations to retail locations and the final transport of retail locations to customers' homes. In addition, multiple modes of transport are often used in the maintenance, disposal and recycling of materials.

⑤ Use and maintenance of the product. For the consumable products used in this study, there are no maintenance issues, only use issues.

⑥ Recycling or waste management. After the product has reached the end of its useful life, the remaining components can be recycled or disposed of, the main waste in this study being plastic or glass bottles of detergent after use.

Since 1990, a number of studies have been conducted on the energy use of the 'freight activity' part of the product supply chain. This includes the transport energy use of raw materials from the point of growth or acquisition to the manufacturer, as well as the transport process in the supply of products. The control and disposal of pollutants emitted during the production and transport of products is also part of the study.

In 1993, a detailed study by Böge of the energy used in the supply chain for strawberry yoghurt sold in Germany. In this study, strawberries were imported from Poland and processed into strawberry jam in West Germany. yoghurt cultures were sourced from northern Germany and used sugar from sugar beets shipped from East Germany. The wheat flour and maize used in the production of the strawberries came from the Netherlands. Even the jar labels and aluminium lids are not produced locally. Only the glass jars and milk come from local production. Each of these two materials has characteristics that do not support long-distance transport: glass jars are fragile and easily damaged during transport, while milk is difficult to store and needs to be transported in the cold chain, which would increase the cost of transporting it if it were sourced from abroad (Böge, 1995). This example shows that the current supply chain is international and multi-local, but even so, the energy consumption generated during transport is still a small fraction. This is a result of the continuous development of industry.

In 2001 the FMS published a report on energy use for cooking different portions of staple foods at home, including pasta, wheat, barley, mashed potatoes etc. (Carlsson- Kanyama & Boström-Carlsson, 2001). This report compares the measured values of energy used for cooking with the pre-cooking life cycle stage, i.e. the production and transport stages. It was found that, for the foods studied, the energy used to cook the food at home was greater than the energy used for industrial food processing. This result is to be expected as industry is usually larger and more mechanised and therefore saves more energy than home cooking. Another life cycle assessment of polyester trousers and men's cotton trousers sold in the UK's leading department stores, Marks & Spencer, showed that commercial freight transport used only 1/5 to 1/2 of the energy used per item transported by consumer cars (ERM, 2002).

These studies that have been carried out show that in most of the household goods and food categories, the energy consumption generated during freight transport is a relatively small part of the overall supply chain. This suggests that the majority of energy consumption in the supply chain is generated in manufacturing and not in transport. Therefore, the research of energy consumption or carbon emission in the supply chains of facility management products should pay most attention on the manufacture process.

3. Facility management under COVID-19

The COVID-19 pandemic caused by the SARS-CoV-2 virus has raised new needs to reduce the risk of virus transmission within the responsibilities of facilities management, of which specialised disinfection measures are an important component (Chongloi & Sachdeva, 2021). Indoor infrastructure in public areas, such as door handles, buttons, desktops and other critical items in lifts and public office spaces require special attention, as people are constantly in contact with these items and respiratory droplet spray from infected individuals may also land on surfaces where the virus may survive and be present in public spaces, becoming a new source of infection and triggering the next round of virus transmission.

Effective disinfection techniques for viruses such as SARS-CoV-2 include ultraviolet radiation, gas disinfection, spray disinfection, liquid disinfection, ultrasonic disinfection, temperature disinfection, and non-thermal plasma disinfection. Among these, spray disinfection has been widely used in the prevention and control of COVID-19 due to its simplicity, low mechanisation and better disinfection effect (Cleaning and disinfection of environmental surfaces in the context of COVID-19, 2022).

The use of disinfectants is important for spray disinfection. Alcohol is an important surface disinfectant and is suitable for disinfecting small surfaces as well as human surfaces (Mulder & Sher, 2020). Studies have shown that contaminated surfaces can be decontaminated in less than one minute using 62-71% ethanol. Furthermore, compared to other disinfectants such as hydrogen peroxide or sodium hypochlorite, alcohol has the advantage of low odour, quick evaporation and is virtually harmless to humans when inhaled. Alcohol is therefore an excellent disinfectant, both for routine use as a preventative for viral contamination in office premises and as a disinfectant for already infected surfaces (Ilyas, Srivastava & Kim, 2020).

As a result, China is now equipped with special alcohol disinfection sessions in a large number of office buildings. The demand for alcohol disinfectant products is also increasing (Jiang *et al.*, 2021). In this context, alcohol disinfectants have become a highly consumed everyday item in office buildings and their production and supply processes should be considered. In the light of the international trend towards carbon reduction, it is also worth discussing whether there are any improvements that can be made in the production of alcohol disinfectants.

4. Research gap

According to previous studies, the supply chain optimisation method that makes the greatest contribution to the potential of materials used in facility management should be carried out in the manufacturing chain, rather than in the transportation chain.

Although studies have been conducted on the supply of pre-construction facilities in the construction sector and on food and household products in the household chemicals sector, there is still a research gap in the analysis of carbon emissions in the supply chain of facility management materials. This study based on a carbon calculation methodology to analyse the energy consumption and carbon emissions of the main household products used in facility management and propose optimisation measures.

III. METHODOLOGY

A. Case Study on CITIC Tower

CITIC Tower (Beijing) is ranked 9th among the 100 Tallest Completed Buildings in the World - The Skyscraper Centre, 2022, in a ranking that ends in September 2021, according to its height. LEED certification is a globally recognised symbol of sustainability achievement and leadership, providing an authoritative quantitative framework for assessing the health, efficiency, low carbon and cost-effectiveness of buildings (USGBC, 2022).

LEED-certified green buildings will be a major trend in the future development of buildings, and when selecting cases, suitable green buildings should be selected to better predict the future of buildings. LEED certification is awarded at four levels: Certified, Silver, Gold and Platinum level, based on the building's design soundness, environmental friendliness and cost-effectiveness. This means that CITIC Tower (Beijing) has made excellent progress in the design of carbon, energy, water, waste, transport, materials, health and indoor environmental quality, and is largely in line with the Green Office Building design philosophy and means that CITIC Tower is a landmark modern building. Due to the certification of LEED, the CITIC Tower could represent the future direction of Chinese architecture and the world's architecture due to its advanced green-building construction technology and concept, which is of great significance. Therefore, CITIC Tower is chosen as a typical case in this case study.

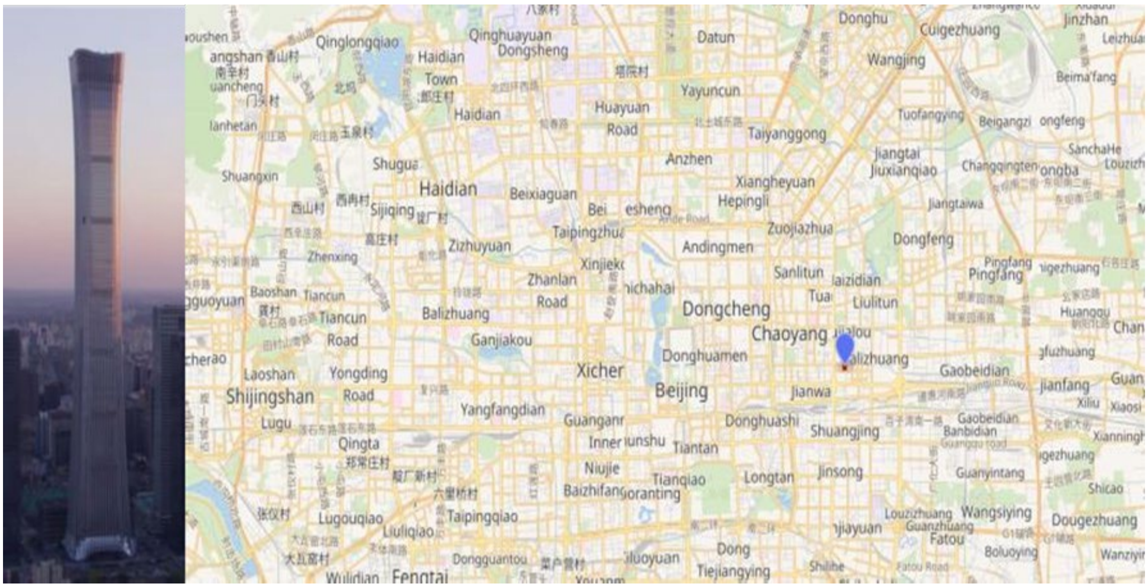

Figure 4. Photo of CITIC Tower and the location of CITIC Tower

Due to the complexity of facilities management in office buildings and the large number of issues involved, calculating the carbon emissions generated by the supply chain of raw materials required for facilities management starts with a list of raw materials required for facilities management. Therefore, a few of the raw materials that are most essential in the management of the building's facilities, in terms of importance and usage, are selected for analysis.

One of the criteria for LEED is the carbon footprint of the building, which includes the carbon footprint of the building's operations as well as the carbon footprint of the facility management. As a representative of green buildings in China, and with the large amount of facility management materials used on a daily basis, the supply chains for facility management materials at CITIC Tower are of great concern. If more sustainable methods are used in the supply chain and these methods are proven to work, it will give CITIC Tower a greater advantage in the LEED rating.

As China is still under strict COVID-19 control, spray alcohol disinfectant will be sprayed inside CITIC Tower several times a day. As CITIC Tower has more than 108 floors and most of them are office areas, which means frequent disinfection is required, the current consumption of alcohol disinfectant in CITIC Tower is significant. Therefore, the supply chain of alcohol disinfectants used in the CITIC Tower is the subject of this study. The specific daily use of alcohol disinfectants at CITIC Tower will be done through a combination of field surveys and estimates.

B. *Interview and Data Collection*

Interviewed the property manager of CITIC Tower to find out the main brands of alcohol disinfectants and floor cleaners that CITIC Tower currently purchases and the manufacturers that supply them. Through researching online and speaking to the property manager, we were able to confirm their main production methods and supply processes. The dosage of Alcohol disinfection was also one of the questions asked.

CITIC Tower is a very large office building and therefore it was not possible for a single department to be responsible for the corresponding facility management. Due to time and resource constraints, this study interviewed the purchasing manager of the property company responsible for the facility management of floors 59-72, Zone 5, the area leased by Ant Financial Services and Alibaba, as a sample to expand the data from the interviews to the whole building.

Interviews revealed that there are three sizes of alcohol used daily on the 59-72 floors of CITIC Tower: 2L bottles, 500ml bottles and 50ml bottles. They are used for disinfecting lifts, for distributing to staff groups for disinfecting their own surfaces and for distributing to individual staff for disinfecting their hands. The average number of bottles per day is shown in the following table.

Table 1. Daily alcohol disinfectant use of CITIC Tower

Specification/L	2000 ml (2 L)	500 ml	50ml
Number	263	137	172

In addition to the amount of alcohol disinfectant used, the interview also provided a basic understanding of the property manager's knowledge and tendency to purchase products with regard to carbon emission as the purchaser of utility management.

C. Quantitative Method

Though in the literature review part, previous studies have proved that the transportation processes during supply chain, the transportation energy consumption still should be calculated. All carbon emissions through the supply chain life cycle should be counted. Ecoinvent database is used for this carbon emission research.

The Ecoinvent Database is a Life Cycle Inventory database that supports various types of sustainability assessments. The Ecoinvent database enables users to gain a deeper understanding of the environmental impact of their products and services. It is a repository covering different sectors at global and regional levels. It currently contains over 18,000 activities, also known as 'datasets', that model human activities or processes. Ecoinvent's datasets contain information on the industrial or agricultural processes they simulate, measure the natural resources extracted from the environment, the emissions released into water, soil and air, and the products from other processes. waste emissions from other processes.

As a third-party database, Ecoinvent is considered to be one of the most authoritative carbon statistics databases in the world today. Most of the data is available to view for a fee, but a small amount of data can still be viewed for free by users with GUEST access. The carbon emission of raw alcohol materials (concentration at 95-99%) manufacturing process is available for free, the manufacture process of either.

D. Supplementary Methods

1. Supply chain confirmation by LCA analyses

Use interviews with property managers and online searches to identify the supply chain of facility management materials.

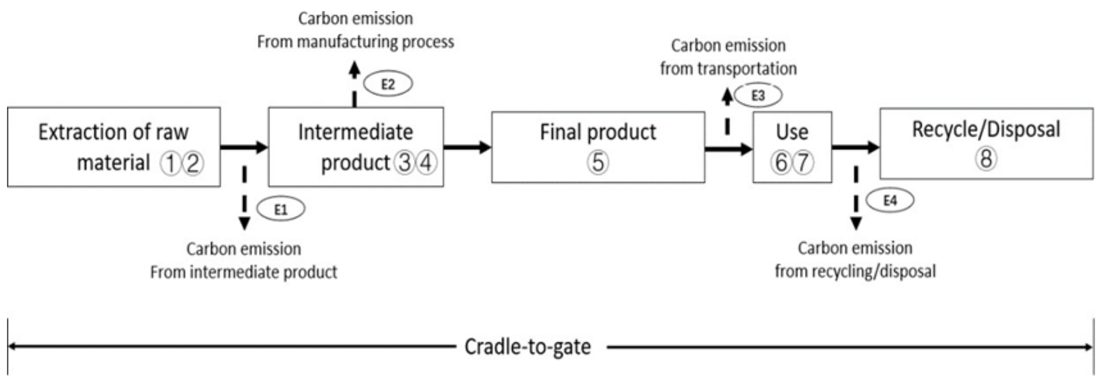

Figure 5. Boundary of product and realm of influence for carbon emission evaluation and analysis

Alcohol disinfectant has a single composition, consisting only of industrial alcohol and water. In China, the fermentation of expired grain and straw and other grains to produce alcohol is one of the main methods of producing industrial alcohol. And from interviews with the property manager and online research, the industrial alcohol used in CITIC Tower comes from grain fermentation. This study therefore analyses the production of alcohol by fermentation as an example. The main production steps need to be split up and an LCA analysis of alcohol disinfectants should be employed to determine whether the most significant means of carbon reduction is used in the supply chain.

2. SWOT analyses

For CITIC Tower, reducing carbon emissions is not the only supply chain improvement objective. The supply chain and the effect that the product has on the facility management is the most important objective to focus on. Changing supply chain methods that have been in use, that are stable and proven to work, implies a number of risks and threats.

SWOT analyses is also used in this study to analyse the pros and cons of different supply chain methods as a supplementary of this quantitative research. Since carbon emission is the only side of consideration when choosing supply chain method. Therefore, SWOT analyses is to help owners to choose specific methods to the sustainability management of the CITIC Tower, will result in impacts other than carbon emission reduction. The SWOT analysis will assess whether the application of sustainable supply methods to the supply chains of materials for CITIC Tower will result in impacts other than carbon emission reduction, and further assess whether these supply methods are worthy of long-term and widespread use.

IV. RESULT AND DISCUSSION

The data shows that the lifecycle carbon emissions of the disinfectant alcohol and toilet cleanser used in CITIC Tower can be significantly reduced when appropriate sustainable supply chain methods are used. The lifecycle and supply chain carbon footprint of alcohol disinfectants created a new reference standard and requirement for choosing sustainable products for facility managers.

A. Supply Chain and Life Cycle Confirmation

According to the interview, the property manager at CITIC Tower did not have a clear understanding of how the carbon emissions of alcohol disinfectant are generated and how much is generated. However, as this is likely to be a strong competitive parameter for future bids, the life cycle of the alcohol disinfectant was analysed, and the possible carbon emissions were analysed on a case-by-case basis to help the facility managers determine the carbon footprint of the product.

Depending on the application, CITIC property management company purchases alcohol disinfectants in three different sizes: 2L, 500ml and 50ml. The 2L bottle is used for disinfecting lifts, the 500ml bottle is used for distributing to each office group for employees to spray and wipe down common surfaces such as desks, and the 50ml bottle is used for hand disinfection.

The production of alcohol disinfectant from raw materials can be broken down into several main operations (if use fermentation way):

① Grain cultivation.
② Harvest.
③ Fermentation.
④ Deeper process from raw production to a specific concentration.
⑤ Filling and packing.
⑥ Bought by the facility management company of CITIC Tower.
⑦ Used by cleaners.
⑧ Recycling or disposing of package bottles.

Therefore, the total carbon emission (TCE) of disinfection alcohol is:

$$TCE = E1 + E2 + E3 + E4 \tag{1}$$

TCE refers to the total carbon emissions per unit of use of a bottle of its product, in this study the unit is defined as a 10 L bottle of alcohol sanitiser. Although transport is not a major contributor to the carbon emissions of a product, its carbon emissions are still significant due to the distance travelled. For example, transporting 1 kg of product by shipping will generate 4.3 g of CO2 eq. However, using trucks as a mode of transport may result in 27-43 times increase in carbon emissions. Air freight, in turn, has 296 times the carbon emissions of sea freight. It is therefore important to consider the appropriate mode of transport to reduce carbon emissions.

The 2L bottles of alcohol solution purchased by CITIC property management company were all from the Lianren Shengbang brand. Upon inspection, the brand of alcohol disinfectant solution was manufactured in Shangqiu City, Henan Province, China, and the raw material for production was corn.

The process flow for the production of corn ethanol from maize is shown in the diagram.

The starch content of most maize is between 60% and 70% and the productivity of maize ethanol can be roughly estimated at 50% maize starch content. With other losses in the process, the mass conversion rate between corn and ethanol is approximately 30%. Again, because the alcohol disinfectant is typically 75%, the mass conversion efficiency between corn mass and disinfectant alcohol is 40%.

In addition to alcohol, which is the main ingredient in the production of alcohol disinfectants, water is also one of the key raw materials. The water used to disinfect alcohol is ultrapure water, which is kept as pure as possible by using multiple cartridges for filtration and ultraviolet sterilisation to eliminate bacteria in the water. However, as the alcohol is up to 75% alcohol and the process of making ultra-pure water is based on filtration and UV sterilisation, it basically does not involve too much actual raw material consumption and is therefore not included in the carbon cost.

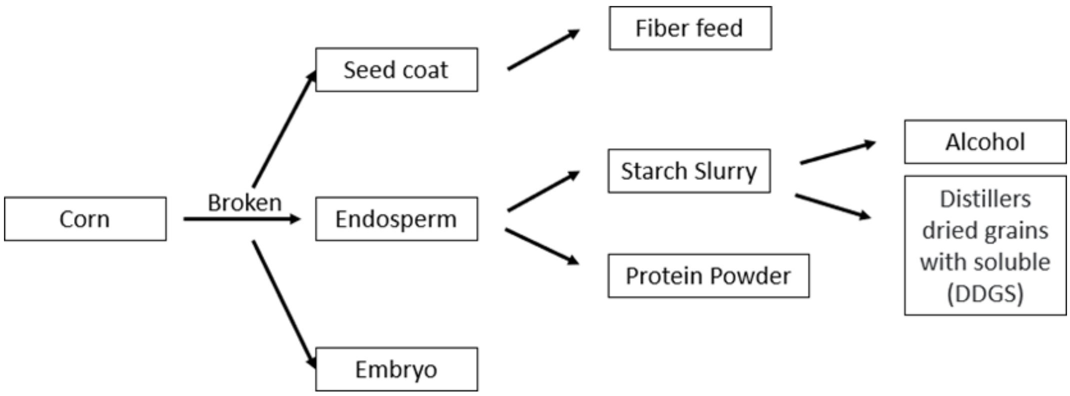

Figure 6. Flow chart for the production of corn ethanol

The other main auxiliary material is the plastic bottle. The disinfected, clean plastic bottles are used to fill the finished alcohol solution and are then sold. A review and enquiry revealed that the supplier of the plastic bottles was from Cangzhou, Hebei Province, China, and that each 2L bottle weighed approximately 30g. Therefore, the key materials for each 1L of 75% alcohol disinfectant produced and where they were supplied are listed in the table below.

Table 2. Key material input for alcohol disinfection production (1kg, 2L package)

Material	Mass	Unit	Supplied
Corn	2.5	kg	Shangqiu, Henan Province
Super pure water	0.25	ml	Shangqiu, Henan Province
Plastic	15	g	Cangzhou, Hebei Province

The number of Corn used to produce the 500ml pack of alcohol solution and the 50ml pack of leave-on hand soap is the same as for the 2L pack, but the number of plastics used is different. Better packaging is required as it is closer to the retail end. The plastic bottles for the 500ml pack of alcohol sanitiser were measured to weigh approximately 50g (with spray nozzle), and the 50ml pack of hand sanitiser weighed approximately 12g each. All plastic products were sourced from Cangzhou City, Hebei Province. Therefore, the quantities of raw materials required to produce these two sizes of alcohol sanitiser (1kg) and where they are supplied are as follows.

Table 3. Key material input for alcohol disinfection production (1kg, 500 ml package)

Material	Mass	Unit	Supplied
Corn	2.5	kg	Shangqiu, Henan Province
Super pure water	0.25	ml	Shangqiu, Henan Province
Plastic	100	g	Cangzhou, Hebei Province

Table 4. Key material input for alcohol disinfection production (1kg, 50 ml package)

Material	Mass	Unit	Supplied
Corn	2.5	kg	Shangqiu, Henan Province
Super pure water	0.25	ml	Shangqiu, Henan Province
Plastic	240	g	Cangzhou, Hebei Province

Total carbon emission produced in this process:
The Ecoinvent database was used to access the carbon emissions generated during the manufacture of ethanol. The data shows that the production of 1 kg of 99.7% ethanol using the corn fermentation process generates 1.02 kg of carbon emissions.

The plastic container used to fill the alcohol disinfectant is polyethylene terephthalate (PET), a No. 1 plastic. The production of 1kg of PET bottles from petroleum-based raw materials will generate 0.625kg of carbon emissions.

It is known that trucks are currently used for all freight in this study. The road distance from Cangzhou City to Shangqiu City is about 520 km, while the road distance from Shangqiu City to Beijing is about 700 km. The plastic products are of light quality, occupy a large area, and are used in large quantities and are usually delivered using large trucks. Conversely, alcohol products are not usually transported in large lorries due to their flammability and explosiveness. Medium-sized trucks, with a capacity of between 6 and 14 tonnes, are the preferred choice for transporting alcohol products. The carbon footprint of transporting one tonne of PET bottles by truck is 0.45 kg CO_2/km. The carbon footprint of transporting a tonne of alcohol is not available, but it is projected that the carbon footprint will be higher than transporting a single PET bottle by taking 0.5kg CO_2/km due to the lower freight carrying capacity and the fact that transporting alcohol requires certain explosion protection measures.

The destination of plastic packaging bottles at the end of use is not considered at present, as China's waste separation system is not yet complete, and a large number of plastic bottles are difficult to recycle. Therefore, the carbon emissions from discarded PET bottles are here equal to those generated at the time of manufacture, i.e. E2 = E4 in (Eq. 1).

Therefore, the carbon emissions per 2L bottle of alcohol disinfectant are:

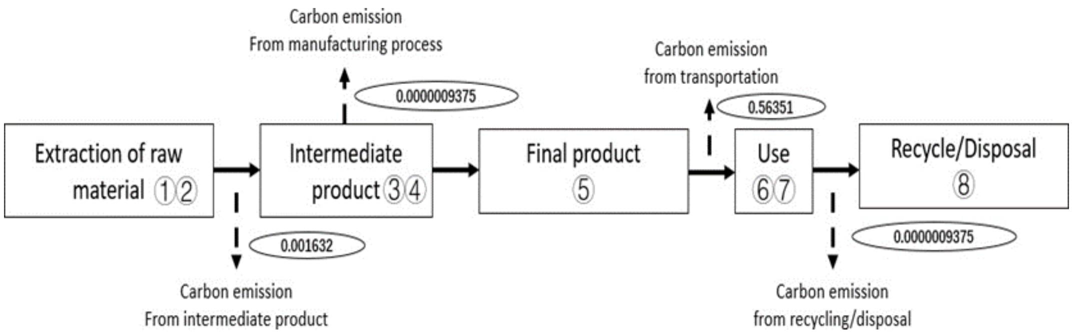

Figure 7. Diagram of carbon emissions from a 2L bottle of alcohol disinfectant

Carbon emissions per 500ml bottle of alcohol disinfectant are:

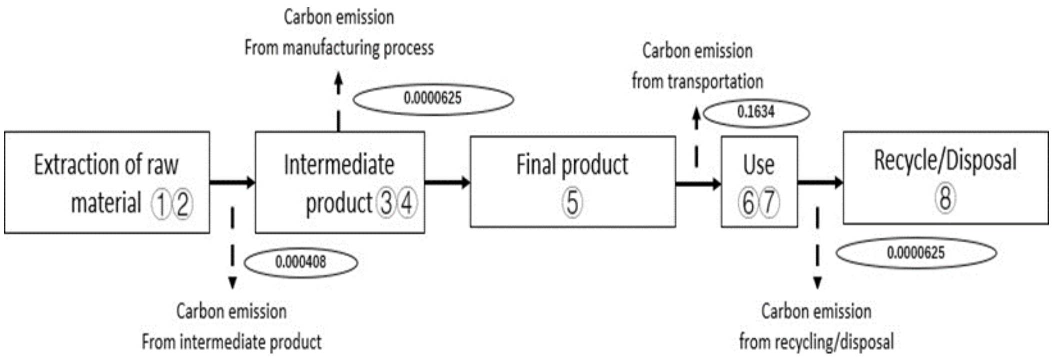

Figure 8. Diagram of carbon emissions from a 500ml bottle of alcohol disinfectant

Carbon emissions from each 50ml bottle of alcohol disinfectant are:

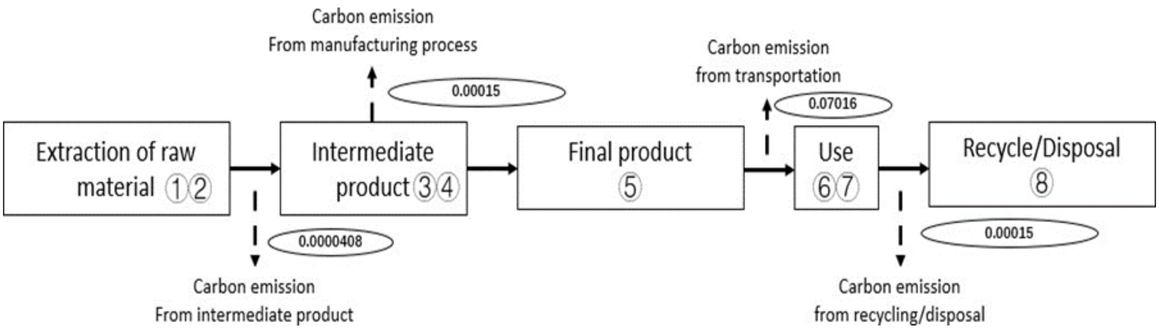

Figure 9. Diagram of the carbon footprint of a 50ml bottle of alcohol disinfectant

It is clear that the carbon emission from transport is the source of carbon emissions for each size of alcohol disinfectant product in the total carbon emissions, and that for each size of alcohol disinfectant product, the carbon emissions from transport account for more than 90% of the total product life cycle carbon emissions. This suggests that supply is important for the life-cycle carbon emissions of the alcohol disinfection products used in CITIC Tower, contrary to the conclusions reached in Section 2 after the literature review.

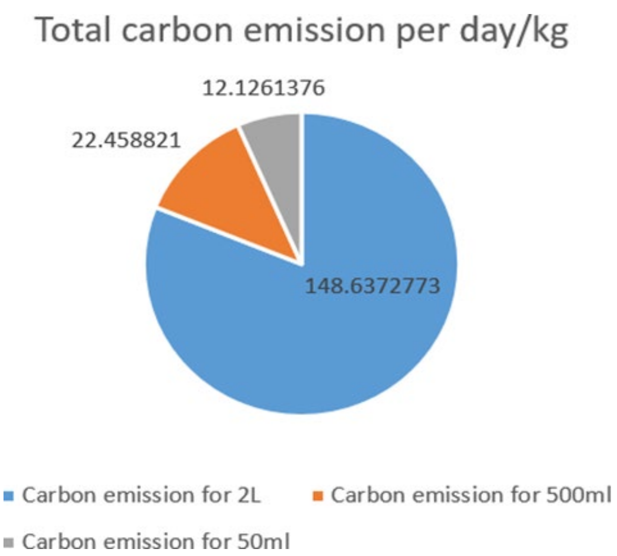

Figure 10. Proportion of carbon emissions generated by different sizes of alcohol disinfectants/day

As can be seen, for the alcohol disinfectants used daily at CITIC Tower, the 2L size accounts for the largest proportion of carbon emissions. Therefore, potential 5B5XKYsupply chain sustainability improvements from 2L alcohol disinfectants would be the most likely way to reduce carbon emissions. In addition, the production and supply of disinfectant for spraying in the CITIC Tower lifts, table cleaning and distribution to staff generates a total of 183 kg of CO_2 emissions per day.

B. Potential Carbon-Reduction Supply Chain Methods

1. Raw material acquisition process

The carbon emissions generated in the harvesting and harvesting of maize are minimal. Henan is one of the more backward and less mechanised provinces in China and traditional farming is still the main method of maize cultivation in Henan, i.e. a lot of human labour and a little machinery. Harvesting machines are rare and most farmers still use traditional methods of harvesting, and electric tricycles are extremely popular in rural Henan province due to their light start, low weight, lack of fuel and lack of driving licence. As a result, the process of harvesting and obtaining maize is already very environmentally friendly and it is difficult to make any changes in the direction of carbon reduction (Han & Zhao, 2009).

What is clear is that the use of maize with a high starch content can lead to a higher conversion rate of maize ethanol. Thus, specific, high starch content maize varieties can help to obtain higher conversion rates and have a probability of saving energy. However, this idea is also controversial because the by-products of maize ethanol also have commercial value, for example bran and DDGS can be used to make feed, while maize germ can be pressed for cooking oil. These carbon emissions will need to be considered together in future studies.

In contrast, another important raw material, plastic, is much more workable. As a recyclable plastic, PET has a high potential for reuse (Song *et al.*, 1999). The carbon content of the reused plastic is the same as the virgin plastic, which means that 100% of the plastic is produced for recycling. Although a certain amount of carbon is emitted during the recycling, transport and re-production process, the transport figure (only 0.071546 kg CO_2/tonne PET plastic per km for recycled PET bottles transported by truck) is already 85% less than the production of PET bottles from virgin material, which is also a significant reduction in emissions.

2. Supply process

According to a review of the literature and the Ecoinvent database, the use of lorries is one of the more carbon-intensive modes of transport.

Ecoinvent Free View usually contains 2-3 available modes of transport, the main comparison being between a freight train and a lorry. In most cases, freight train usually produces 50% less carbon emissions than lorry or other modes. Since it is known from the calculations in 4.3, even though some of the previous studies have shown that transportation is not the main source of carbon emissions from products, in fact in this study transportation has produced much more carbon emissions than manufacturing.

This may have something to do with geography. China is a very large country, especially compared to European countries. Therefore, the potential energy consumption spent on the road may be higher, even if it is only across provinces, and may take longer distances than in Europe for cross-country transport. Therefore, improvements in transport are also more likely to be useful than studies in European regions.

Alternatively, choosing a better, closer supplier would be a good approach. The fact that the plastic bottles and alcohol solutions in this study were sourced from a greater distance does not make for a very scientific supply chain. But it is also common for each region to have a better production group for a specific product. If suppliers could be chosen that are closer to both locations, for example choosing an alcohol disinfectant manufacturer whose production site is in Hebei, this would significantly reduce the carbon emissions generated during transportation.

Taking the above factors into account, improved transport methods would calculate the reduction in carbon emissions based on a 50% reduction.

C. Comparison Before and After

As it is difficult to verify the product life cycle of other alcohol disinfectant manufacturers, it is assumed that CITIC Tower, in order to reduce its carbon footprint, will no longer use maize ethanol produced by Lianren Shengbang and will instead use maize ethanol produced by brand X for its daily disinfection.

Brand X ethanol disinfection products are packaged in biodegradable 2L, 500ml and 50ml PET bottles from Shangqiu, Henan Province. The production process for corn ethanol is the same as that of Lianren Shengbang. The finished disinfectant is transported to Beijing, China by freight train. By comparing the life-cycle differences in carbon emissions between the brand X alcohol disinfectant purchased by the facility manager of CITIC Tower and the alcohol disinfectant produced by Lianren Shengbang, appropriate guidance was given to the facility managers on their purchasing behaviour. The difference in carbon emissions between alcohol disinfectant and alcohol disinfectant produced by Lianren Shengbang over the whole life cycle has led to appropriate guidance on the purchasing behaviour of facility managers.

In general, when brand X is used instead of the alcohol disinfectant produced by the Lianren Shengbang company, the total carbon emissions generated by CITIC Tower during the life cycle of the alcohol products used for sterilisation were calculated to be 92 kg CO_2 per day. The total carbon emissions generated by CITIC Tower during the life cycle of the alcohol products used for disinfection is 92 kg CO_2 per day, which is 91 kg CO_2 saved per day compared to before the sustainable supply method, which is equivalent to 91 kWh of electricity.

The detailed calculation process can be found in Appendix 1. It is also clear from the calculation process that the most significant carbon reduction occurs during the transport process, i.e. during the supply process. Therefore, the use of appropriate supply chain methods for the product is indeed effective in reducing the carbon emission of alcohol disinfectant.

Table 5. Situation compared before & after

Before (Conventional)	**After (CITIC)**
183 kg CO_2/day Over 50% is produced during supplying process around total life cycle	91 kg CO_2/day About 50% is produced during supplying process around total life cycle
Different produce places of different life-cycle materials	Same produce places of different life-cycle materials
Transportation by lorry	Transportation by freight train
Use a traditional plastic bottle	Use recyclable PET bottle
No plastic bottles recycled	Plastic bottles are well-recycled
Price and quality are the first considerations	Product carbon emissions also considered by facility managers

D. Contribution to Chinese Building Industry Carbon Reduction

According to China's emission reduction commitments in the Paris Agreement, the country will have an annual carbon emissions gap of between 12-15 billion tonnes if it is to meet the 2030 carbon peak and 2060 carbon neutral targets on time (ICCSD, 2019).

According to the calculations in section 4.5, if appropriate sustainable supply methods were adopted, the lifecycle carbon emissions from the alcoholic disinfectant for surface cleaning obtained at CITIC Tower would be reduced by 91 kg CO_2 per day. Therefore, if these more appropriate methods were used consistently throughout the year, the annual reduction in CO_2 emissions would be 33,215 kg. Although this carbon emission reduction of around 30,000 is insignificant compared to the annual carbon reduction of 12 billion, it hides a much bigger problem.

As mentioned in the background research in Section 1, there are approximately 6,000 office buildings in China. Therefore, even if the CITIC Tower itself does not have enough emission reductions in the alcohol disinfectant supply chain to have an impact on China-wide emission reduction targets, these sustainable supply methods are also applicable to other office buildings in China. office buildings in China and have a significant potential to reduce emissions.

E. SWOT Analyses

For the producer of corn ethanol in this case study, Lianren Shengbang Enterprises, internal strengths and weaknesses come from cost control in the production process and quality assurance, while external opportunities and threats come from competition from other brands, the stability of CITIC Tower's fixed supply and market acceptance. While adopting appropriate ways to reduce the carbon footprint of the product life cycle, the stability of production and supply is a sector that should be safeguarded even more.

Accordingly, price and quality are still the main considerations of facility managers when purchasing materials due to the lack of financial support from the CITIC Tower facility managers. Therefore, there may be a certain conflict between the current sustainable products and the most suitable products and a SWOT analysis is necessary for the best choice in carbon emission and financial budget.

The advantages of adopting sustainable supply chain methods can be defined more generally as environmental friendliness and an increase in social reputation. Public opinion and policy in China is currently very friendly to companies that adopt green and sustainable practices, which is one of the reasons why the green office criteria is becoming increasingly popular. Therefore, if CITIC Tower can demonstrate and publicise that they have chosen a supplier that uses sustainable supply chain methods through a fair and reasonable bidding and tendering policy, their reputation will be affirmed, and this may increase the likelihood of the landlord considering CITIC Tower for lease.

However, there are also disadvantages. The use of recyclable PET bottles can mean higher production costs in terms of money, and the potential quality issues of PET bottles are also worthy of attention. Due to the nature of biodegradable, recycled plastics, they are generally more fragile than normal plastics, have a shorter shelf life and are more susceptible to degradation in the environment. As a result, they are not as resistant to storage after manufacture as regular PET plastic, but need to be put into production, use processes and recycled properly relatively quickly. Consequently, they will not be as stable as ordinary plastics and may cause losses to entrepreneurs if they encounter logistical obstacles that prevent them from being shipped due to the effects of COVID-19, or continuous extreme weather.

The other disadvantage stems from the reliability of choosing a new supplier of plastic bottles. For Lianren Shengbang companies, a plastic bottle manufacturer in Cangzhou is likely to be the one they work with for a long time. Moreover, as a plastic producer with many plastic bottle manufacturers, Cangzhou has more advanced production processes and production procedures. Therefore, businesses need to fully examine the sophistication of their processes, the quality of their products, their output and prices, and their carbon footprint before changing to a more recent plastic bottle supply location.

Finally, the proper recycling of plastic products is also a challenge. Currently, China's waste separation and recycling system is not well developed, and while some major cities such as Beijing and Shanghai have started to implement waste separation on a pilot basis with some success, in most Chinese cities there is not a robust system for separating and recycling plastic products. Most plastic products are still transported to waste transfer stations and treatment plants where they are compacted and then incinerated or landfilled. Therefore, the need to sort, transport and recycle PET bottles in a regulated manner is one of the disadvantages of using sustainable supply methods.

The opportunities arise mainly from the advantages, i.e. the increase in social reputation. The other opportunity comes from the potential for financial subsidies from the government for choosing sustainable supply methods. Although the Chinese government does not currently have clear regulations on subsidies for the use of sustainable products in facility management, this is an event that can be expected to occur as policy develops. These opportunities could help CITIC Tower property management companies to continue to order products with sustainable supply methods and create a good positive cycle.

A possible threat is the competition from other products. As carbon reduction research progresses and carbon neutrality policies continue to be promoted, it is likely that individual products will be manufactured with the use of recycled raw materials and with the use of nearby raw material suppliers. This is of course a good market trend for the advancement of carbon neutrality, but at a time when the market is becoming increasingly homogeneous, new selling points need to be identified to stand out from the crowd of sustainable products in order to ensure that CITIC Tower property management company continues to order their products.

For CITIC Tower, however, the increase in the number of sustainable products on the market also means an increase in purchasing options. When all products use more or less the same carbon reduction process, financial costs are probably the most important consideration. This means that while maintaining the production and sourcing of plastic bottles using the carbon reduction process, the production of corn ethanol needs to be consistent in terms of quality of output and a lower carbon, sustainable production method is sought.

Table 6. Potential change before and after using sustainable supply chain methods by SWOT analyses

Before (Conventional)	After (CITIC)
PET bottles have better quality but lower carbon emission	PET bottles are more fragile but environmentally friendly
Government no sponsor	Government potential sponsor
Lower social reputation	Higher social reputation
Higher carbon emission	Lower carbon emission

F. Directions for Facility Management

Calculations of chapter 4 showed that by simply changing the lifecycle of a product and its supply methods, carbon savings of more than 50% can be achieved in a year's time. This is therefore very informative for facility managers or property management managers and places new demands on the procurement of products for facility management. It is the responsibility of the facility manager to help the construction industry reduce its carbon footprint by selecting products with the right lifecycle for facility management.

For facility managers, the first step is to select the right product by where it is produced. As calculations have shown, the main source of carbon emissions in the life cycle of alcohol disinfectant supplies is the transport process, i.e. the supply process. Therefore, when selecting suppliers, facility managers can choose suppliers that are closer to the place of production or, depending on the tender, suppliers that use renewable energy transport vehicles or freight trains for transport, in order to support low carbon production and reduce the carbon emissions generated by the building industry through their own choice as much as possible. This approach to product selection applies not only to alcohol disinfectants but also to all utility management products such as floor cleaners, toilet cleaners, air fresheners and garden pesticides. The choice of supplier should be based on quality and on-time delivery, with the smallest possible transport distances.

Secondly, property management should try to source recycled plastic products and recycle them as much as possible and find reliable recyclers. This includes not only the plastic packaging products produced by property management, but also all the recyclable plastics produced in the building. This initiative will not only benefit the carbon footprint of facility management, contributing to China's carbon peak and carbon neutrality targets, but will also help the burden of waste plastic products on the planet. It is well known that waste plastics take hundreds of years to degrade in nature, causing environmental damage including, but not limited to, affecting the habitat of marine and terrestrial organisms, breaking down into microplastics that enter the food chain cycle and eventually accumulate in the human body.

The findings of this study therefore provide a clear recommendation for the potential of sourcing materials for facility managers to reduce carbon in the context of facility management. Based on the carbon footprint of facility management materials, facility managers can determine whether a product meets sustainable supply criteria when bidding for a product, through tender descriptions and questions to company representatives, and thus reduce carbon in the facility management process (Min, 2012).

G. Summary

From all the statistical analyses carried out, the results of the study suggest that the use of sustainable supply methods for alcoholic disinfectants in the CITIC Tower single case does not have a disproportionate impact on China's carbon neutrality targets. However, these calculation models can be extended to other office buildings. It can also provide the basis for procurement criteria for facility managers.

V. CONCLUSION AND RECOMMENDATION

This paper discusses the findings of the report and the implications for future research in this area and make recommendations for the supply and procurement of materials for facilities management based on the findings.

The process currently used for most alcohol production in China is still fermentation, using starch-bearing crops to saccharify and purify them, based on which they are distilled at a specific temperature to extract a more concentrated alcohol.

There is the specific process of distillation, which requires heat, and the fact that the contribution to carbon emissions varies according to the type of heat used. The use of burnt maize straw would be the best option, which makes maximum use of every growing part of the maize. At the same time, the environmental impact of the by- products should be properly assessed. Using a separate life cycle carbon analysis for corn ethanol products is relatively biased, as other by-products produced during the manufacturing process may have a greater environmental value than corn ethanol. These errors should be considered in future studies to correct for any errors that may arise.

A. Summary and Conclusion

The research objectives of this study are to investigate the current carbon footprint of facility management in China's construction industry and to examine the supply and lifecycle carbon footprint of the materials required for facility management using the CITIC Tower daily disinfectant as a case study. The study also examines the supply and lifecycle carbon emissions of materials required for facility management, discusses possible sustainable supply chain approaches, and helps facility managers to reduce their carbon emissions through the selection of appropriate products.

The findings show that China's construction sector accounts for approximately 1/3 of the country's total carbon emissions. Before using sustainable supply chain methods, CITIC Tower's alcohol disinfection supply chain generated 183 kg of CO_2 emissions per day. With the use of recyclable plastic packaging, the use of more proximate suppliers with shorter transport distances and proper recycling of plastic packaging, the daily carbon emissions were reduced by approximately 50%, resulting in a reduction of approximately 33,000 kg of CO_2 emissions per year. CITIC Tower's supply chain improvements will not make a significant difference. However, if this same reduction were to be extended to the 6,000 office buildings in China, it could generate approximately 2 billion kilograms emissions reductions, which would help China to achieve 0.016% of its annual reduction target.

Facility managers can use the findings of this study to determine the carbon footprint of the alcohol disinfectant product supply chain in order to find more appropriate, low carbon, sustainable facility management materials for their companies.

B. Contribution of the Study

The research model and findings of this study are applicable to the calculation of carbon emissions from the supply of facility management materials for all office buildings in China and provide a reference for the calculation of carbon emissions from the wider facility management material supplying process. In addition, because of CITIC Tower has passed LEED certification, short construction life, new construction ideology and large scale, CITIC Tower represents the future trend of office buildings in China. With the development of urbanisation in China, the number of office buildings in China will rise in the future. Including the past decades, the number of commercial buildings in China has also maintained a steady upward trend. Therefore, the application of this sustainable supply chain approach to more commercial buildings and offices will bring greater benefits.

On the other hand, alcohol disinfectants are only one item on the list of materials required for facility management. In fact, for a large commercial building, the list of materials required for facility management includes a wide range of household products, including, but not limited to, floor cleaners, toilet cleaners, glass water, insecticides, etc. In this study, only alcohol disinfectant was investigated, and no other materials were discussed.

Although the life cycle of other household products is different from that of alcohol disinfectants, they share some commonality with alcohol disinfectants in terms of life cycle and supply chain carbon emissions. Due to the large geographical area of China, inter-provincial transport will have longer journeyed than in Europe, Australia etc., which also means more potential carbon emissions in the transport process. Therefore, this study of alcohol disinfectants used in CITIC Tower will provide a useful reference for future lifecycle and supply chain carbon emissions of all utility management materials used in office buildings.

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Appendix 1. Calculation tables for carbon emission during alcohol disinfectant’s life cycle

Process	E1	E2	E3/kg	E4	Total/kg	Number o	Total carbon emission per day/kg	PET bottle	520	km
Carbon emission for 2L	0.001632	9.38E-06	0.5635	9.38E-06	0.56516	263	148.6372773	Product tra	700	km
Carbon emission for 500ml	0.000408	6.25E-05	0.1634	6.25E-05	0.16393	137	22.458821			
Carbon emission for 50ml	0.0000408	1.50E-04	0.0702	1.50E-04	0.0705	172	12.1261376	Mass of Alcolhol		
							183.2222359	For 2L	1.6	kg
								For 500ml	0.4	kg
Process	E1	E2	E3/kg	E4	Total/kg	Number o	Total carbon emission per day/kg	For 50ml	0.04	kg
Carbon emission for 2L	0.001632	1.07319E-06	0.281755	0	0.28339	263	74.53106325			
Carbon emission for 500ml	0.000408	7.1546E-06	0.0817	0	0.08212	137	11.24977618	Mass of PET bottle		
Carbon emission for 50ml	0.0000408	1.7171E-05	0.03508	0	0.03514	172	6.043731019	For 2L	1.50E-05	ton
							91.82457045	For 500ml	1.00E-04	ton
	2L	500	50					For 50ml	2.40E-04	ton
Before	9.38E-06	6.25E-05	1.50E-04							
After	1.0732E-06	7.1546E-06	1.7171E-05							
	2L	500	50							
Before	0.56351	0.1634	0.07016							
After	0.281755	0.0817	0.03508							

Process	E1	E2	E3/kg	E4	Total/kg	Number o	Total carbon emissior	PET bottle	520	km
Carbon em	0.001632	1.07E-06	0.2818	0.00E+00	0.283388	263	74.53106	Product tra	700	km
Carbon em	0.000408	7.15E-06	0.0817	0.00E+00	0.082115	137	11.24978			
Carbon em	4.08E-05	1.72E-05	0.0351	0.00E+00	0.035138	172	6.043731	Mass of Alcolhol		
							91.82457	For 2L	1.6	kg
								For 500ml	0.4	kg
								For 50ml	0.04	kg
								Mass of PET bottle		
								For 2L	1.50E-05	ton
								For 500ml	1.00E-04	ton
								For 50ml	2.40E-04	ton