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PNNL-31929

Certified Green Building Materials – Policy Impact Assessment

Closing the Gap in China's Building Energy Efficiency: Building Materials Certification System

September 2021

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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Executive Summary

Chinese building construction is rapidly expanding, making it critical to focus on energy efficiency to curb the increase of energy consumption and emissions over a building's lifetime. A key mechanism to do so is through building material certification systems and programs. These establish how building materials will perform and can be used to promote energy and resource efficiency, which help create a more sustainable and healthy building industry.

This report begins by identifying characteristics of a strong certification system and ways to improve existing systems. To be a strong and robust certification system, there needs to be a national, uniform system with transparent and clear coordination across multiple agencies. There needs to be a clear alignment between standards to improve transparency and consistency. To optimize impact, certification systems need to be connected to programs and policies such as building energy codes and building rating systems.

To curb building energy demand, the Chinese government began developing a building material certification program to encourage energy and resource efficiency in the building sector. The report provides a timeline of their program's development and provides analysis. In 2014, the Chinese building material certification system began developing from a localized, fragmented system to the current unified, national system. Today, building material certification exists under a larger green product system. Their system has improved by developing a national material database and increasing collaboration across multiple agencies. Efforts to improve the current national system include further developing the material database and connecting to policies and programs.

This report also highlights China's building material database and analyzes their significance and opportunities for improvement. Material databases provide many benefits to a certification system, such as improving transparency, allowing quick access to information, and efficiently connecting to other systems and software. China's national material database was developed in 2019 and can be further improved by connecting the database to a building certification system. Another opportunity for further improvement is utilizing new technology, such as blockchain, to improve transparency and efficiency of the system.

The report also analyzes the importance of policies such as procurement programs, and the Chinese government is developing their procurement programs for certified green building materials. Procurement programs utilize the government's large purchasing power to transform the market by increasing demand for greener materials. The Chinese government launched a new green procurement policy pilot program in October 2020 in five cities, where they will implement regulations and observe the results of various strategies. Regardless of the jurisdiction, one of the largest challenges with procurement programs is developing mechanisms to finance them since green building materials often have higher upfront costs. Most jurisdictions justify the higher costs by understanding that the upfront investment in energy efficiency will save money over the product's lifecycle, along with providing other benefits, such as reducing environmental harm and improving health of buildings. Coordinating across multiple agencies can help distribute the upfront costs since the benefits of green buildings are realized across agencies. Overall, governments in general have enormous purchasing power of building material products and can shift the market to become more efficient, reducing this upfront cost over the long term.

To understand the potential large-scale impacts of green building material certifications, Pacific Northwest National Laboratory (PNNL) conducted an analysis of the environmental and market impact of a nationwide green building procurement policy for all new residential and commercial construction. In addition, we also looked at the potential impact of certified green building materials being incorporated into China's national building codes. Green building material certification is the foundation of successful procurement or national building codes. We calculated that a procurement policy would save between 263 to 11,800 GWh, and that incorporation into national building codes would save between 4,130 and 24,800 GWh. Policy that supports certified materials increases their demand and, therefore, impacts the market. Looking at insulation, we calculated that a nationwide procurement policy would result in $8.87 billion of investment in insulation per year, and an incorporation into national building codes and standards would result in $27.9 billion of investment in insulation per year. These analyses demonstrate the importance of connecting certified building materials with policy to reduce energy, costs, and emissions, while also increasing demand to help the market reduce the upfront cost.

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Acronyms and Abbreviations

CAGR	compound annual growth rate
CMA	China Metrology Accreditation
CO_2e	CO_2 equivalent
CQC	China Quality and Certification Center
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
IEA	International Energy Agency
ktoe	Kilotonnes of oil equivalent
LEED	Leadership in Energy and Environmental Design
MIIT	Ministry of Industry and Information Technology of China
MOHURD	Ministry of Housing and Urban-Rural Development
PNNL	Pacific Northwest National Laboratory
SC	Shading Coefficient
SHGC	Solar Heat Gain Coefficient

Contents

1.0 Introduction

China's rapid economic development and urbanization has made it the largest building energy consumer in the world. China's commercial and residential building electricity demand is currently at 420,000 kilotonnes of oil equivalent (ktoe), or 4,885 TWh, and has had an annual growth rate of 3% in the last decade, mostly due to new building construction. With such rapid increase in the building sector, energy efficiency is more important than ever since it helps curb building energy consumption and emissions over the lifetime of the building.

Building material testing and certification systems are a building block for all building energy efficiency policies, and they help establish whether the materials will likely perform well. Utilizing certified materials and certification programs can create a more sustainable, healthier building industry through promoting energy and resource efficiency. For example, building energy codes with robust implementation can reduce building-related emissions in China by 14% to 22%, compared to a reference scenario [2]. China has significant potential to improve its building energy efficiency by improving its materials testing, rating, and certification.

The Chinese government started to develop a building material certification program to promote the use of green building materials and reduce energy consumption. The U.S. Department of Energy (DOE) has been collaborating with the National Development and Reform Commission of China and other partners to improve China's national green building product standard, testing, certification, and labeling system. This report summarizes key progress in establishing a building material certification system in China, discusses pilot projects that can promote the use of certified products in green, efficient buildings, and highlights key outcomes and lessons learned.

1.1 Certification Systems

Certification systems for building materials help determine overall environmental impact of building products within specified categories or frameworks. Certification programs provide transparency, uniformity, and efficiency in identifying building standards and ensuring compliance with building codes. Robust certification systems can also allow consumers to understand the environmental, economic, and social impact of the products they purchase, as well as the benefits that are associated.

Since 2016, Pacific Northwest National Laboratory (PNNL) has been collaborating with Chinese ministries and stakeholders to improve the transparency and robustness of the building material certification program in China and develop a national certification system. The collaboration has covered several aspects of developing a strong building material rating and certification system, including

- Institutional Framework
- Standards Development
- Stakeholder Engagement
- System Integration.

PNNL examined the Chinese certification programs, reviewed literature, and conducted interviews to develop insights. The following section elaborates on the results of our analysis.

Institutional Framework of Certification Systems

The certification process aims to provide assurance that a product meets whatever requirements are determined by the program. Regarding green building materials, this would mean certifying products based on criteria such as energy efficiency, impact on air quality, safety, composition of sustainable materials, and adaption of sustainable practices.

The framework of the certification system consists of connections between institutions, such as the accreditation bodies, certification bodies, testing and simulation laboratories, manufacturers, certification program, and their link to policies. The process of the certification program and its key stakeholders is shown in the Figure 1, adapted from a PNNL report by Y. Zhou et al. [3].

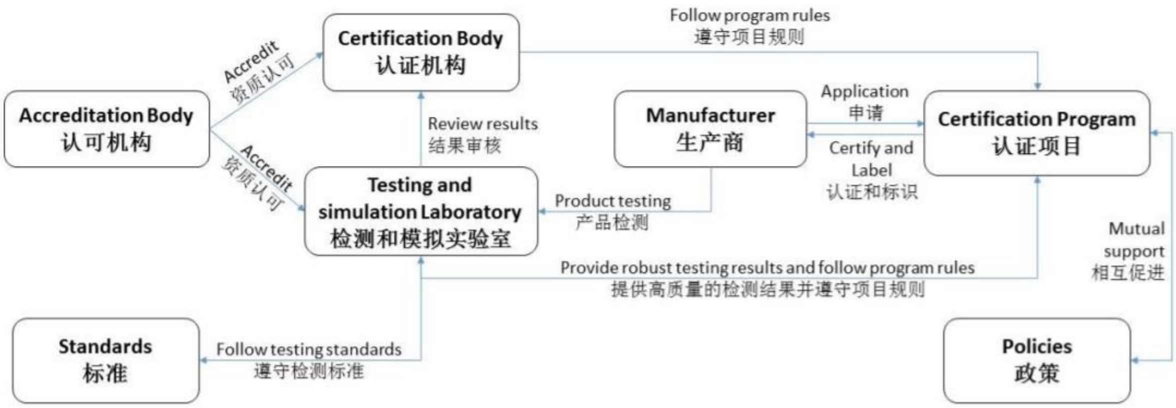


Figure 1: Flow chart of Chinese certification system [3]

The current key agencies and institutions involved are described in more detail below. These stakeholders all work together to create a robust certification system, endorsing green building materials [3]. The evolution of the agencies and system is described in section 2.

- The Standardization Administration of China and the Ministry of Housing and Urban-Rural Development (MOHURD) develop the product standards, which provide the basis for product measurement and certification.
- The China Quality and Certification Center (CQC) administers the certification programs and is responsible for the implementation of product certification and developing product standards.
- The accreditation body in China is the Certification and Accreditation Administration of China, meaning they approve the testing and simulation laboratories and certification bodies. They also issue the China Metrology Accreditation (CMA), which is a requirement for any third-party testing laboratories or inspection bodies in China.
- The China National Accreditation Service for Conformity Assessment is the national accreditation body, established and authorized by the Certification and Accreditation Administration of China, that provides voluntary accreditation to all kinds of certification bodies, testing sites, and inspection bodies, rather than just third-party (like CMA).
- The manufacturer creates a product that then is tested and simulated in a laboratory.
- After testing, a certification body reviews the results and certifies the product, ensuring the product's performance. The manufacturer can then label the product, connected to the certification program, which identifies the product's features easily to aid customer decisions.
- The overall certification program can then be tied to policies that promote certified materials.

There must be strong linkages between standards, testing, certification, and labeling systems to make the certification system more efficient and cost-effective [3]. Having strong communication and collaboration from all the institutions involved in product testing, product certification, and product labeling naturally results in a more robust national certification system. Otherwise, there could be duplicated efforts, redundant testing, confusing certification labels, and ineffective connection to policy. For example, it is important to avoid having multiple, unconnected certification programs for single product categories since this can confuse customers and prevent manufacturers from distinguishing their products. Along the same line, it is also important for certification programs to have promotional strategies to expand their program and get even more products certified or expanding to more product categories. In addition, the link to policies and incentives is important to encourage implementation at a large scale, further strengthening the program [4]. Many of these insights and recommendations were developed based on engagement from relevant stakeholders.

Stakeholder Engagement

A robust national certification system requires collaboration from all those involved in product testing, product certification, and product labeling [3]. Naturally, input from the system's stakeholder is critical to developing deeper understanding of the industry and the market, identifying barriers and challenges, and finding effective solutions to enhance a national standard, testing, certification, and labeling system. Therefore, PNNL, along with Chinese collaborators, organized two working groups to collect feedback by product category. Members of the working group included policy makers, standard makers, researchers, manufacturers, industry associations, and experts on specific building materials. These working groups help meetings to discuss testing standards, accreditation programs, and certification programs in the United States and in China. This stakeholder engagement led to the insights incorporated into this report, such as the importance of strong linkages between standards, certification programs, and policies, or the importance of transparency of measurement and testing processes.

There has been increased private sector engagement throughout the Chinese certification process, as well. This is seen through increase in third-party laboratories and inspection bodies. Third-party certification helps ensure program integrity, to guarantee there's no fraud or abuse influencing the certification.

Standards Development

Standards are the foundation of product testing and certification since they ensure the properties of a product are upheld. Standards are used within almost all aspects of the certification system, such as developing product specifications and testing procedures, accreditation of laboratories and certification bodies, and creating methods for third parties to ensure the requirements are reached. Standards can be aligned with other programs, such as building energy codes, which can increase the use of the green products.

Standards are the technical base of the certification. In the past, China had overlapping performance standards for the same product categories. These overlapping standards resulted in redundant testing, which is more expensive. For example, there are multiple accredited intuitions labeling energy-saving windows and doors, including Shanghai Ingeer Certification Assessment Co. Ltd (ICAS), CQC, CTC, and China Quality Mark Certification Group. Each of these institutions have their own standards for implementation, making it redundant and confusing to consumers [4]. Strong alignment and consistency across testing standards and institutions can help streamline the certification process, while also building merit to the certification system. This then increases the certification's market value.

Using consistent standards and methods across countries makes it easier to compare products internationally and helps place all products on an even playing field in the international market. For example, for windows, the solar heat gain coefficient (SHGC) is commonly and internationally used to determine the total solar energy transmittance. In China, they use the standard of shading coefficient (SC), which does account for a product’s total solar energy transmittance, but only for a specific area of the window and does not account for the optimal performance of coated glazing. Therefore, a Chinese SC and products that use SHGC cannot be accurately compared. Replacing the SC with SHGC can not only more accurately evaluate the performance of the whole window and accurately represent all types of glazing, but also ensure consistency among different standards and align more strongly with international standards [3]. In addition, having the same level of stringency in standards across countries would create a level playing field.

System Integration

Building material certification is a powerful tool when connected to programs and policies such as building energy codes and building rating systems. Buildings can be required to use certified materials that meet specific environmental standards. These connections to policy or larger systems allow the certification to be implemented at a wide scale, increasing the use of green materials in the market. This works since certified products help building designers meet part of a designated code, construction companies to install the specific materials, and building instructors to determine compliance. Certified materials also can be connected to procurement policy, which leverages the government’s purchasing power to influence the market. Connecting to policy has the potential to make a large impact on the green building materials market while seeing environmental and cost benefits.

Certified building materials can be linked to overall building certification, which also can be linked further to energy codes or policies. Common green building certification programs include Leadership in Energy and Environmental Design (or LEED, which is based in the United States) or the 3-Star Rating System in China. These building certification systems quickly identify if a range of environmental standards have been met for the entire building. The 3-Star Rating System operates on a point system for various categories. However, for the 3-Star method in China, according to the 2019 GB/T 50378-2019 Green Building evaluation standards, the total weight of green building materials is only 12 points out of 1,000 points, corresponding to 1.2% of the total evaluation. This leaves an opportunity for further connection of green building certification and certified green building materials in China.

Policies can help incentivize the use of green building materials to help offset the fact that green buildings are often more expensive than conventional buildings due to more costly building materials, consultant costs, and additional certification costs. Incentives can balance out these additional transaction costs. Throughout the literature, it is apparent that the initial cost is the main barrier hindering the private sector in green building development and that government can provide incentives to lower those costs [5]. Many studies have shown that financial incentives encourage using green materials and can drive private sector change. Incentives can be financial, such as direct grants, tax incentives, rebates, and discounted development application fees. Incentives can also be non-financial, such as expedited permitting or technical assistance, which save time and money by mitigating risk and process issues. Financial incentives are the most common green building incentives from the government, especially in the United States, though governments frequently favor non-financial incentives because they bear no direct costs [5], [6]. These various mechanisms can help offset the higher cost of green building materials.

Supporting policies can help increase demand for certified materials. And regardless of the mechanism, having a consistent, reliable certification program naturally allows more robust green building policies.

Moving Forward

China's building certification system has evolved and advanced over the past several years. Section 2 of this report reviews and analyzes the history of China's certification system. Section 3 discusses the current projects being developed: the material databases and procurement policies. Section 4 quantifies the impact of procurement policies, and Section 5 discusses outcomes and lessons learned.

2.0 Developing a National Building Certification System: Policies and Programs

As a part of China's ongoing efforts to advance energy efficiency, the Chinese government has issued numerous guidelines and policies regarding the implementation of a national certification system to increase the market share of green building materials. What started out as several localized, fragmented certification systems prior to 2014, eventually developed into the unified national system today, complete with a national material database and collaboration across multiple agencies, under a larger green product system. This section describes the history and evolution of the national building certification system. Figure 2 shows a timeline from 2014 to present.

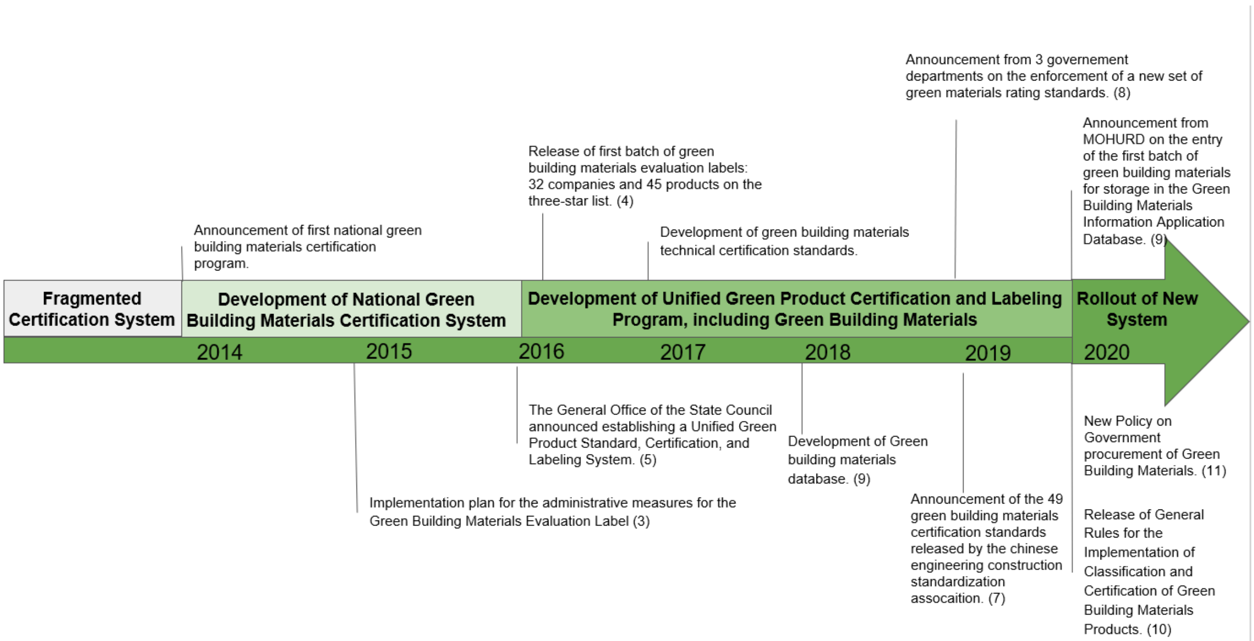


Figure 2. Timeline of China Green building materials certification program

2.1 Before 2016: Transitioning from a Fragmented to a National System

In 2014, the first national green building materials certification program in China was announced [7]. The program was developed by MOHURD and the Ministry of Industry and Information Technology of China (MIIT) and was intended to replace the previously regional and non-standardized systems. They developed a three-level certification scheme for the program and a set of green building certification technical standards/specifications. They also planned supporting infrastructures, such as a green building materials classification catalog and a public database to provide credible and transparent access to the product certification process and its results [8]. Certification agencies are accredited via an application requiring provincial level MOHURD and MIIT vouching. A pilot version of the assessment/technical standards was released in 2015, along with policy details on the planned implementation [9]. In October 2016, the first batch of the green building material products approved by the certification program were announced and released [10]. This was the starting point of certified green building materials in China, providing a foundation for future work.

The development of a national green building materials certification system was halted and evolved in 2016, however, due to a larger policy change resulting in the merger of the green building materials certification system into a new, broader national green product certification/labeling system, elaborated on more in the next section. [8]

2.2 2016–2020: Development of a National Product Certification System

In 2016, the General Office of the State Council of China called for the establishment of a unified green product certification/label program across China (5). The new program intended to combine several previously distinct product-specific certification programs under a new unified system with a common labeling system. Some products merged under the new program include building materials and other products that meet criteria of sustainability and environmental friendliness, such as green electric appliances and green consumer packaging.

Figure 3: Green Product Insignia

The new uniform green product certification program encompasses all environmentally friendly, energy-efficient, resource-efficient, low-carbon, renewable, organic products under the large designation of green products. This uniformity with one certification label (see Figure 3) helps increase customer awareness of the green products and increases market acceptance. Larger numbers of certifications and labels can confuse customers.

The new program retained a three-level tier system and maintained many of the same features as part of the 2014 program regarding infrastructure. In addition, three new ministries were introduced to assist in the establishment of the green building materials certification technical specifications and certification agency: Certification and Accreditation Administration, Administration of Quality Supervision, and National Standards Committee [11]. MOHURD was assigned to develop the product database, and a joint effort of MOHURD, MIIT, and General Administration of Market Supervision developed the green building materials classification catalog [12].

The new program enabled construction developers to take advantage of green product bonuses. In addition, a new program called for the increase of green building materials usage in government-funded projects, public infrastructure projects, and other public sector projects. The overall objective of the plan is to increase the green building materials market share to 40% by 2020 [11].

In 2017, MOHURD began developing the technical specifications for the green building materials program jointly with the project management professional committee of the China Engineering Construction Standard Association. The specifications were reviewed and released in 2019 [13]. A green building materials database was then developed and released by MOHURD in 2019, as well [14]. In the same year, a green building materials classification catalog, which classifies building materials into broader categories, was released by the General Administration of Market Supervision, as a part of the specifications and standards for the certification agencies' sampling and testing methods [15]. In addition, a service platform website for the green building materials database was created. The site's purpose is to facilitate the manufacturers of building materials during the certification process of products and to assist in the advertisement of green building materials post-certification. These are all part of the certification program's broader market-based approach at promoting green building materials, where information transparency regarding the certification program and consumer awareness are prioritized.

Plans to cease operation of existing/legacy green building materials certification bodies by May 2021 were announced, along with a detailed procedural document by the State Administration for Market Regulation and CQC on the operations of certification bodies [15].

Overall, from 2016 to 2020, China merged its national certification system for green building materials into its broader national certification/labeling system for green products, where they created new standards, policies, and programs. The new system created large institutional changes, such as coordinating between multiple agencies. In addition, it completed critical infrastructure, such as a product database, a classification catalog, and a one-stop service platform to facilitate the certification and promotion of green building materials. These large institutional changes created more uniformity across systems and increased transparency and scalability with the development of the database.

2.3 Post 2020: Roll-out of New System

Currently, the certification program is being implemented, along with other government fiscal policies intended to boost the performance of green products within the building materials market. One of the recent government initiatives was an October 2020 government procurement pilot program implemented in several major Chinese cities that aimed to increase the use of green building materials in government projects [16]. This pilot project is elaborated on in the Section 3.

The Procedures for Green Building Material Certification

The green building materials certification system in China falls under the broader green product certification system. As a result, all green building materials are classified within a 3-star, tiered system. Below are the current steps in the green material certification process.

Request for Certification

To request certification, the following documents are required: certification request; certificate of the trust relationship between the certification client, manufacturer, and production plant; production flow chart; manufacturer organization chart; product quality evaluation report; critical raw material list; and other related documents. The certification body needs to respond to the request within three days.

Initial Inspection

The manufacturers submit a self-evaluation prior to an on-site evaluation. The evaluators check the legality of the organization, the completeness of documents, and manufacturer's ability to assure. The review of the self-evaluation submitted by manufacturers should be completed within 15 days.

Product Evaluation and Certification

The on-site evaluation checks the technical qualifications within 30 days. They check the manufacturer's ability to assure, the uniformity of product, and the qualification of product for green building materials certification. Product sampling can be conducted during on-site evaluation and conforms to specifications outlined in the technical specifications. Sample evaluations would be conducted by a CMA-certified lab, and the evaluation process would be recorded for transparency. After the certification, a decision would be released within five days.

Supervision After Certification

The supervision period begins six months after the initial certification and is conducted annually. The post-certification supervision includes checking the quality, product uniformity, and manufacturer's credibility. Successfully passing these evaluations can extend and renew certification.

3.0 Pilot Elements: Improving the National System

PNNL has been discussing ideas to improve their national material certification system and increase the use of green building materials with CQC, the China Academy of Building Research, and other Chinese partners. Specifically, PNNL explored two programs that are in development: improving material databases and implementing government procurement programs.

3.1 Material Database

Robust material databases have numerous benefits for the building and certification industries. They support the overall development of the industries by providing easy access to information for all customers, manufacturers, designers, developers, and enforcement officers. They help streamline building code compliance because they improve transparency and allow quick access to information, which allows project designs to be passed to plan review quickly. They can be tied to software, such as those for building design, or broader building certification systems. A comprehensive database can also record product performance and market trends, enabling understanding of the new technologies, and aid in future developments. They also can be tied to the product testing process, improving transparency, and providing open resources. Material databases are a key component of a strong building material certification system.

United States

The United States has several green product material databases, such as Energy Star and Greenseal. Energy Star is a material certification program and database operated by the U.S. Environmental Protection Agency (EPA) and partnered with DOE. The products are third-party certified, and the standards come from the EPA. The database includes brand name, product category, certification date, key performance factors, and energy efficiency. Greenseal is another example of a U.S. online green product database that is managed by a nonprofit, and the products are third-party certified. The standards come from American Society for Testing and Materials (ASTM) International, and products are frequently tied to LEED certification.

Chinese Database Status

China established a national certified materials database in 2019, which replaced the legacy regional-/city-level databases that were used when the system was fragmented. This national database provides a centralized location for all certified materials in China. The database covers all the products that have been certified by the system already, such as the listing for green building materials certified by various regional-/city-level certification authorities. A typical listing of a product includes basic information, such as certification ID, name, certification agencies, and certification level. In addition, the database includes customer reviews of the products and whether the products comply with government procurement policies. The green building materials insignia is shown in Figure 4.

Figure 4: Green Building Materials Insignia

The Chinese database is stored on the website: Lsjccx.org.cn, which is the official service platform of the Chinese green building materials initiative. The platform intends to provide one-step services for green building materials certification and to promote green building materials on the market through utilizing CAD, BIM, blockchain, cloud computing, big-data, and other technologies that can provide businesses with quality assurance, credibility, and targeted advertisement services. The platform claims that through green building certification, products have an advantage in the market and can be utilized in projects for government benefits. The database currently has blockchain under development.

Challenges

One challenge of the material database is connecting it to larger certification systems. For instance, connecting the certified building materials to a building certification system. Another challenge is providing as much transparency as possible in the process, ensuring certified materials meet their required criteria.

Opportunities for Improvement

Material databases can further be developed with technology such as blockchain. Blockchain is frequently utilized in supply chain management and explored for sustainability purposes. It can be used to track the building materials in the supply chain to verify they meet the requirements for certification. Blockchain also can be used to increase transparency and efficiency in the building material supply chains and certification processes. PNNL had discussions with CQC on blockchain application in their building material database. The database currently has blockchain applications under development.

Blockchain is a distributed, decentralized, public ledger that records transactions and data in a transparent, efficient way. Anyone can add digital information (the “block”) to the most recent part of the database (the “chain”) but cannot change any of the chain’s existing properties. This makes it incredibly secure because every participant acts independently from each other. This also makes the process highly transparent, which is useful for when there’s distrust between two parties. Blockchain also removes the need for a single controlling entity to administer the database, which can streamline transactions and reduce transaction costs.

Blockchain technology is often proposed to revolutionize the way many industries work. However, just like any technology, it is only beneficial when applied correctly. The current Chinese database is a centralized database, which uses a centralized server to maintain the database and allows others to access it. Users can access the data and modify it, but the master copy is always on the master server. This more traditional database is easy to increase in size by just adding more resources for computational power. Open blockchains are where anyone can read and write the respective blockchain. Permissioned blockchains are where only authorized entities can read or write the respective blockchain. Permissioned blockchains, however, can be very similar to centralized databases, which raises the debate of whether a blockchain should be use at all [17], [18]. Figure 5 shows the blockchain decision process.

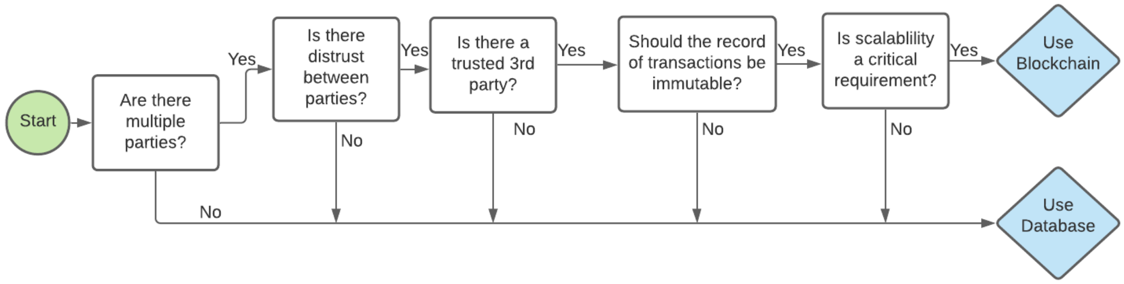


Figure 5: Decision tree to determine blockchain decisions [18]

Using blockchain technologies requires upfront dedication and costs by all parties involved. In the Chinese database, blockchain is currently under development, and MOHURD is presenting on how they will use blockchain in their certification systems, tracking materials through the supply chain, and connecting to certifications. This work is in the pilot stages and aims to be done one material at a time, starting with concrete. The challenges include coordinating with all manufacturers and government policies and agencies. While a huge undertaking, the government needs a transparent system to track and promote materials more efficiently.

3.2 Procurement Pilot Program

Chinese Procurement Policy

The Chinese government is also developing procurement programs for certified green building materials. Procurement policies utilize the government's large-scale purchasing power to help the environment and boost the market demand for greener products. These policies require more expensive building materials, naturally requiring more funds allocated from the government. Public procurement uses regulations to purchase products that meet specific requirements, using justifications like environmental social cost of carbon or life cycle costs.

The Chinese government launched their new green procurement policy pilot program in October 2020 in the cities of Nanjing, Hangzhou, Zhaoxing, Huzhou, Qingdao, and Fushan [16]. This is the first reform of government procurement actions, promoting green building materials and green buildings and the relationship between the two. The policy applies to the following types of new buildings: hospitals, schools, office buildings, complexes, exhibition halls, convention centers, stadiums, insurance buildings, and new construction projects, such as barrier housing. This is a large, comprehensive reform, starting with green building materials but aiming to include all forms of sustainable development (such as energy conservation). The Department of Finance is leading these changes, while the Department of Construction offers more of a supporting role, providing technical assistance at the local level.

CQC was directed to provide general guidance and a framework for all the pilot cities, but the implementation plans occur at the local level, allowing them to adapt to local standards and markets. In the future, the national government wants these cities to have influence on the areas surrounding them with their standards and policies. These cities will implement regulations and observe the results of the various strategies over the two-year pilot program. The next steps would be to follow the results of the pilot and expand the procurement program to other cities and regions. PNNL has been collaborating with CQC to analyze the progress and results of the pilot programs.

Challenges

The most common challenge across jurisdictions is developing mechanisms to finance the procurement policy. Green building materials have a higher upfront cost, requiring more money to be allocated to the building construction, and that money needs to get taken from somewhere.

Proposed Solutions

Most jurisdictions justify the higher cost of green building materials by understanding that the upfront investment will save money over the product's lifecycle, as well as reducing environmental harms to humans and their surroundings. Life cycle analyses can determine if it will save money over the product's lifetime. Understanding that energy-efficient products or green materials have higher upfront costs but tend to save energy and money over time, along with reducing environmental harms, can help encourage more expensive procurement programs.

However, the upfront costs still need to come from somewhere, and restructuring the budget to acknowledge future energy savings is often necessary. Coordinating among multiple agencies can help distribute the upfront costs, realizing that the benefits of having green buildings can be seen across agencies. In addition, some of the higher costs may be offset by cost savings elsewhere or in the future [19].

In Fushan, the local government is addressing the higher upfront cost by providing green material manufacturing companies money to lower their cost of building materials below the market prices for those buildings whose construction has already been approved. These future buildings are already under contract with fixed prices, and green building materials generally are more expensive. Therefore, the green building material manufacturers are receiving extra money to allow them to sell them below the market value. This is only an issue right now since they are in a gap between policies and other large reform changes are taking place; it is not considered a long-term solution.

In general, governments recognize that as the largest purchasing body of building material products, they can institutionalize change and shift the entire market to become more efficient, reducing costs. As the demand for green products increase, green products become more affordable.

United States

In the United States, the government recognizes that purchasing energy-efficient products can save energy and money while reducing environmental impacts. They can assume that products that are ENERGY STAR or meet the Federal Energy Management Program designated requirements will be cost-effective from a life cycle perspective due to a trusted and tested certification system. National requirements should be designed to be cost-effective and so that significant savings can be realized without compromising functional performance of the product. This approach applies to state and local levels of government, as well, like how the city of Portland, Oregon, sees the life cycle of products as “reduces risks, practices fiscal responsibility, reduces adverse social and environmental impacts, and contributes to sustainable development in general” [25].

Other U.S. federal requirements of procurement include that the specifications can be achieved by more than one manufacturer, and the energy specification can be measured and verified through testing [26]. This allows for competition to drive efficiency and lower the prices.

4.0 Quantification of Impact

Implementing green building materials programs can create significant economic and environmental benefits. To understand the potential impact of green building materials, we quantified the environmental and market impact of a nationwide green building procurement policy for all new residential and commercial construction. We also looked at the environmental and market impact from incorporating certified building materials for new construction into the national building codes. Green building material certification underpins the success of procurement programs or national building codes. We focused on the operational energy, emissions, and cost savings, along with the added value of insulation to the market.

4.1 China Energy Overview

Buildings in China are rapidly developing with an annual energy consumption growth rate of about 3% from 2015 to 2017, making practices and policies for new buildings critical to reducing energy consumption and emissions. About 20% of China's energy consumption goes to buildings, while the other 80% is industry and transportation sectors [19]. According to the International Energy Agency's (IEA's) Energy Data from 2018, residential and commercial building energy consumption was about 335,000 ktoe (3,896 TWh) and 88,000 ktoe (1,020 TWh), respectively [1]. Understanding the current building energy consumption helps illustrate how it can be reduced over time.

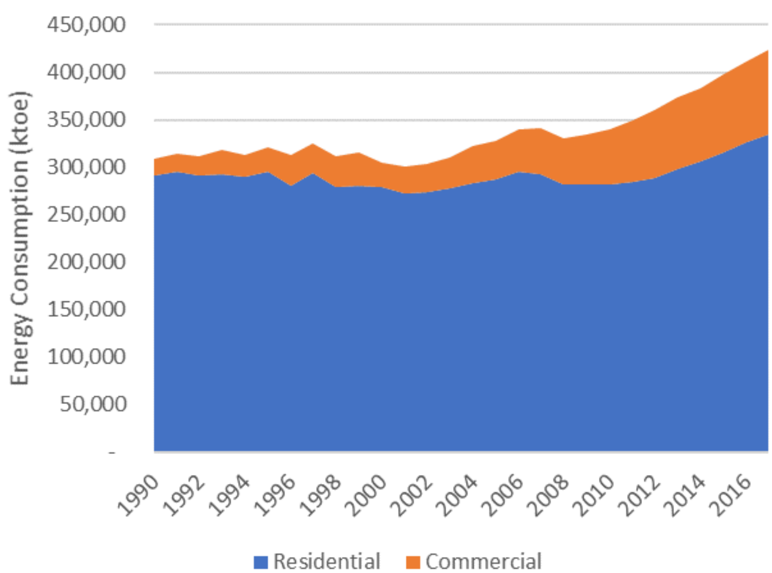


Figure 6: Residential and commercial energy combined in China over time [1]

China's building fuel comes from primarily electricity, coal, natural gas, and liquified petroleum gas (LPG). The energy breakdown of the most prevalent fuels is shown in Figures 7 and 8, taken from IEA energy data [1]. Solid biofuels (firewood) have been a primary form of energy for residential buildings for years, though are incredibly inefficient compared to other fuel sources. Firewood is being replaced by more efficient forms of energy as rural areas are being developed. The primary form of energy for commercial buildings is electricity.

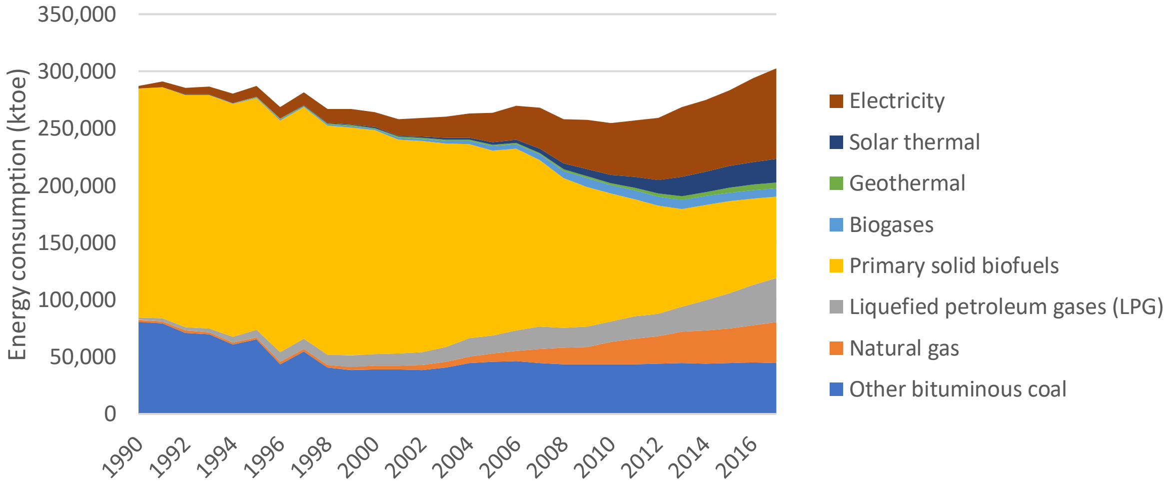


Figure 7: China residential energy consumption by fuel [1]

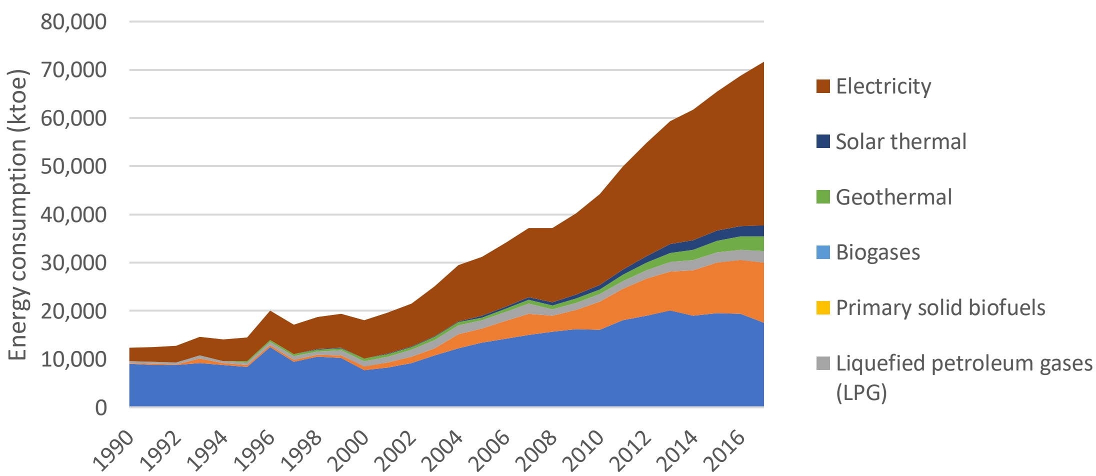


Figure 8: China commercial energy consumption by fuel [1]

4.2 Environmental Impact

Certified building materials would reduce a building's operational and embodied energy. Operational energy, cost, and emissions includes everything in operating the building, such as the energy from HVAC, lighting, and operating appliances and equipment. These are affected over the building's lifespan. Embodied emissions are those emissions that occur in acquiring raw materials; processing, manufacturing, and transporting the materials; and the building's construction and demolition.

While certified materials would reduce embodied energy and emissions, studies have shown that calculating embodied emissions is complex, with no generally accepted method available to calculate reliably and accurately [21]. Therefore, this assessment specifically focuses on operational emissions (scope 1 emissions, which occurs directly from sources owned or controlled by an organization) rather than embodied emissions. This results in a conservative estimate of the impact of certified materials on building energy, costs, and emissions. Due to a wide range of energy savings in the literature due to various regions and building types, we applied a range of energy savings from 5% to 30%. Detailed methodology and calculations can be found in the appendix.

Procurement Policy

Building material certification is an essential component of building procurement policies. Incorporating the certified green building procurement policy to the entire country of China would result in operational energy savings (Tables 1 and 2). A 5% reduction in energy from certified materials would result in 263 GWh annual savings, and a 30% reduction in energy from certified materials would be 11,900 GWh. This corresponds to the annual operational cost savings ranging from $12,400,000 to $74,500,000. In addition, the new buildings annually would save between 126 and 757 kilotons of CO_2 equivalent (CO_2e) per year. According to the EPA greenhouse gas equivalent calculator, this is equivalent to the emissions produced by between 27,000 to 164,000 passenger vehicles driven in one year or 0.032 to 0.194 coal-fired power plants in one year. It is also equivalent to the avoided emissions of 27 to 163 wind turbines running for a year. Certified building materials and certification systems allow these savings from a procurement policy to occur.

Table 1: Minimum annual building operation savings

Minimum Annual Building Operation Savings			
	Energy (GWh)	*Emissions (kt CO2e)*	*Cost ($)*
Electricity	77	48	$6,862,670
District Heating	104	65	$2,007,406
Natural Gas	54	8	$1,201,074
LPG	29	6	$2,349,228
Total	**263**	**126**	**$12,420,378**

Table 2: Maximum annual building operation savings

Maximum Annual Building Operation Savings			
	Energy (GWh)	*Emissions (kt CO2e)*	*Cost ($)*
Electricity	464	289	$41,176,022
District Heating	621	387	$12,044,434
Natural Gas	322	47	$7,206,445
LPG	172	33	$14,095,368
Total	**1,578**	**757**	**$74,522,269**

The residential and commercial energy growth rate for new buildings is assumed to be 2% until 2030, when the population is estimated to level off, and China's Nationally Determined Contributions as part of the Paris Agreement are expected to be met. Therefore, savings over time will increase annually until the energy growth rate stabilizes. Buildings in China have a lifespan of approximately 30 years. From 2018 to 2050, investing in green buildings would result in emissions savings between 5,050 and 29,900 kt CO_2e and cost savings of $497,000,000 to $3,020,000,000. Figure 9 below shows cost and emissions savings over the next 10 years (through 2030) and the buildings lifespans (through 2050).

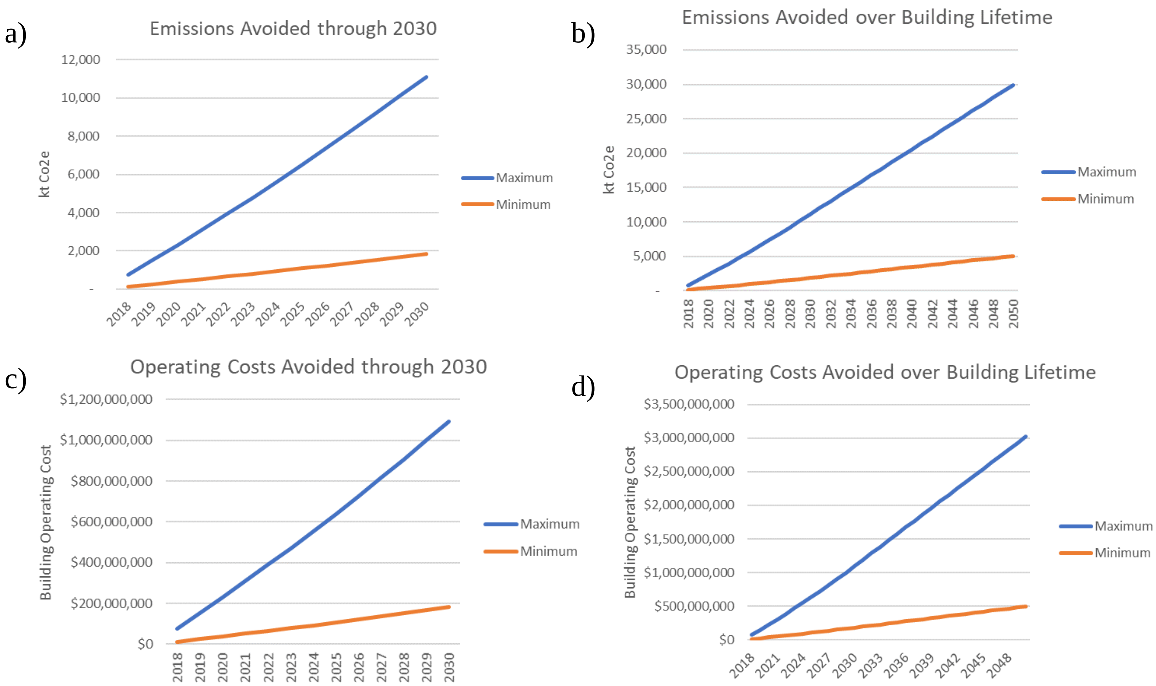


Figure 9: For a nationwide procurement policy: a) Emissions avoided through 2030; b) emissions avoided over a buildings lifetime; c) operating costs avoided through 2030; d) operating costs avoided over building lifetime.

Nationwide Building Code Policy

We also analyzed what would happen if green building materials were required in the building codes for all new construction across China. This would require a nationwide policy change.

Incorporating certified green building standards or requirements into all new buildings in the entire country would result in significant annual savings (Tables 3 and 4). A reduction of 5% of energy from certified materials save 4,134 GWh and a 30% reduction in energy saves 24,800 GWh. This corresponds to an operational cost savings ranging from $202,000,000 to $1,210,000,000, and the new buildings would save between 1,980 and 11,900 kilotons of CO_2e per year. According to the EPA greenhouse gas equivalent calculator, this is equivalent to the emissions produced by between 429,000 to 2,570,000 passenger vehicles driven in one year or 0.51 to 3.1 coal-fired power plants in one year. It is also equivalent to the avoided emissions of 428 to 2,570 wind turbines running for a year.

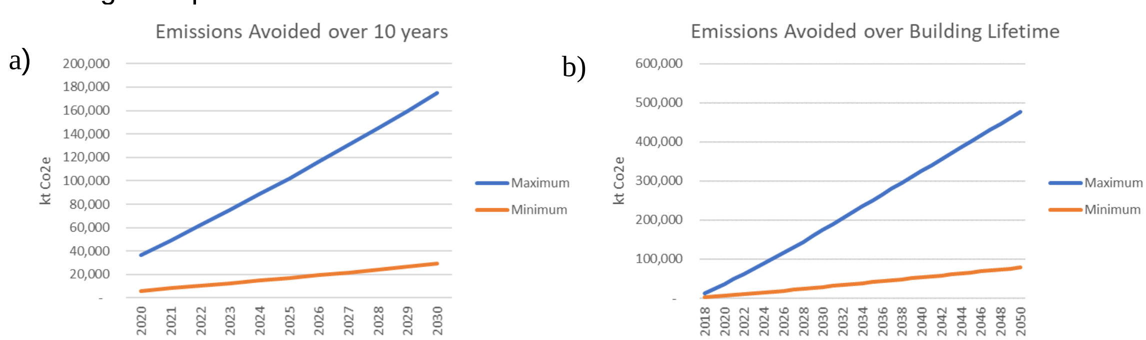
Table 3: Minimum annual building operation savings

Minimum Annual Building Operation Savings			
	Energy (GWh)	*Emissions (kt CO2e)*	*Cost ($)*
Electricity	1,215	758	$107,875,578
District Heating	1,627	1,015	$38,140,708
Natural Gas	842	124	$18,879,907
LPG	450	88	$36,927,946
Total	**4,134**	**1,984**	**$201,824,139**

Table 4: Maximum annual building operations savings

Maximum Annual Building Operation Savings			
	Energy (GWh)	*Emissions (kt CO2e)*	*Cost ($)*
Electricity	7,289	4,545	$647,253,468
District Heating	9,765	6,089	$228,844,245
Natural Gas	5,054	745	$113,279,441
LPG	2,698	525	$221,567,677
Total	**24,806**	**11,905**	**$1,210,944,831**

The residential and commercial energy growth rate for new buildings is assumed to be 2% until 2030, when the population is estimated to level off, and China's Nationally Determined Contributions as part of the Paris Agreement are expected to be met. Therefore, savings over time will increase annually until the energy growth rate stabilizes. Buildings in China have a lifespan of approximately 30 years. From 2018 to 2050, investing in green buildings would result in emissions savings between 78,400 and 476,700 kt CO_2e and cost savings of $7,880,000,000 to $48,500,000,000. Figure 8 below shows cost and emission savings over 10 years and the buildings lifespans.



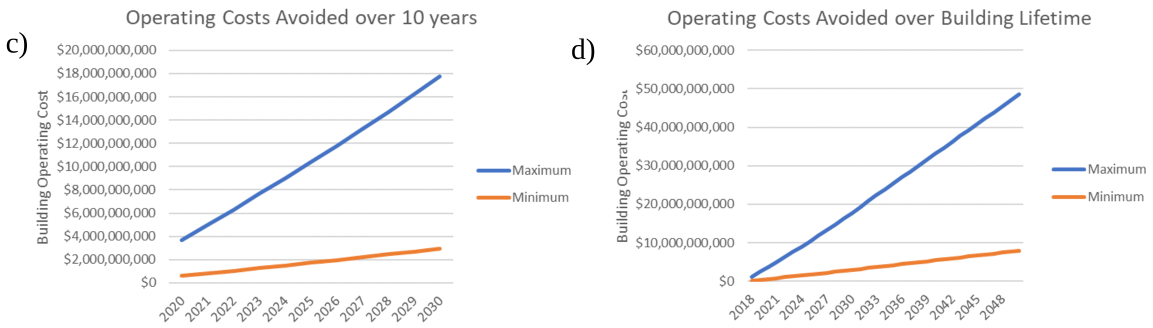


Figure 10: For a nationwide building code policy: a) Emissions avoided through 2030; b) emissions avoided over a buildings lifetime; c) operating costs avoided through 2030; d) operating costs avoided over building lifetime.

4.3 Market Impact

Policy that encourages or mandates certified materials increases their demand, therefore, impacting the building materials market. Certification programs can help the market grow faster by increasing confidence in the market.

Chinese and Global Markets

Green building materials are an expanding market, even during the global pandemic. The global green building materials market is predicted to grow at a rate of 8.6%, from $238 billion in 2020 to $425.4 billion in 2027 [22]. This is primarily due to increased government initiatives for environmentally friendly and energy-efficient construction standards. Developers and consumers are, therefore, placing higher demands for economic, greener structures, causing the industry to grow. Increased building regulations and energy-efficiency standards are driving the market for environmentally friendly and energy-efficient materials. It is worth noting that the compound annual growth rate (CAGR) did decrease from 11% to 8.6% due to the pandemic and is expected to rebound [22].

Chinese policy encouraging green building materials would greatly increase their demand, influencing the global markets and investments. With signing the Paris climate agreement and rapidly growing infrastructure, China’s green building market is estimated to reach $84.8 billion by the year 2027, with an estimated CAGR of 11%. This trend is forecasted to continue due to China’s building codes and policies, such as encouraging green building materials in new construction [22].

The increase of demand from a nationwide green procurement policy or more stringent building energy codes would increase revenue streams and market shares for green-certified materials globally. This analysis quantifies the additional market value of certified insulation. Insulation is expected to have the most significant global market of green building materials, forecasted to reach $137.17 billion by 2027 due to its ability to reduce energy. Interior materials, including lighting and HVAC equipment, are estimated to be the second-largest market due their benefits of reducing energy, improving air quality, and creating healthier and more comfortable spaces

[24]. Future work could continue this analysis for other building materials, like LED lighting and low-e windows.

North American Market

North America is estimated to have the most substantial green building material's market at about 37% of the total global market share. The U.S. building market is estimated at $64.6 billion in 2020 and growing at a CAGR of 7.5% [27]. Developing countries, such as China, with a rapidly growing construction sector, provide a great opportunity for the U.S. and global market to continue growing.

The U.S. investment in energy efficiency has leveled off in recent years, spending around $240 billion a year on energy efficiency in building, transportation, and industry. Growth stalled in the U.S. energy efficiency sector, as spending for energy efficiency decreased for the first time in four years in 2018. However, growth in China offset the decline in U.S. spending in the global market. China represented 37% of the total investment in industrial energy efficiency in 2018, up from 25% in 2015 [1]. North America, on the other hand, dropped from 17% in 2015 to 10% in 2018 [1]. The modernization of the Chinese industrial sector and focus on energy efficiency was driven by nationwide mandates.

Market Impact

To determine the market impact of the policies, the applicable buildings floor space is multiplied by the additional cost of insulation to calculate the additional market value of using new building materials. As of 2016, the total building area of China is around 60.6 billion m^2 [28]. The additional cost of insulation investment is conservatively $17/m^2$ [2].

For a national procurement policy, assuming that it applies to 10% of all new commercial buildings and 5% of new residential buildings, the additional floor area added each year for residential and commercial buildings is 155 million m^2. This results in $2.63 billion per year of additional investment in insulation. For a national building codes and standards change, assuming that it applies to 95% of all new buildings, the additional floor area added each year is 1.64 billion m^2. This results in $27.9 billion per year of investment in insulation. The detailed calculations are found in the appendix. This increased demand for insulation from procurement policies and changes in building codes would greatly impact the global market.

5.0 Outcomes and Lessons Learned

Certified building materials are critical for reducing energy in buildings. Having a strong national certification program in place is foundational for expanding green building materials and developing policies. Elements of a robust certification system include

- A national, unified system
- Coordinated efforts across agencies and systems
- Alignment between standards and sectors to improve transparency and consistency
- Promotion of strategies and incentives.

Over the past four years, many improvements have been incorporated into the Chinese certification system, which made it more transparent and unified. These potential improvements included developing a unified certification system, increased collaboration across government agencies, increased transparency in testing, and developing a central material database over regional ones. Further developments in process include advancing the material database and implementing procurement policies.

The certification of materials is essential to a result in energy savings from policies. We analyzed the environmental and market impact of using certified building materials in a nationwide procurement policy and nationwide building standards. Certification of building materials allows policies and energy codes to be effective. The nationwide procurement program, if well-implemented, can save between 263 to 11,800 GWh energy and 126 and 757 kilotons of CO_2e per year in emissions, and create $8.87 billion of insulation investment opportunities. In addition, if certified building materials became part of the national building standards, it could save 4,130 to 24,800 GWh energy and 1,980 and 11,900 kilotons of CO_2e per year in emissions and create $27.9 billion dollars of insulation investment opportunities. Table 5 summarizes these changes. This showcases the importance of connecting certified materials with policy for widespread energy, cost, and emissions savings. In addition, policy influences the market demand for green building materials, driving down the costs.

Table 5: Overview of results of impact analysis of nationwide procurement policy and building standards

	Nationwide Procurement Policy	**Nationwide Building Standards**
Annual Energy Savings	263 to 11,800 GWh	4,130 to 24,800 GWh
Annual Cost Savings	$12.4 to $74.5 million	$202 to $1,211 million
Annual Emission Savings	126 and 757 kt CO2e	1,980 and 11,900 kt CO2e
Annual Insulation Investment	$2.63 billion	$27.9 billion

6.0 Future Work

Government procurement is one of the first major steps to expanding certified building materials to a larger scale. Datapoints of project costs and program effectiveness will need to be trended and analyzed from the pilot procurement program. This will help determine the next steps of expanding the procurement policy across the nation. Further analysis needs to be done on how different departments coordinate across the system and how much the procurement program costs. Higher upfront costs of certified building materials still need to be addressed, and the potential for these costs can be split among relevant agencies and justified by receiving more savings over a building's lifetime.

7.0 References

[1] IEA. 2018. "World Energy Balances," purchased data product. International Energy Agency. Accessed November 12, 2020 at https://www.iea.org/data-and-statistics/data-product/world-energy-balances.

[2] Yu S., M. Evans, and Q. Shi. 2014. "Analysis of the Chinese Market for Building Energy Efficiency." PNNL-22761, Pacific Northwest National Laboratory, Richland, Washington.

[3] Zhou Y., M. Evans, S. Yu, J. Ruan, and H. Xu. 2018. *A Roadmap for Green Building Products in China Towards a National Standard, Testing, Certification, and Labeling System*. PNNL-27954, Pacific Northwest National Laboratory, Richland, Washington.

[4] Staniszewski A., S. Yu, M. Evans, T. Liu, Q. Tan, Z. Shao, X. Shen, T. Li, D. Gao, and B. Song. 2017. *Evaluating the Certification System of Green Building Materials in China*. PNNL-26461, Pacific Northwest National Laboratory, Richland, Washington.

[5] Olubunmi O.A., P.B. Xia, and M. Skitmore. 2016. "Green Building Incentives: A Review." *Renew. Sustain. Energy Rev.* 59:1611–1621. doi: 10.1016/j.rser.2016.01.028.

[6] Ghodrati N., M. Samari, M. Wira, and M.W.M. Shafiei. 2012. "Investigation on Government Financial Incentives to Simulate Green Homes Purchase." *World Appl. Sci. J.* 6(20):832–841. doi: 10.5829/idosi.wasj.2012.20.06.2017.

[7] MOHURD and MIIT. 2014. *Administrative Measures for the Evaluation of Green Building Materials (*绿色建材评价标识管理办法). Ministry of Housing and Urban-Rural Development and Ministry of Industry and Information Technology, China. Accessed Feb. 7, 2021 at https://www.waizi.org.cn/doc/26542.html.

[8] MOHURD and MIIT. 2015. *Action Plan to Encourage the Production and Application of Green Building Materials* (促进绿色建材生产和应用行动方案). Ministry of Housing and Urban-Rural Development and Ministry of Industry and Information Technology, China. Accesed Feb. 7, 2021 at http://www.gxjnjp.org/html/2015/zhengcefagui_1009/308.html.

[9] MOHURD and MIIT. 2015. *Implementation Plan for the Administrative Measures for the Green Building Materials Evaluation Label* (绿色建材评价标识管理办法实施细则). Ministry of Housing and Urban-Rural Development and Ministry of Industry and Information Technology, China. Accessed Feb. 15, 2021 at http://www.mohurd.gov.cn/wjfb/201510/W020151022052120.doc.

[10] MOHURD. 2016. "Two Departments Issued the First Batch of Green Building Materials Evaluation Labels." Ministry of Housing and Urban-Rural Development, China. Accessed Feb. 15, 2021 at http://www.gov.cn/xinwen/2016-05/30/content_5078046.htm.

[11] General Administration of Quality Supervision, Inspection and Quarantine, Ministry of Housing and Urban-Rural Development, Ministry of Industry and Information Technology, National Certification and Accreditation Administration, and National Standards Committee. 2017. *Guiding Opinions on Promoting the Standards, Certification and Labeling of Green Building Materials Products (*关于推动绿色建材产品标准、认证、标识工作的指导意见). National Quality Inspection and Certification Program, China. Accessed Feb. 17, 2021 at https://www.lsjccx.org.cn/h-nd-7.html#groupId=-1.

[12] National Quality Inspection and Certification Union. 2019. *Notice of the Three Departments on the Issuance of the Implementation Plan for Certification of Green Building Materials Products*. China: General Office of the State Administration for Market Regulation, General Office of the Ministry of Housing and Urban-Rural Development, General Office of the Ministry of Industry and Information Technology.

[13] China Engineering Construction Standardization Association. 2019. "Green Building Materials Evaluation-Prefabricated Components (绿色建材评价-预制构件)," China. Accessed Feb. 15, 2021 at http://tzsbwj.oss-cn-zhangjiakou.aliyuncs.com/XwHtml/3D9BC21C50C84A65BBC749C2D6695C4F.html.

[14] MOHURD. 2019. *Announcement of the Initiation of the Green Building Material Database Data Entry Work*. Science and Technology and Industrialization Development Center of Ministry of Housing and Urban-Rural Development, China. Accessed Feb. 7, 2021 https://www.lsjcpjbs.org/website/xxfb/ywjs/ywjsEntry.html?sf.id=402881036c1837b501707b7670eb4888

[15] MOHURD and MIIT, State Administration for Market Regulation, Department of Raw Materials Industry. 2020. *Notice of the Three Departments on Accelerating the Promotion of Green Building Materials Product Certification and Production Application*. Municipal Supervison Certification, China. Accessed Feb. 15, 2021 at https://www.miit.gov.cn/xwdt/gxdt/sjdt/art/2020/art_423251ef58f4419cb4cd753318717e88.html.

[16] MOHURD and Ministry of Finance. 2020. *Notice on the Government Procurement Program's Pilot Support of Green Building Materials to Accelerate Building Quality (关于政府采购支持绿色建材促进建筑品质提升试点工作的通知)*. Ministry of Housing and Urban-Rural Development and Ministry of Finance, China. Accesed Feb. 7, 2021 at http://www.gov.cn/zhengce/zhengceku/2020-10/22/content_5553250.htm.

[17] Chowdhury M.J.M., A. Colman, M.A. Kabir, J. Han, and P. Sarda. 2018. "Blockchain Versus Database: A Critical Analysis," *Proc. of 17th IEEE Int. Conf. Trust. Secur. Priv. Comput. Commun. 12th IEEE Int. Conf. Big Data Sci. Eng. Trust*, 1348–1353. doi: 10.1109/TrustCom/BigDataSE.2018.00186.

[18] Wust K. and A. Gervais. 2018. "Do You Need a Blockchain?" *Proc. of 2018 Crypto Val. Conf. Blockchain Technol. CVCBT 2018*, 45–54. doi: 10.1109/CVCBT.2018.00011.

[19] FEMP. 2011. "Energy-Efficient Product Procurement for Federal Agencies." Federal Energy Management Program. DOE/GO-102012-364.

[20] Huo T., H. Ren, X. Zhang, W. Cai, W. Feng, N. Zhou, and X. Wang. 2018. "China's Energy Consumption in the Building Sector: A Statistical Yearbook-Energy Balance Sheet Based Splitting Method." *J. Clean. Prod.* 185:665–679. doi: 10.1016/j.jclepro.2018.02.283.

[21] Ibn-Mohammed T., R. Greenough, S. Taylor, L. Ozawa-Meida, and A. Acquaye. 2013. "Operational vs. Embodied Emissions in Buildings—A Review of Current Trends." *Energy Build.* 66:232–245. doi: 10.1016/j.enbuild.2013.07.026.

[22] Global Industry Analysts, Inc. 2020. *Green Building Materials – Global Market Trajectory*

& Analytics. San Jose, CA.

[23] IEA. 2019. *World Energy Investment 2019*, p. 176. International Energy Agency. Available at https://www.iea.org/data-and-statistics/data-products.

[24] Cision. July 1, 2020. "Green Building Materials Market to Reach USD 573.91 Billion by 2027 | Reports and Data." Accessed Jan. 27, 2021 at https://www.prnewswire.com/news-releases/green-building-materials-market-to-reach-usd-573-91-billion-by-2027--reports-and-data-301086930.html.

[25] City of Portland. 2018. "City of Portland Sustainable Procurement Policy: 2018 Update." Portland, OR. Accessed Jan. 15, 2021 at https://www.portlandoregon.gov/shared/cfm/image.cfm?id=204110.

[26] Bunch S. and C.T. Payne. 2019. *Contracting for Efficiency: A Best Practices Guide for Energy-Efficient Product Procurement*. DOE/EE-1391 7402, Lawrence Berkeley National Laboratory, Berkeley, California.

[27] Holbrook E. 2020. "Even with Covid-19, Green Buildings Materials Market Expected to Grow by $187 Billion," *Environment + Energy Leader*. Accessed Jan. 27, 2021 at https://www.environmentalleader.com/2020/06/even-with-covid-19-green-buildings-materials-market-expected-to-grow-by-187-billion.

[28] IEC. 2018. China: Energy Efficiency Report, 2018. http://www05.abb.com/global/scot/scot316.nsf/veritydisplay/0a9c91a9a97f3bbdc12579d0004ef177/$file/China Energy efficiency Report.pdf.

Appendix A

Assumptions and Methodology

The new Chinese government procurement policy applies to the following types of buildings: hospitals, schools, office buildings, complexes, exhibition halls, convention centers, stadiums, insurance buildings, and new construction projects such as barrier housing. We assumed a nationwide government procurement policy would apply to 5% of residential and 10% of commercial buildings nationwide, based on the knowledge that government buildings contribute to a smaller percentage of the building stock. We assumed that a nationwide building code policy would apply to 95% of all new residential and commercial buildings, since no building code is ever perfectly implemented. We assumed both the procurement policy and nationwide building codes are implemented with a success rate of 95% since no policy is ever perfectly implemented.

Environmental and market impact was quantified using IEA energy fuel breakdown by residential and commercial buildings. The fraction of energy for residential and commercial buildings were calculated using IEA energy data. Savings were calculated at the site level (rather than source) by breaking down building operational energy consumption by fuel source. New construction would not use firewood or coal as fuel sources for heating, so districting heating is assumed to replace burning firewood and coal in new construction.

Many studies exist on the efficiency of green buildings versus conventional buildings but range in amount of savings due to different locations, standards of green materials, and standards of conventional materials. The literature showed potential savings ranging from around 5% to around 30%, so we decided to use a wide maximum and minimum range to account for the uncertainty. Therefore, to be conservative, we assume a minimum savings of 5% and a maximum savings of 30% of operational energy for residential and commercial buildings.

Emission factors were calculated using EPA and U.S. Energy Information Association data. To be conservative, district heating emission factors were assumed to be the same as those from the electric power sector. They may be higher due to greater inefficiencies in boilers than in large power plants.

Energy prices used are averages across the country. District heating cost savings are approximated using the district heating floor area. China's district heating system is 8,780,500,000 m^2 (CNKI, National Urban Centralized Heating in the Past Few Years). The average cost of district heating is $3/$m^2$ in China. We assume the energy savings is proportional to the district heating area.

As of 2016, the total building area of China is around 60.6 billion m^2 [28]. The additional cost of insulation investment is $17/$m^2$ [2]. The annual increase in investment in insulation is calculated using the same assumptions for the energy savings, such as a national procurement policy would impact 10% of new commercial buildings and 5% of new residential buildings, and a building code change would impact 95% of all new buildings. The increase in investment is calculated by multiplying the additional floor space by the additional cost of insulation.

Procurement Policy Calculations

Below shows the preliminary calculations for the energy savings for the procurement policy. It should be noted that the national building code follows the same process, except applied to 95% of all new building construction.

Operational Energy Savings (Site Level)		
IEA Residential Energy	334,979	ktoe
IEA Commerical Energy	88,356	ktoe
Fraction Residential Energy	79%	
Fraction Commerical Energy	21%	
New BEC for Applicable Buildings	486	ktoe
% Energy Reduction for Residential	5%	*
% Energy Reduction for Commerical	5%	*
Residential Energy Savings	19	ktoe
Commercial Energy Savings	5	ktoe
Total Energy Savings	**24**	**ktoe**
% Energy Reduction	**5%**	

% Building Site Energy by Fuel		
Residential	IEA Data	For New Buildings*
Electricity	24%	24%
District Heating	8%	36%
Firewood	21%	0%
Geothermal	2%	2%
LPG	12%	12%
Gas	11%	20%
Coal	13%	0%
Solar Thermal	6%	6%
Total:	**96%**	**100%**
Commercial	IEA Data	For New Buildings*
Electricity	38%	40%
District Heating	3%	39%
Firewood	0%	
Geothermal	3%	3%
LPG	3%	3%
Gas	14%	15%
Coal	20%	0%
Gas/Diesel	13%	
Solar Thermal	3%	3%
Total:	**94%**	**100%**

Emission Factors by Fuel		
Electricity	0.6236	kgCO2e/kWh
District Heating	0.6236	kgCO2e/kWh
Firewood	95	kgCo2e/mmBtu
Natural Gas	0.1475	kg CO2e/kWh
Coal	94	kg CO2e/mmBtu
LPG	62	kg CO2e/mmBtu

Cost by Fuel		
	Residential	*Commercial*
Electricity Cost ($/kWh)	$0.0830	$0.1020
District Heating ($/m2)*	$3.00	$4.00
Natural Gas ($/mmBtu)	$6.36	$7.63
Firewood		
Coal ($/ton)	$85	$85
LPG ($/gal)	$2.30	$2.30

Minimum Savings:

Energy Savings by Fuel		
	Residential (kWh)	*Commercial (kWh)*
Electricity	5.37E+07	2.36E+07
District Heating	8.05E+07	2.30E+07
Firewood	0.00E+00	0.00E+00
Natural Gas	4.47E+07	8.85E+06
Coal	0.00E+00	0.00E+00
LPG	2.68E+07	1.77E+06
Total Energy Savings (kWh)	**223,673,487**	**58,997,414**

Cost Savings by Fuel		
	Residential	*Commercial*
Electricity	$4,455,576	$2,407,094
District Heating	$1,485,111	$522,295
Firewood	$0	$0
Natural Gas	$970,652	$230,422
Coal	$0	$0
LPG	$2,203,900	$145,328
Total Operational Cost Savings	**$9,115,238**	**$3,305,140**

Emission Savings by Fuel		
	Residential (kg CO2e)	*ommercial (kg CO2e*
Electricity	3.35E+07	1.47E+07
District Heating	5.02E+07	1.43E+07
Firewood	0.00E+00	0.00E+00
Natural Gas	6.60E+06	1.30E+06
Coal	0.00E+00	0.00E+00
LPG	5.22E+06	3.44E+05
Total Emission Savings (kg CO2e)	**9.55E+07**	**3.07E+07**

Maximum Savings:

Energy Savings by Fuel		
	Residential (kWh)	*Commercial (kWh)*
Electricity	3.22E+08	1.42E+08
District Heating	4.83E+08	1.38E+08
Firewood	0.00E+00	0.00E+00
Natural Gas	2.68E+08	5.31E+07
Coal	0.00E+00	0.00E+00
LPG	1.61E+08	1.06E+07
Total Energy Savings (kWh)	**1,342,040,922**	**353,984,482**

Cost Savings by Fuel		
	Residential	*Commercial*
Electricity	$26,733,455	$14,442,567
District Heating	$8,910,663	$3,133,771
Firewood	$0	$0
Natural Gas	$5,823,912	$1,382,534
Coal	$0	$0
LPG	$13,223,398	$871,970
Total Operational Cost Savings	**$54,691,428**	**$19,830,841**

Emission Savings by Fuel		
	Residential (kg CO2e)	*Commercial (kg CO2e)*
Electricity	2.01E+08	8.83E+07
District Heating	3.01E+08	8.61E+07
Firewood	0.00E+00	0.00E+00
Natural Gas	3.96E+07	7.83E+06
Coal	0.00E+00	0.00E+00
LPG	3.13E+07	2.07E+06
Total Emission Savings (kg CO2e)	**5.73E+08**	**1.84E+08**

Nationwide Policy Calculations

Operational Energy Savings (Site Level)		
IEA Residential Energy	334,979	ktoe
IEA Commerical Energy	88,356	ktoe
Fraction Residential Energy	79%	
Fraction Commerical Energy	21%	
New BEC for Applicable Buildings	7,641	ktoe
% Energy Reduction for Residential	5%	*
% Energy Reduction for Commerical	5%	*
Residential Energy Savings	302	ktoe
Commercial Energy Savings	80	ktoe
Total Energy Savings	**382**	**ktoe**
% Energy Reduction	**5%**	

% Building Site Energy by Fuel		
Residential	IEA Data	For New Buildings*
Electricity	24%	24%
District Heating	8%	36%
Firewood	21%	0%
Geothermal	2%	2%
LPG	12%	12%
Gas	11%	20%
Coal	13%	0%
Solar Thermal	6%	6%
Total:	**96%**	**100%**
Commercial	IEA Data	For New Buildings*
Electricity	38%	40%
District Heating	3%	39%
Firewood	0%	
Geothermal	3%	3%
LPG	3%	3%
Gas	14%	15%
Coal	20%	0%
Gas/Diesel	13%	
Solar Thermal	3%	3%
Total:	**94%**	**100%**

Emission Factors by Fuel		
Electricity	0.6236	kgCO2e/kWh
District Heating	0.6236	kgCO2e/kWh
Firewood	95	kgCo2e/mmBtu
Natural Gas	0.1475	kg CO2e/kWh
Coal	94	kg CO2e/mmBtu
LPG	62	kg CO2e/mmBtu

Cost by Fuel		
	Residential	*Commercial*
Electricity Cost ($/kWh)	$0.0830	$0.1020
District Heating ($/m2)*	$3.00	$4.00
Natural Gas ($/mmBtu)	$6.36	$7.63
Firewood		
Coal ($/ton)	$85	$85
LPG ($/gal)	$2.30	$2.30

Energy Savings by Fuel		
	Residential (kWh)	*Commercial (kWh)*
Electricity	8.44E+08	3.71E+08
District Heating	1.27E+09	3.62E+08
Firewood	0.00E+00	0.00E+00
Natural Gas	7.03E+08	1.39E+08
Coal	0.00E+00	0.00E+00
LPG	4.22E+08	2.78E+07
Total Energy Savings (kWh)	**3,515,964,707**	**927,391,203**

Cost Savings by Fuel		
	Residential	*Commercial*
Electricity	$70,038,017	$37,837,561
District Heating	$28,217,100	$9,923,608
Firewood	$0	$0
Natural Gas	$15,257,856	$3,622,050
Coal	$0	$0
LPG	$34,643,503	$2,284,443
Total Operational Cost Savings	**$148,156,477**	**$53,667,662**

Emission Savings by Fuel		
	Residential (kg CO2e)	*Commercial (kg CO2e)*
Electricity	5.26E+08	2.31E+08
District Heating	7.89E+08	2.26E+08
Firewood	0.00E+00	0.00E+00
Natural Gas	1.04E+08	2.05E+07
Coal	0.00E+00	0.00E+00
LPG	8.21E+07	5.41E+06
Total Emission Savings (kg CO2e)	**1.50E+09**	**4.83E+08**

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