sustainability

MDPI

Article

Dynamic Feedback Analysis of Influencing Factors of Existing Building Energy-Saving Renovation Market Based on System Dynamics in China

Handing Guo, Wanzhen Qiao * and Jiren Liu

School of Economics and Management, Tianjin Chengjian University, Tianjin 300384, China; guohanding@tcu.edu.cn (H.G.); Liujr679@126.com (J.L.)

* Correspondence: qwz0603@126.com; Tel.: +86-022-2308-5191

Received: 3 December 2018; Accepted: 5 January 2019; Published: 8 January 2019

check for updates

Abstract: Existing buildings energy-saving renovation is an important means to cope with global warming and an essential component of achieving China's energy conservation and pollution emissions reduction strategy goals. The development of the energy-saving renovation market is closely related to its influencing factors, which determine the reasons and conditions for the development of the system; therefore, it is necessary to study the influencing factors of energy-saving transformations. System dynamics was applied to explore the feedback relationship between the service subsystem, the demand market subsystem, and the market regulation subsystem. Analysis was performed for the intrinsic influencing factors of the development of the existing building energy-saving renovation market and the interaction law of feedback relationship. This paper discusses the basic characteristics of government incentives, Energy Service Company (ESCO) technology innovation, ESCO's revenue, and owner's awareness to promote the development of the existing building energy-saving renovation market. Base on those, it puts forward suggestions for promoting the market development of existing buildings energy-saving reconstruction. The findings provided a theoretical basis and guiding role for the Chinese government to formulate support policies for existing building energy-saving renovation. At the same time, it also provides reference for other countries to develop existing buildings energy-saving renovation market.

Keywords: building energy-saving; market development; causal loop; dynamic feedback; influencing factor analysis

1. Introduction

The energy issue is the core issue of today's world economy, technological development, and politics. Over the past 30 years of reform and opening, China's economic development achievements have made the world pay attention to it. However, in the process of developing the economy and promoting industrialization and urbanization with great strides, huge energy consumption has accompanied, so energy conservation and emission reduction is urgent. Building energy-saving is an indispensable part of China's implementation of its sustainable development strategy; this is because there are currently more than 52 billion square meters of existing buildings in China, most of which are high-energy buildings. Less than 30% of energy-saving buildings, and a lot of energy resources are wasted [1]. Building energy efficiency work includes the construction of green energy-efficient buildings and energy-saving renovation of existing buildings. Newly built green energy-efficient buildings are subject to "access" restrictions by setting indicators, and buildings that do not meet the standards are not subject to approval. New energy-efficient buildings will be subject to "permitted access" by setting indicators, and buildings that do not meet the standards will not be approved. Therefore, we can strictly control the building of high energy consumption into the market. However, the existing building energy-saving retrofits require complex system engineering, and not only involve complex technical and social issues, but also need huge capital investment and scientific operational mechanisms. The mutual constraints and interdependence between system elements need to be coordinated and optimized from the overall linkage mechanism. Under different market development factors, the interaction between the main building energy-saving renovation subjects is complex, which makes the main factors of market structures and function changes difficult to implement, and as such the existing building energy-saving renovation market is developing slowly. Therefore, how to clarify the interaction of various factors within the existing building energy-saving retrofit market system and implement targeted optimization measures is a key issue that needs to be addressed. Since the oil crisis broke out in the 1970s, foreign developed countries have always attached importance to green initiatives and energy-saving. In the European Union, more than 30% of energy is consumed by buildings. Therefore, utilizing energy efficiency to lower energy demand in buildings is a key policy goal of the European Commission [2], and the energy-saving renovation of existing buildings has attracted early attention. The United States government has given ESCO tax deductions, deferred taxation, and other preferential policies to mobilize ESCO's enthusiasm [3]. The European Union has issued a number of directives on energy conservation and energy efficiency, such as the establishment of a building energy efficiency labeling system in 2002 [4]. The German government promulgated the "Energy Conservation Law" to regulate the subjects' behavior of the energy-saving market. The energy-saving renovation funds were supported by the National Development Bank for low-interest loans, and federal government-subsidized banks [5]. The British government adopted the cooperation mode of "state subsidy + bank advancement + personal contribution" to break the bottleneck of building energy-saving renovation funds [6]. The Swedish Gradstein community has innovated passive energy-efficient buildings and achieved significant economic benefits [7]. The Japanese government spends about $120 million a year on advertising media to instill awareness of environmental protection and energy conservation [8].

By the end of 2017, China had completed an area of 990 million square meters of existing residential buildings energy-saving renovation, and an area of 44.5 million square meters of public buildings energy-saving renovation. The national buildings energy-saving renovation rate is only 2%. Looking at foreign building energy-saving work, the existing buildings area in the United States is 15 billion square meters [3]; the percentage of the total construction works that are a renovation is 12%, as of 2016. According to the EU energy efficiency process, Germany has completed 3% of the existing public buildings energy-saving renovation every year. In the existing 39 million residential buildings, 6 million sets have completed energy-saving renovation work, and the energy-saving renovation rate is 15% [2]. Developed countries continue to lead in the field of existing building energy-saving renovation, and China's existing building energy-saving renovation is an urgent task.

The purpose of this research is to explore the feedback relationship and interaction rules of influencing factors of the existing building energy-saving reconstruction market development. In the process, we also hope to uncover the characteristics of dynamic feedback systems to gain a deeper understanding of the development of the existing building energy-saving reconstruction market. This provides the basis for promoting system behavior improvement and formulating reasonable market development strategies. The advantage of a dynamic feedback analysis of influencing factors is that it can clearly reflect the complexity and interactive dynamic characteristics of existing building energy-saving reconstruction market. It gets rid of the limitation that previous studies of only focusing on a single influencing factor. In the process of exploration, the structural relationship of the system is fully revealed, and the overall relationship between the various influencing factors in the existing building energy-saving renovation market can be systematically analyzed. This research intuitively represents the market structure of existing building energy-saving renovation, the interrelationship between market entities, and the role and function process of market influencing factors. Meanwhile, it provides a useful reference for government to formulate support policies for existing building energy-saving renovation.

The remainder of this paper is structured into five sections. Section 2 reviews the influence factors of existing building energy-saving renovation literature. Section 3 describes the system dynamics and relevant research methodologies. Section 4 presents the results and dynamic feedback system characteristics. Section 5 discusses the research. Section 6 present the conclusions of the study, and proposes suggestions for promoting market development of existing building energy-saving reconstruction.

2. Literature Review

Globally, buildings are responsible for approximately 36% of the total energy use and 40% of greenhouse gas emissions. Global awareness of climate change, excessive energy consumption, waste of resources, and environmental pollution in the construction industry are increasing; therefore, there is an increased market demand and investment space for existing buildings energy-saving reconstruction. In addition, research on existing buildings energy-saving reconstruction has received significant attention in recent years. Our research is mainly related to two research streams in the literature. First, this paper reviews the existing research on the development of existing buildings energy-saving reconstruction market factors, including existing buildings energy-saving reconstruction impetus, barriers, and guarantee. Second, this paper summarizes the research methods of the development of existing buildings energy-saving reconstruction market factors and provides strong support for the selection of appropriate methods for this study. In what follows, we will review the papers in each research stream.

On the basis of an exhaustive literature review, it was found that the existing buildings energy-saving reconstruction market factors research mainly focuses on impetus, barriers, and guarantee factors. Johnstone [9] found that technological innovation is the fundamental force for the development of energy-saving markets. Meyer [10] pointed out that enterprise competition is the core driving force for the development of the existing building energy-saving transformation market. Raji [11] found that the flow of capital determines the behavioral decisions and choices of market players. Broin [2] compared the energy-saving transformation market in 27 countries and believed that the purpose of the energy-saving transformation market development is to meet demand. Goldman [12] surveyed a database of 1500 ESCOs in the United States and found that ESCOs are concentrated in countries with high economic activity and strong policy support. Schmidt [13] explored the government's positive behaviors to attract investment into existing building energy efficiency retrofit markets and drive other elements into the market. Rausch [14] conducted a survey of 146 European countries and found that most corporate social responsibilities are lacking, resulting in insufficient internal driving forces. Restrictive factors also play an important role in the process of developing the existing buildings energy-saving reconstruction market. Hanssen [15] explored the market for existing residential buildings energy-saving renovations in Denmark, and proposed that the value orientation of the owners and the difference in consciousness constrained the market development. Baek [16] believes that the general lack of awareness of energy conservation is the direct cause of insufficient market demand. Pan [17] used EnergyPlus to build a model to prove that cost is a core factor in ESCO's investment in energy efficiency retrofit considerations. Wang [18] pointed out that financing difficulties hindered the promotion of existing building energy conservation reform policies. Nolden [19] proposed that the UK's energy services market development potential is limited by transaction costs. Guarantee factors are crucial to maintaining the current situation of market development. Vreeken [20] analyzed the main reasons for the continued stable operation of the energy-saving transformation market in developed countries such as Germany, France, and Austria, which is the effective supervision measures of the government. Zhang [21] demonstrated that laws and regulations are the fundamental means to ensure the smooth progress of energy-saving renovation.

In terms of research methods, the past decade has witnessed a number of studies examining the factors of existing buildings energy-saving reconstruction market development. A questionnaire survey by Gillingham given to owners identified energy efficiency policies as the most important drivers for building energy service market development [22]. Zhou's case study highlighted energy-saving technology for market development [23]. Hori's survey revealed a positive relation between CSR and energy-saving [24]. Pombo [25] proposed a multi-criteria methodology, which is Life Cycle Assessment, for the fund input analysis of retrofitting solutions. These studies investigated energy-saving reconstruction related factors in different ways, but little attention was paid to the relationship between different influencing factors. In practice, the existing building energy-saving reconstruction market is a complex dynamic development system under the combined effect of multiple factors, implying that even a small variation in one factor might affect other factors in the system [26]. Thus, it is necessary to make a systematic analysis of the interaction between multiple factors. However, the research processes on the relationship among existing building energy-saving reconstruction market influencing factors are extremely complex. System dynamics can be effectively applied to the establishment of the existing building energy-saving reconstruction market development model. System dynamics is a powerful tool for analysis social systems, and this concept was introduced by Forrester of MIT in 1956. For example, Zhao [27] applied it to the analysis of land use planning. Ziemele [28] used it to research district heating. Vulturius [29] used it to analyze socio-ecological systems. In this paper, system dynamics is used to identify the dynamic feedback among the different factors related to the existing buildings energy-saving renovation market, and with the aid of system dynamics theory, analyze the dynamic feedback system characteristics of the existing building energy-saving renovation market. This research could also provide scientific advice for the development of government policies.

3. Methods

This paper uses system dynamics theory and establishes a dynamic feedback relationship model to analyze the intrinsic influencing factors of the development of the existing building energy-saving renovation market and the interaction law of feedback relationship. The principle of system dynamics is insensitive to numbers and focuses on the "structure" of the system [30], treating the system as a feedback mechanism with multiple information causalities and seeks to identify both their causes and effects. In general, there are five steps of system dynamics as follows.

3.1. Determination of the Boundary

The first step in applying system dynamics analysis is to determine the system boundary. System internal variables have a fundamental impact on system operation [31], and system exogenous variables affect system endogenous variables [32]. In order to define the endogenous and exogenous variables of the existing building energy-saving retrofit market system, it is necessary to determine the system boundary. One must determine the boundary of the existing building energy-saving retrofit market system to determine which level the market belongs to; that is, to distinguish between narrow market and generalized market [33]. The market relationship is in line with the market supply and demand mechanism, market competition mechanism, and market supervision mechanism [34]. Because the external environmental factors are uncontrollable, the structure of the system cannot be determined and changed. Therefore, the focus of system analysis is the process of interaction within the system. In this paper, the generalized market definition is adopted in the determination of the system boundary; that is, all the elements that constitute the general market structure and function belong to the system endogenous variables, and the rest are exogenous variables.

3.2. Identification of the Influencing Factors

This research first involved a large amount of original collections of "what are the influencing factors" in academic literature, publications by international organizations, and authoritative reports. Through classification, extraction, and sorting, the influencing factors of existing building energy-saving reconstruction market development are logically displayed. On this basis, interviews and discussions are conducted to correct, adjust, and supplement the influencing factors. The advantages of this identification method can be summarized that the situation in China can be taken into consideration and the characteristics of the existing building energy-saving reconstruction market can be combined, so that the research objects are more targeted and more scientific. In this part, the variables of the influencing factors are identified.

3.3. Construction of Dynamic Feedback Model

Vensim PLE is a system dynamics specific software, used to draw a dynamic feedback model of complex systems. In Vensim PLE, the model is built around the causal relationship between variables [35], which is used to draw the causal relationship diagram of the existing buildings energy-saving renovation market development system. The causal loop diagram (CLD) is an important tool for representing the system feedback structure, which can express the reason for the dynamic formation of the system clearly [36]. It does not need to describe the model in such detail as a mathematical formula. The establishment of the CLD is based on two parts: variable and causal chain. After identifying the variables of the causal loop, that is, the influencing factors, you then start from any element in the system, find out the element that has a direct causal relationship with it, and confirm the causal relationship between the two. The determination of causality can be easily obtained from the logical relationships we know, along with the arguments of authoritative journals and the technical guidance of domain experts. In the CLD, the variables are connected by a causal chain, which is represented by an arrow. Each causal chain has a polarity, either positive (+) or negative (−) [37]. This polarity describes the structure of the system and points out how the relevant variables change as the independent variables change. Drawing the CLD requires the following basic principles:

(1) Use curves to represent information feedback. This helps readers form a visual image.
(2) Let the important circuit follow a circular or elliptical path.
(3) Organize your maps reasonably to minimize cross lines.
(4) Try again and again. Redraw multiple times to find the best layout.

3.4. Feedback Loop Analysis of the Subsystem

Due to the complexity of the model, it is unrealistic to fully analyze all its properties. Subsystem variables are relatively less, but the relationship between variables is still relatively complex. Therefore, it is necessary to refine the complex system into multiple subsystems according to the function positioning, and obtain a single-loop causal loop or variable relationship tree structure diagram. Subsystems have enough details to show the actual work of the process and how the cycles interact with each other. In order to reduce the repetitiveness of the work, the author divided loops with similar mechanisms into one category, and then conducted a unified analysis for each category, focusing on the causal loop. In this way, the dynamic feedback relationship of influencing factors of existing buildings energy-saving reconstruction market is analysed comprehensively.

The core of system dynamics is feedback relationship analysis. The feedback relationship is described by a feedback loop [38]. The feedback loop is divided into a positive feedback loop and a negative feedback loop. The important loop is specifically marked with a loop identifier to indicate whether the loop is positive feedback or negative feedback [39]. The variables in the positive feedback loop will change in the same direction, eventually causing the system to deviate from the original state. The variables in the negative feedback loop weaken the trend of the same direction through the fluctuation of the feedback loop, and have the function of self-adjustment, making the system a stable state [40].

3.5. Characteristics Analysis of Dynamic Feedback System

The system dynamics theory has been demonstrated as a useful tool for analysing the running characteristics of the system by Wu and Wang (2016) [41]. Therefore, we use this model to analyse dynamic feedback system characteristics based on the results in the last step.

4. Results

4.1. The Framework of the Existing Building Energy-Saving Renovation Market

The existing building energy-saving retrofit market is an economic system with energy-saving services as the core, requiring the demand market, factor market, and regulation organization to operate together. Among them, the factor market is an important part of the existing building energy-saving transformation industrial chain, so it can be summarized as the energy-saving service market. According to the functional orientation of each market, Figure 1 shows the existing building energy-saving renovation market system is divided into the energy-saving service market subsystem, the demand market subsystem, and market regulation subsystem.

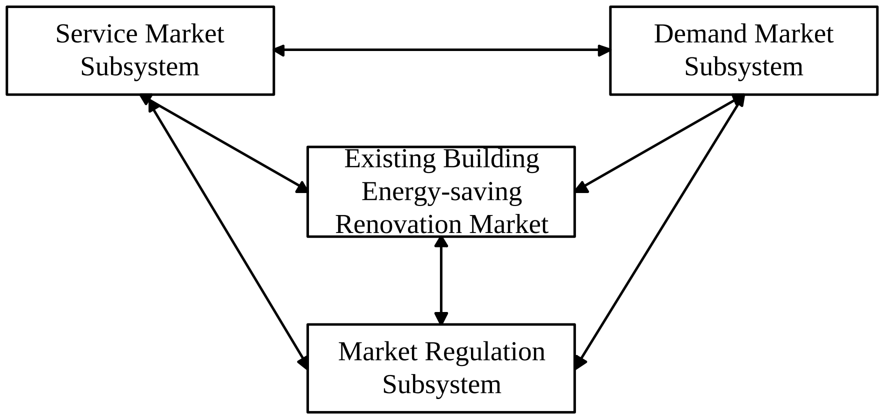

Figure 1. Market development system analysis framework.

4.2. Building the Total System Causal Diagram

On the basis of literature analysis, through correction, adjustment, and supplement, a total of 52 "energy-saving-related" associated influencing factors were identified. According to the structural function of different subsystems, we classified the influencing factors of the existing buildings energy-saving renovation market.

The essence of service market subsystem development is the increase of ESCO, the growth of total capital, and the expansion of energy-saving service industries. There are 32 variables in the service market subsystem of the existing building energy-saving renovation: ESCO willingness [14], ESCO invest capital [19], ESCO income [20], ESCO service capacity [11], ESCO input cost [17], ESCO operation management capability, industry scale, industrial restructuring and alliance [14], talent cultivation and introduction, different services, market competition [10], bank income, service cost, technology research and development innovation [9], technology research and development costs [9], technology research and development investment, investment recovery period, investment risk, market competition, service price, explicit demand, service efficiency, energy price, energy-saving income, factor cost, industry average profit, scale economy, entry barriers, willingness to participate in financial institutions, project loans [17], project operational risks [14], and expected benefits.

The demand market subsystem is the internal driving force for the development of the existing building energy-saving transformation market. The key to promoting demand explicitness is the owner's willingness to transform, and the will depends on the owner's energy-saving income, energy-saving cost, energy-saving awareness, and energy-saving service quality. There are 20 variables that constitute the demand market subsystem of the existing building energy-saving renovation: owner cost [18], owner income [29], owner's willingness [15], special funds [13], publicity, ESCO asset level, government energy-saving pressure [12], loan discount, back income, investment risk, explicit demand [24], project achievability, other reconstruction method, potential demand [24], incentive policies [13], energy prices, propaganda, owners' energy-saving awareness, and tax incentives.

The market regulation system with the government as the main body interacts with other market subsystems. The government's regulatory actions are used in various market subsystems widely to stimulate, constrain, guide, and supervise the development of existing building energy-saving retrofit markets. Depending on the purpose of the role, the government's regulatory behavior variables can be classified into other subsystem markets [34]. For example, the government set up a special fund for existing building energy-saving renovation, in order to reduce the cost of owners' renovation effectively, improve owners 'willingness to transform, and increase the explicit market demand. Therefore, the special fund elements in government incentives should belong to the demand market subsystem.

In this paper, the relations between varibales are identified by the logical relationships we know, along with the arguments of authoritative journals and the technical guidance of domain experts. For example, starting from the variable of energy-saving technology innovation, we can get a feedback loop that reduces the demand for heat supply, increases energy-savings income, and improves economic benefits, thereby increasing ESCO's revenue. One can start with any varibales of the system, identify the varibales that have a direct causal relationship with it, confirm the relationship, and repeat the process until all causal relationships are complete, as shown in Figure 2.

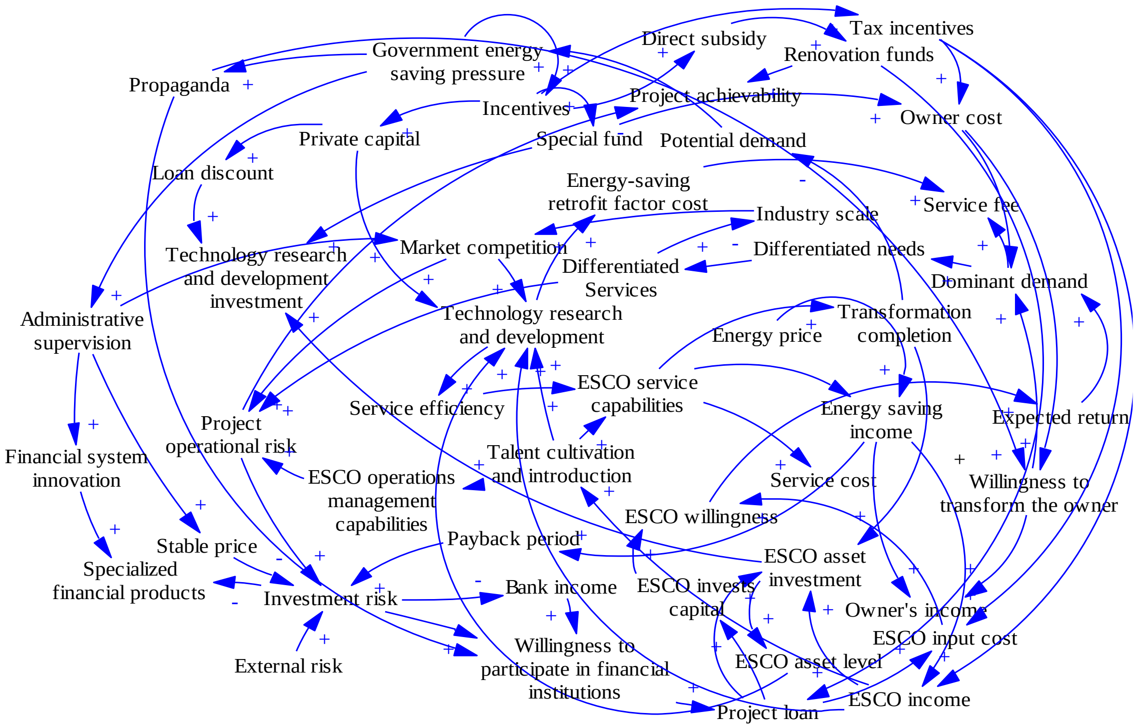

Figure 2. Total system causal diagram of existing buildings energy-saving renovation market.

There are many variables in this figure, and the relationship between them is complicated. Therefore, the direct analysis of the total system is very complex and the feedback relationship between the elements cannot be explained clearly. However, the following conclusions can be drawn from the figure. First, the existing building energy-saving renovation service market has ESCO as the main body, the internal related elements interact and have close relationships, and so it can be regarded as a subsystem that satisfies the self-organized development conditions of the existing building energy-saving renovation service market as the system boundary. Second, the existing building energy-saving renovation demand market with the owner as the main body has the internal process of demand formation, and its constituent elements are relatively independent and complete, so it can be divided into a subsystem that forms a system boundary by participating in the market supply and demand mechanism. Third, the government is the main bearer of market regulation and control behavior, in the total system, market regulation has three types and seven ways to cross-exist in the service market and the demand market, which has an impact on each market.

4.3. Results of Dynamic Feedback Analysis

4.3.1. Service Market Subsystem Loop Analysis

The service market subsystem includes two types of causal loops. One is the self-organized development of the energy-saving renovation service industry, and the other is the self-organized development of the energy-saving renovation service enterprise [42].

Figure 3 depicts eight positive feedback loops and a negative feedback loop in the self-organized development causal loop of the energy-saving transformation service industry. The elements that change the polarity of the loop are service cost and energy-saving revenue. This type of causal feedback loop mainly describes the causal cycle process which ESCO enterprises as the main body of the market self-organized development in energy-saving service market under the changing industrial environment. The positive feedback loop explains that in the process of industrial environment change, the improvement of the company's profitability will help to expand the market scale. The negative feedback loop explains that in the process of industrial development, with the expansion of the market, the competition is increasingly fierce. At this time, the profit margin of energy-saving services will shrink, and the market development has a balance state. The positive and negative feedback loops are combined to form a growth upper limit fundamental model; that is, the market competition and industrial competition will have a bottleneck stage. When the incentives of ESCO's income are insufficient to offset the negative impact of the expected profit space, ESCO's market competition and industry scale will degenerate. Therefore, there is a maximum size constraint in market development.

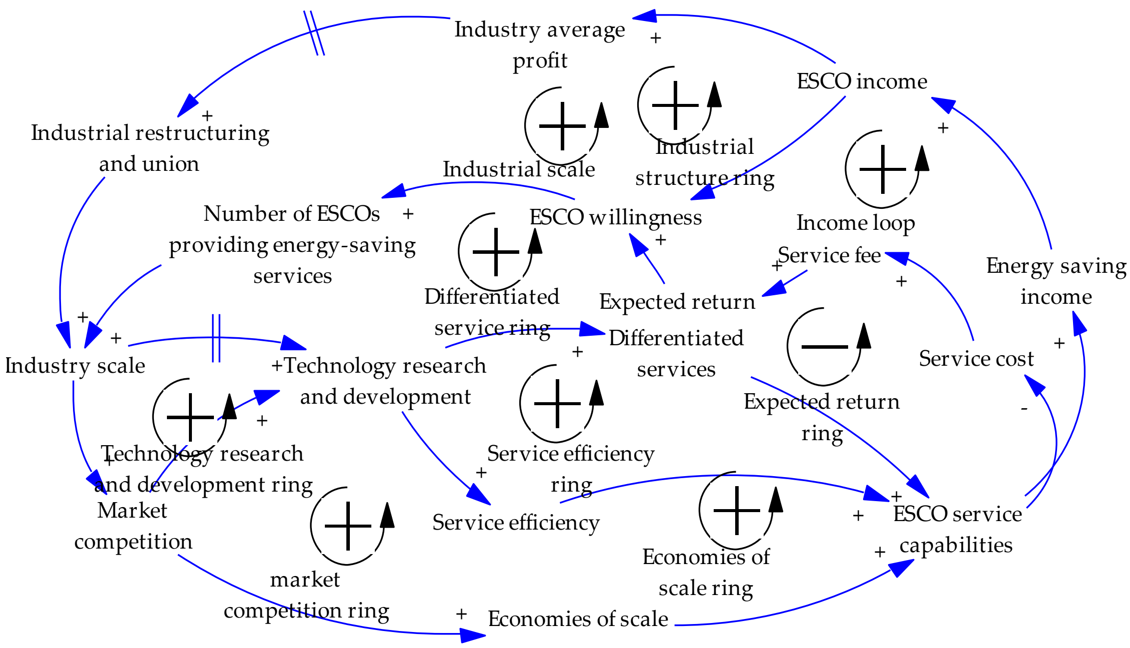

Figure 3. Energy-saving service industry self-organizational development causal loop.

Figure 4 reveals the causal cycle process of ESCO enterprises achieving self-organization development. The positive feedback loop indicates that ESCO strengthens asset construction, upgrades and introduces energy-saving equipment, and actively carries out technological R&D innovation and the introduction of professional talents to effectively realize the value-added by the enterprise; the negative feedback loop indicates that ESCO faces decision-making problems in asset investment and technology R&D investment. The two strategies are efficient and the investment in assets is quick. Because technology research and development needs to go through the development cycle and there are certain risks, enterprises are more inclined to invest in assets expansion. However, from the perspective of improve core competitiveness of enterprises and the knowledge-intensive characteristics of the existing building energy-saving retrofit market [43], technological innovation is the most important influencing factor for enterprises to maintain competitiveness [44]. Therefore, if enterprises lack new technology development, they will be eliminated from the competition [45]. From the medium measure, if most enterprises in the industry choose to expand assets and neglect technology research and development investment, the market development space will be reduced, services will become more homogenized, and the focus of competition will gradually shift to price wars. This is obviously not conducive to the sound development of the market. Therefore, although asset expansion can achieve the growth of enterprise benefits in the short term, enterprises still need to pay attention to technology research and development to adapt to changes in the market environment. In terms of strategy selection, enterprises should temporarily increase the amount of investment in assets in order to cope with special circumstances. In daily operations, they should seek the proportion of technology research and development investment that meets the development needs of the enterprise and the market environment, so that the overall benefits are optimal.

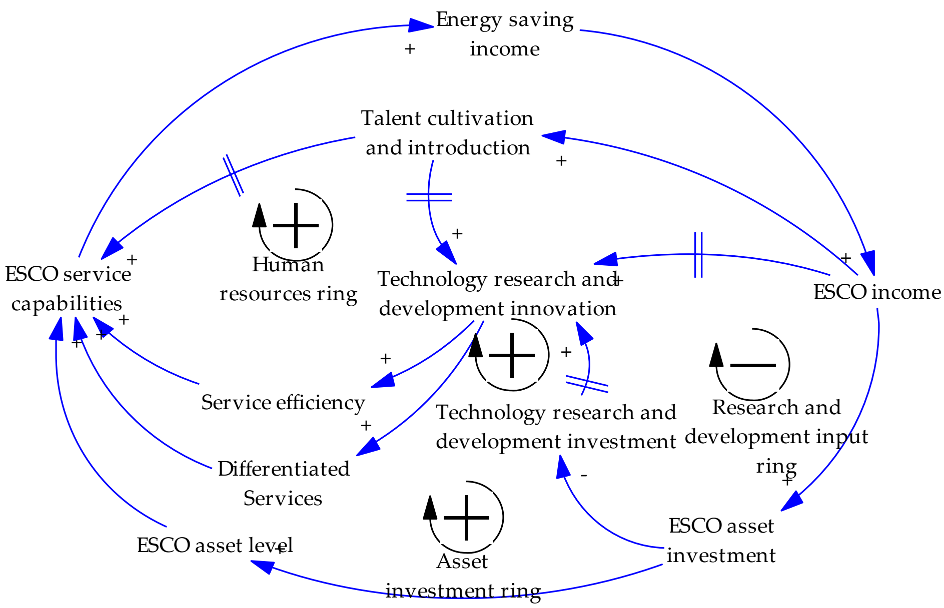

Figure 4. ESCO self-organizational development causal loop.

4.3.2. Demand Market Subsystem Loop Analysis

The demand market subsystem contains two types of causal loops, one that interacts with the service market subsystem, and the other that interacts with government behavior. The interaction between the demand market subsystems and service market subsystems includes two positive feedback loops. Figure 5 depicts the causal cycle process that ESCO enterprises increase the revenue and reduce the cost of energy-saving renovation by enhancing competitiveness, thereby increasing the demand market capacity and providing more development space for ESCO enterprises. The ESCO service capability is an active variable, and the owner's willingness to transform is a passive variable. That is to say, in the environment of China's existing building energy-saving renovation market, ESCO should actively improve its service capacity and expand the market's dominant demand. In addition, ESCO tries to increase the demand market activity through other means to stimulate market development, but the owner's willingness to transform is still a passive change.

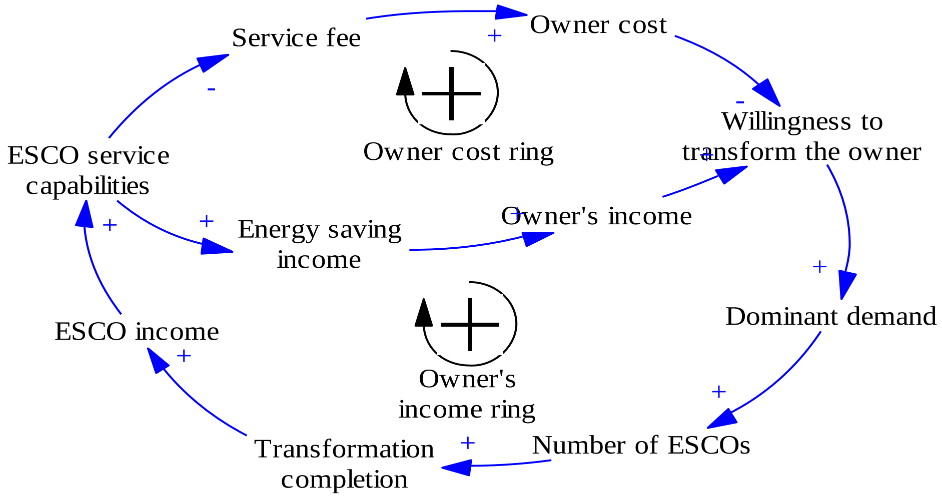

Figure 5. Demand and service market interaction process causal loop.

The interaction loop between demand and government behavior is mainly composed of three negative feedback loops. Figure 6 depicts a causal loop cycle. The government increases the owner's willingness by providing publicity, setting up special funds, implementing tax incentives, etc., thereby promoting the large-scale implementation of existing building energy-saving renovation projects and reducing social energy-saving pressure [46]. From the stability principle of negative feedback, it can be seen that any element in the market is in a stable dynamic process after a period of operation. When the factors are unchanged, the market development will be in equilibrium. Therefore, at this stage, the owner's awareness of energy conservation is not high, and the energy-saving renovation of existing buildings is generally lack of initiative. In order to break market stability, the government should strive to implement various policy tools to promote market development [47]. Energy conservation awareness is a passive variable in the early stages of market development, but as the market develops, it will gradually transform into an active variable. Therefore, after the market enters the growth stage and the maturity stage, the awareness of energy conservation will increase. Under the negative feedback mechanism, the government's force is gradually weakened until it reaches a new steady state.

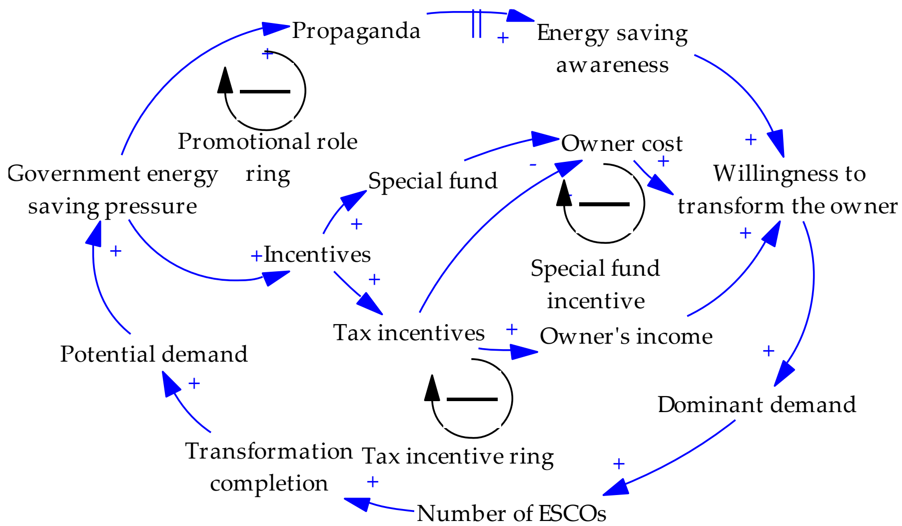

Figure 6. Demand and government behavior interaction process causal loop.

4.3.3. Variable Tree Structure of Market Regulation Subsystem Analysis

The analysis of the market regulation subsystem should introduce the variable tree structure chart analysis method. On the one hand, the causal loop of the control subsystem contains a large part of the elements and causal chains of the other three subsystems, and the analysis loop makes the work repetitive; on the other hand, the variable tree structure graph can clearly express the action process and principle of the variable, and as such it is suitable for analyzing horizontal problems. Existing building energy-saving retrofits have the attributes of public good [48]. The government, as direct beneficiary, has the responsibility to promote existing buildings energy-saving renovation countrywide. The more demand for transformation, the greater the government's energy-saving pressure. It should be pointed out that the demand for existing buildings energy-saving renovation is divided into potential demand and explicit demand. Explicit demand is an important component of the relationship between supply and demand in the market, but from the perspective of the government, potential demand is an important source of government energy-saving pressure. Therefore, the government should not only guide the explicit demand through the market operation mode, but also undertake overall planning, make reasonable predictions on potential demand, and formulate development strategies.

Figure 7 shows the government regulates the operation and development of the existing building energy-saving renovation market through public welfare propaganda, incentive policies, and administrative supervision. Firstly, the main purpose of propaganda for existing buildings energy-saving renovation is to change the mental model of market participants [49]. By enhancing the owner's awareness of energy conservation and transforming the concept of unique interests, the owner's recognition of the existing buildings energy-saving renovation will be improved. It is easier to turn potential demand into explicit demand and provide space for market development. Secondly, the government implements incentives to stimulate the willingness of the owners and ESCOs to participate effectively, solve the problem of funds in a short period of time, and activate the market. In the market formation stage, direct means should be used. In the market development and maturity stage, indirect economic regulation and the development of diversified financing channels should be valued. Thirdly, the government supervises the behavior of market entities, maintains a stable market order, and enables building energy conservation to proceed in an orderly manner and continue to develop. On the one hand, the government is mainly responsible for supervising the operation of the price mechanism of the existing building energy-saving renovation market, controlling the price to fluctuate slightly, and preventing the market from turbulence due to price volatility. On the other hand, it is necessary to maintain a benign competitive environment in the market, by establishing an access and exit mechanism to prevent vicious competition and ineffective competition in the market, avoid monopoly, and market failure. Finally, the government protects the intellectual property rights of enterprises through legal means, solving the worries of enterprise technology research and development. The government encourages enterprises to develop energy-saving products with greater competitiveness and adaptability through policy encouragement and supervision. Under the premise of making relevant preferential policies, we will attach importance to the acceptance of new products and prevent unqualified products from entering the market.

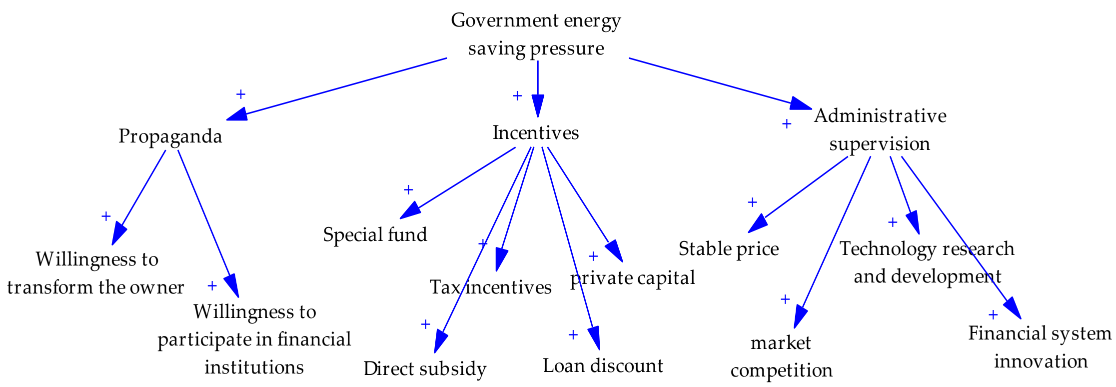

Figure 7. Government energy stress application variable tree structure.

4.4. Characteristics Analysis of Dynamic Feedback System

Based on the dynamic feedback analysis of the existing building energy-saving retrofit market development system, the market development system has the following five characteristics: (1) Figure 3 indicates that when ESCO's revenue does not reach the expected profit, ESCO's competition mechanism and industry scale will degenerate, and market development has the largest size constraint. In addition, the increase in earnings makes ESCO more willing to transform energy-savings, which makes the number of ESCOs in the market increase significantly. At this time, the existing buildings energy-saving renovation market has developed rapidly. Therefore, the government should take appropriate economic subsidy measures in order to improve ESCO income. (2) Figure 4 show that technological innovation is the most important factor influencing companies to maintain their competitiveness. On the one hand, enterprises improve service efficiency by developing new technologies, and reduce project management costs with high quality service level, thereby increasing energy-saving benefits. On the other hand, ESCO attaches great importance to technological innovation, which can change the focus of enterprise competition and pursue maximum benefit with minimum investment. Therefore, in order to promote the market development of existing buildings energy-saving renovation, we should pay attention to the development and improvement of the energy-saving technology. (3) The results in Figure 5 indicate that ESCO should take the initiative to improve its service capabilities to expand market demand. (4) Figure 6 displays that owners have low awareness of energy conservation and generally lack the initiative to transform. Through the value guidance of government, the owners' potential demand is transformed into explicit demand, which provides guarantees for market development. (5) As Figure 7 shows, through public welfare propaganda, incentive policies, and administrative supervision, the government effectively stimulates the owners and ESCO's willingness to reform energy conservation, and injects continuous power into the existing building energy-saving renovation market.

5. Discussion

The building sector is well known to be one of the key energy consumers worldwide. The renovation of existing buildings provides excellent opportunities for an effective reduction of energy consumption and greenhouse gas emissions but it is essential to identify the influencing factors. In what follows, we discuss the results obtained from Section 4.

(1) The research results indicate that "ESCO's revenue" is perceived to be an important influencing factor in the dynamic feedback. This finding supports previous research that with the revenue increase, the number of ESCO in the market shows an upward trend. In fact, all rational economic entities are profit-oriented. When ESCO's revenue does not reach the expected profit, ESCO's competition mechanism and industry scale will degenerate, and market development has the largest size constraint. In addition, the increase in earnings makes ESCO more willing to transform energy-saving, which makes the number of ESCOs in the market increase significantly. At this time, the existing buildings energy-saving renovation market has developed rapidly. Therefore, to achieve successful and widespread adoption of existing building energy-saving reconstruction, the government should take appropriate economic subsidy measures in order to improve ESCO's income.

(2) As expected, technological innovation is an important influencing factor in the dynamic feedback to maintain competitiveness. On the one hand, enterprises improve service efficiency by developing new technologies, and reduce project management costs with high quality service level, thereby increasing energy-saving benefits. On the other hand, ESCO attaches great importance to technological innovation, which can change the focus of enterprise competition and pursue maximum benefit with minimum investment. Therefore, in order to ensure the sustainable development of the existing buildings energy-saving reconstruction market, it is wise to pursue technological innovation as the focus to improve economic benefits.

(3) As a critical influencing factor to implementing existing buildings energy-saving renovation in China, "the willingness of stakeholders to participate" has attracted the attention of scholars. Many scholars found that while existing building energy-saving renovation has the attributes of public good, part of the main body of the market exhibits the behavior of "free riding", and so weaken the enthusiasm of other stakeholders. Therefore, in order to break the negative stable state, it is necessary for the government to implement appropriate policy measures to improve the recognition of energy-saving renovation, so as to make it easier for potential demand to be converted into explicit demand.
(4) Government incentives are as important as perceived and can be found in the results obtained from the dynamic feedback. Previous studies have pointed out that there are special properties such as externality in existing building energy-saving reconstruction. This determines that the healthy development of its market is bound to be inseparable from the external engine of the government. The government is the leading force in the existing building energy-saving reconstruction market. It has been a consensus among Chinese scholars that incentive policies are effective measures to solve externalities. The degree of incentive is closely related to the benefits of energy income. In addition, energy-saving propaganda and administrative supervision have also been affirmed. Through these means, the owners' and ESCO's willingness to support energy-saving reconstruction have been stimulated effectively and the market has become more active.
(5) An interesting finding is that owner energy-saving awareness has become very important in the dynamic feedback. Currently, the knowledge and understanding of existing building energy-saving reconstruction by the public needs to be further promoted. Although an increasing amount of the public recognized that energy-saving is a serious issue, it is difficult for them to take this social problem into their own hands. Especially in the current building market environment, very few people are willing to change the current situation, even if existing buildings are energy-intensive. In addition, due to lack of awareness about existing building energy-saving reconstruction, it is difficult to control the owner's energy use behavior in the operation process of energy-saving transformation. Ultimately, the energy-saving cannot be realized and the cost has not been reduced.

6. Conclusions

Based on the analysis of the factors affecting the development of the existing building energy-saving retrofit market, this paper establishes a system dynamics model and simulates the interaction of influencing factors through Vensim PLM software. From the feedback loop analysis of the market development system, the development of the existing building energy-saving renovation market is mainly affected by the government incentive level, ESCO technology innovation, ESCO service capability, and owner energy conservation awareness. These findings standardized the behavior of market entities and provide the basis and guiding role for the Chinese government to formulate support policies for existing buildings energy conservation renovation. At the same time, it also provides reference for other countries to develop existing buildings energy-saving renovation projects. Based on the results of the model analysis, the following suggestions are proposed for promoting the development of existing building energy-saving retrofit markets:

(1) Promote the market-oriented development model of "market-led, government-regulated". Because the existing building energy-saving retrofit market has externalities, information asymmetry, insufficient explicit demand, and high capital barriers, the government should play a key role and adopt various means to support enterprises, owners, and investors to participate in the market. The specific measures are to establish a market access and exit mechanism for existing building energy-saving renovation to enhance the enterprise's competition awareness. Further, the government should improve the industry's supervision system for energy-saving renovation, to promote cooperation and exchanges, improve the system of regulations and standards, provide

a stable development environment, and accelerate the transformation of government functions and coordinate the allocation of market resources.

(2) Optimize the composition of the factor market and support the sustainable development of the market. Optimizing the composition of the factor market is the necessary condition to realize the sustainable development of the existing building energy-saving reconstruction market. To achieve this goal, we need to optimize the labor market talent composition, expand financing channels, and build information exchange platforms within the industry. In addition, it is necessary to optimize the labor market composition and increase the proportion of professionals, promote financial product innovation, expand enterprise financing channels, and build information exchange platforms to reduce market transaction costs.

(3) Guided by market demand, it is necessary to promote technological innovation of energy-saving service enterprises. First of all, through rapid and accurate information diffusion, the information on the technical needs of the existing building energy-saving transformation market will be conveyed to enterprises to avoid information asymmetry, so that enterprises can fully grasp the market demand situation. Secondly, it is necessary to increase investment in basic research involved in energy-saving renovation of existing buildings, and the state must support enterprises and research institutes to cooperate in scientific research to form original capabilities. Third, the state formulate corresponding industrial policies and technical policies, reduce the cost of enterprise innovation, and guide enterprises to form innovative capabilities. Finally, the state establish a building energy-saving product certification system, standardize the technology transfer market, promote technology exchange and integration between enterprises, enhance the overall production and service level of the industry, and promote the stable development of the market.

Author Contributions: H.G. provided good research advices. W.Q. designed this study and completed the paper in English. J.L. and W.Q. prepared the original draft.

Funding: This research was funded by the National Natural Science Foundation of China (71573188), Late-stage Subsidy Project of Humanities and Social Sciences of the Education Department of China (16JHQ031), Social Science Planning Later Project of Tianjin Province of China (TJGLHQ1403), Higher Education Innovation Team of Tianjin (TD13-5006).

Acknowledgments: The authors are grateful to all our family and friends for their encouragement and support. In addition, we appreciate editors and anonymous reviewers for the invaluable comments and suggestions that helped in improving this paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ministry of Housing and Urban-Rural Development of the People's Republic of China. *Guidelines for Energy-Saving Renovation of Existing Residential Buildings*; China Building Industry Press: Beijing, China, 2012.
2. Broin, E.; Mata, É.; Göransson, A. The effect of improved efficiency on energy savings in EU-27 buildings. *Energy* **2013**, *57*, 134–148. [CrossRef]
3. Markandya, A.; Ortiz, R.A.; Mudgal, S. Analysis of tax incentives for energy-efficient durables in the EU. *Energy Policy* **2009**, *37*, 5662–5674. [CrossRef]
4. Hsu, D. How much information disclosure of building energy performance is necessary? *Energy Policy* **2014**, *64*, 263–272. [CrossRef]
5. Fayaz, K.; Behrouz, M. Comparison of energy conservation building codes of Iran, Turkey, Germany, China, ISO 9164 and EN 832. *Appl. Energy* **2009**, *86*, 1949–1955. [CrossRef]
6. Parkinson, A.; Guthrie, P. Evaluating the energy performance of buildings within a value at risk framework with demonstration on UK offices. *Appl. Energy* **2014**, *133*, 40–55. [CrossRef]
7. Nair, G.L.; Mahapatra, K. Factors influencing energy efficiency investments in existing Swedish residential buildings. *Energy Policy* **2010**, *38*, 2956–2963. [CrossRef]

8. Ueno, T.; Sano, F.; Saeki, O. Effectiveness of an energy-consumption information system on energy savings in residential houses based on monitored data. *Appl. Energy* **2006**, *83*, 166–183. [CrossRef]
9. Johnstone, N.; Haščič, I.; Popp, D. Renewable Energy Policies and Technological Innovation: Evidence Based on Patent Counts. *Environ. Resour. Econ.* **2010**, *45*, 133–155. [CrossRef]
10. Meyer, N.; Shining, S. The competition honored creative and stylish energy-saving residential lighting designs (Lighting for Tomorrow Design and Technology competition). *Trop. Med. Int. Health* **1969**, *7*, 383–390.
11. Raji, B.; Tenpierik, M.J.; Dobbelsteen, A.V.D. The impact of greening systems on building energy performance: A literature review. *Renew. Sustain. Energy Rev.* **2015**, *45*, 610–623. [CrossRef]
12. Goldman, C.A.; Hopper, N.C.; Osborn, J.G. Review of US ESCO industry market trends: an empirical analysis of project data. *Energy Policy* **2005**, *33*, 387–405. [CrossRef]
13. Schmidt, C.W. Room to Grow: Incentives Boost Energy-Efficient Homebuilding. *Environ. Health Perspect.* **2008**, *116*, A32–A35. [CrossRef] [PubMed]
14. Rausch, A.; Bedeik, N.O.; Fafaliou, A.I. Corporate Social Responsibility and Company Performance—Evidence from four European Countries. *Holis Apprord. Environ.* **2013**, *3*, 153–173.
15. Kirsten, G.H. Residential heat comfort practices: understanding users. *Build. Res. Inf.* **2010**, *38*, 175–186.
16. Baek, C.; Park, S. Policy measures to overcome barriers to energy renovation of existing buildings. *Renew. Sustain. Energy Rev.* **2012**, *16*, 3939–3947. [CrossRef]
17. Pan, Y.; Zuo, M.; Wu, G. Whole building energy simulation and energy saving potential analysis of a large public building. *J. Build. Perf. Simul.* **2011**, *4*, 11. [CrossRef]
18. Wang, X.; Lu, M.; Wei, M. Improving benefit-cost analysis to overcome financing difficulties in promoting energy-efficient renovation of existing residential buildings in China. *Appl. Energy* **2015**, *141*, 119–130. [CrossRef]
19. Nolden, C.; Sorrell, S. The UK market for energy service contracts in 2014–2015. *Energy Effic.* **2016**, *9*, 1–16. [CrossRef]
20. Labanca, N.; Suerkemper, F.; Bertoldi, P. Energy efficiency services for residential buildings: market situation and existing potentials in the European Union. *J. Clean. Prod.* **2015**, *109*, 284–295. [CrossRef]
21. Zhang, Y.; Wang, Y. Barriers' and policies' analysis of China's building energy efficiency. *Energy Policy* **2013**, *62*, 768–773. [CrossRef]
22. Gillingham, K.; Newell, R.; Palmer, K. Energy efficiency economics and policy. *Annu. Rev. Resour. Econ.* **2009**, *1*, 597–619. [CrossRef]
23. Zhou, Z.; Zhang, S.; Wang, C. Achieving energy efficient buildings via retrofitting of existing buildings: A case study. *J. Clean. Prod.* **2016**, *112*, 3605–3615. [CrossRef]
24. Hori, S.; Shinozaki, M.; Nogata, D. The role of CSR in promoting companies' energy-saving actions in two Asian cities. *Energy Policy* **2014**, *69*, 116–121. [CrossRef]
25. Pombo, O.; Allacker, K.; Rivela, B. Sustainability assessment of energy saving measures: A multi-criteria approach for residential buildings retrofitting—A case study of the Spanish housing stock. *Energy Build.* **2016**, *116*, 384–394. [CrossRef]
26. Lee, D.; Cheng, C.C. Energy savings by energy management systems: A review. *Renew. Sustain. Energy Rev.* **2016**, *56*, 760–777. [CrossRef]
27. Zhao, J.S.; Yuan, L.; Zhang, M. A study of the system dynamics coupling model of the driving factors for multi-scale land use change. *Environ. Earth Sci.* **2016**, *75*, 1–13. [CrossRef]
28. Ziemele, J.; Gravelsins, A.; Blumberga, A. Combining energy efficiency at source and at consumer to reach 4th generation district heating: Economic and system dynamics analysis. *Energy* **2017**, *137*, 595–606. [CrossRef]
29. Vulturius, G. The importance of socio-ecological system dynamics in understanding adaptation to global change in the forestry sector. *J. Environ. Manag.* **2017**, *196*, 36.
30. Coyle, R.G. System Dynamics Modelling: A Practical Approach. *J. Oper. Res. Soc.* **1997**, *48*, 544. [CrossRef]
31. Kotir, J.H.; Smith, C.; Brown, G. A system dynamics simulation model for sustainable water resources management and agricultural development in the Volta River Basin, Ghana. *Sci. Total Environ.* **2016**, *573*, 444–457. [CrossRef]
32. Hamdan, A.M.A. Coupling measures between modes and state variables in power-system dynamics. *Int. J. Control* **2012**, *43*, 1029–1041. [CrossRef]
33. Bertrand, A. A clear description of system dynamics through the physical parameters; and generalized coordinates. *Int. J. Control* **2013**, *29*, 213–233. [CrossRef]

34. Omer, A.M. Focus on low carbon technologies: The positive solution. *Renew. Sustain. Energy Rev.* **2008**, *12*, 2331–2357. [CrossRef]
35. Shih, Y.H.; Tseng, C.H. Cost-benefit analysis of sustainable energy development using life-cycle co-benefits assessment and the system dynamics approach. *Appl. Energy* **2014**, *119*, 57–66. [CrossRef]
36. Guo, H.C.; Liu, L.; Huang, G.H. A system dynamics approach for regional environmental planning and management: A study for the Lake Erhai Basin. *J. Environ. Manag.* **2011**, *61*, 93–111. [CrossRef] [PubMed]
37. Randers, J. Elements of the System Dynamics Method. *J. Oper. Res. Soc.* **1997**, *48*, 1144–1145. [CrossRef]
38. Ford, D.N. A behavioral approach to feedback loop dominance analysis. *Syst. Dyn. Rev.* **1999**, *15*, 3–36. [CrossRef]
39. Škraba, A.; Kljajić, M.; Leskovar, R. Group exploration of system dynamics models—Is there a place for a feedback loop in the decision process? *Syst. Dyn. Rev.* **2010**, *19*, 243–263. [CrossRef]
40. Vlachos, D.; Georgiadis, P.; Iakovou, E. A system dynamics model for dynamic capacity planning of remanufacturing in closed-loop supply chains. *Comput. Oper. Res.* **2007**, *34*, 367–394. [CrossRef]
41. Wu, Z.; Wang, B.; Xia, X. Large-scale building energy efficiency retrofit: Concept, model and control. *Energy* **2016**, *109*, 456–465. [CrossRef]
42. Chen, Y.; Keyser, M.; Tackett, M.H. Incorporating Short-Term Stored Energy Resource Into Midwest ISO Energy and Ancillary Service Market. *IEEE Trans. Power Syst.* **2011**, *26*, 829–838. [CrossRef]
43. Bleda, M.; Río, P.D. The market failure and the systemic failure rationales in technological innovation systems. *Res. Policy* **2013**, *42*, 1039–1052. [CrossRef]
44. Cristofari, C.; Storai, C.; Canaletti, J.L. Development policy to increase the competitiveness of renewable energy-sector companies in a territory like Corsica (France). *Renew. Sustain. Energy Rev.* **2014**, *32*, 61–66. [CrossRef]
45. Tran, M. Technology-behavioural modelling of energy innovation diffusion in the UK. *Appl. Energy* **2012**, *95*, 1–11. [CrossRef]
46. Siano, P.; Sarno, D. Assessing the benefits of residential demand response in a real time distribution energy market. *Appl. Energy* **2016**, *161*, 533–551. [CrossRef]
47. Li, J.; Colombier, M. Managing carbon emissions in China through building energy efficiency. *J. Environ. Manag.* **2009**, *90*, 2436–2447. [CrossRef]
48. Ma, Z.; Wang, S. Building energy research in Hong Kong: A review. *Renew. Sustain. Energy Rev.* **2009**, *13*, 1870–1883. [CrossRef]
49. Liu, W.; Zhang, J.; Bluemling, B. Public participation in energy saving retrofitting of residential buildings in China. *Appl. Energy* **2015**, *147*, 287–296. [CrossRef]

© 2019 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).