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Review

Analysis of Existing Problems and Improvement Schemes for Substituting Electricity for Scattered Coal in China

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Abstract: In recent years, a coal-induced haze erupted over a large area in China. Implementing a strategy of substituting electricity for scattered coal (hereafter referred to as SEFSC) for the control of scattered coal is thus urgently needed. In particular, there lies great practical significance in analyzing the existing problems and improving the path of SEFSC in order to ensure rapid and effective advancement in this area. In light of this, the current paper first analyzes the distribution of China's scattered coal and the relevant policy implementation, and discusses the potential for China to implement SEFSC. Secondly, PEST (policy, economy, society and technology) analysis is used to analyze the existing problems in China's SEFSC strategy. From this, it becomes clear that the effect of scattered coal handling is still poor due to poor policy implementation, a weak economy, a low level of social acceptance and technical bottlenecks. Finally, based on the present situation and existing problems, this paper puts forward recommendations for improving China's SEFSC strategy.

Keywords: control of scattered coal; energy substitution; existing problems; strategies for improvement; China

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1. Introduction

Coal use can be classified into concentrated coal and scattered coal; the former mainly occurs in power plants and large industrial production, while the latter mainly occurs among related to residents and tertiary production heating, cooking and bathing, small industrial production heating and steaming, agricultural production, and so forth. Scattered coal thus refers to the decentralized use of coal as opposed to its centrally overseen, large scale and concentrated use.

1.1. Background

In recent years, China has been facing a grim situation with regard to its air pollution, which hazes frequently in heating season, especially in the northern region [1]. This is the result of China's long-term coal-based energy structure, which contains a high proportion of scattered coal [2]. Studies have shown that coal combustion is the most important factor causing environmental pollution [3], which has a similar spatial distribution to the annual mean $PM_{2.5}$ concentration [4]. Among them, the emission intensity of scattered coal is 17.5 times that of coal for generating electricity, with the nitrogen oxides, sulfur dioxide and smoke dust emitted by scattered coal being two times, five times and 66 times that emitted by electricity-generating coal, respectively [5]. However, China's annual consumption of scattered coal accounts for approximately 20% of total coal consumption—much higher than that in developed countries, where this represents less than 5% [6]. The control of scattered coal has thus become an urgent issue in controlling haze in China, having significant knock on environmental benefits.

To a great extent, scattered coal can be substituted with electricity [7]. Compared with coal, oil, natural gas and other energy resources, electricity has the distinct advantages of cleanliness, efficiency, safety and convenience [8]. Studies have shown that, among the terminal consumption of energy exerting the same calorific value, electricity creates economic value that is 3.2 times that of oil, and 17.3 times that of coal [9]. For every proportion that electricity consumption account for terminal energy consumption increases 1%, the unit GDP energy consumption will decrease by 4% accordingly [10]. Solving the problem of scattered coal is thus the key to solving China's haze dilemma.

Replacing the direct consumption of scattered coal by electricity could provide a fundamental solution to the challenges of sustainable development and the reduction of the environmental impact of energy consumption [11,12].

1.2. Literature Review

1.2.1. International Research

To reduce global warming and geopolitical tensions, most developed countries have long considered substituting electricity for coal to be a policy priority [13]. For example, in the United States, the government invested $100 million on the ground source heat pump to raise the level of electrification, and by 1960 the country had complete rural electrical coverage [14]. Japan was the world's leading country of application on household air-source heat pump. At the same time, the Japanese government increased environmental supervision by way of taxing the use of fossil fuels at a rate of 2400 yen per ton of carbon since 2005 [15]. EU countries have implemented self-pricing mechanisms, meaning that power companies have more flexibility to use market mechanisms to serve their customers. Moreover, environmental and social responsibility is linked with encouraging enterprises to reduce their pollutant emissions [14]. With the ongoing development of Western economics, many scholars have analyzed and explained the internal relationship between energy systems and the economic system using mathematical models and quantitative analysis methods. For example, Sehlegelmilch (2000) [16] used the general linear model to analyze the impact of the government's energy tax in the EU and some Member Status on different energy prices and also the investment behavior of energy conservation and emission reduction. In another study, Willeme (2003) [17] obtained the logistic curve after adjusting the hypothesis of the traditional stepped energy supply curve. He argued that there exists a significant positive relationship between energy prices and energy saving, and that energy saving measures will affect each other in such a ways as to reduce the energy saving potential; however, it does not affect the price sensitivity of energy saving measures. Lopes et al. (2005) [18] conducted a detailed questionnaire survey on household energy consumption among 13 households in Kansai, Japan, and found that energy price was the main factor influencing energy consumption. In light of this, it can further be argued that successful energy policies need to consider the use of pricing tools to make the costs for residents more reasonable. Smyth et al. (2011) [19] pointed out that the core issue of energy policy design and planning is the extent to which other factors can substitute for energy and the impact of such substitution on economic growth. Pettersson et al. (2012) [20] analyzed the role of fuel switching behavior and public policies in influencing fuel choices in the Western European power sector. They noted that national policies, such as the elimination of coal subsidies and the liberalization of electricity markets, have had notable impacts on fuel choices.

1.2.2. Research in China

China has attracted the attention of many scholars as the world's largest coal consumer, accounting for over half of the world's total coal consumption. Crompton and Wu (2005) [21] forecasted China's future energy consumption based on a time series analysis of energy consumption and economic growth. Bloch et al. (2015) [22] investigated the links between economic growth, energy and emissions in China by considering oil, coal and renewable energy consumption to reach robust energy conservation policy implications. To date, most studies by Chinese scholars on energy conservation and emission reduction have been based on the mature theory of foreign countries. They tend to contain theoretical analysis and discussion pertaining to the rational exploitation of energy, environmental protection, clean production, circular economy and sustainable development [23]. For example, Song (2008) [24] analyzed the causes and behavioral activities of government intervention in energy conservation and emission reduction, providing a theoretical basis for the scientific evaluation of government intervention in the reality. The findings of this study enabled the construction of an index system to evaluate the rationalization of government behavior in energy conservation and emission reduction. Ma et al. (2008) [7] suggested that energy can be substituted with both capital and labor, and that coal can be significantly substituted with electricity. Liu (2009) [25] analyzed the reality of China's energy-saving and emission-reduction activities, studying the relationship between environmental protection and public finance. She also put forward basic ideas to comprehensively promote and improve the fiscal and taxation system of the country's energy-saving and emission-reduction policy. Li and Lin (2016) [26] empirically investigated inter-factor/inter-fuel substitution in China and evaluated the determinants of China's energy-related carbon intensity as well as mitigation effects of tax; they proved that carbon tax provided an incentive for firms to avoid high carbon technologies. The successful experience of advanced energy conservation and emission reduction has been widely introduced across several countries, which could be used as reference for the formulation of policies and measures for energy conservation and emission reduction in China. For example, Gao (2003) [27] provided a good foundation for China's energy saving, emission reduction policy formulation, by elaborating on the new measures in the field of energy in Japan. Zhao and He (2003) [28] reviewed the ways in which government supports the energy-saving mode of operation in the EU, the UK and France under the public finance system, with reference to how this could work in China. The motivation, mechanism, policy and other problems regarding China's energy conservation and emission reduction have also been specifically studied, considering the country's unique national conditions. This field of research tends to be very specific, focusing on the refinement of different regions, industries and sectors. For example, Zhou (2009) [29] provided a detailed introduction to the coal policy, the benchmarking agreement, the emissions trading, the government subsidy plan and the tax in the energy conservation and emission reduction of the Netherlands, discussing the application of these five policy tools in China. Wu (2008) [30] studied the current situation and implementation effect of energy conservation and emission reduction policies in the power industry. Zheng (2012) [31] used the data envelopment analysis (DEA) model and gray prediction model to analyze the potential of electric power substitution in rural China, finding that China's rural electric energy substitution has great potential both in the near and long-term state. Yuan et al. (2015) [32] analyzed the electricity replacement situation and potential in Tianjin according to terminal consumption, measuring the economic value of several different types of electricity substitution.

1.3. Rationale and Structure of the Current Paper

To date, exiting studies have mainly focused on the adaptability, economy and running optimization of specific technologies for SEFSC (substituting electricity for scattered coal), lacking a strategic study on the long-term and large-scale control of scattered coal, which would inevitably affect the effectiveness of such a transition. The focus of this study, therefore, is on two issues. The first is to summarize and analyze the distribution of scattered coal in China. The second is to provide the framework for discussing potential barriers to the SEFSC strategy in China, along with the relationships between the various political economic, social and technological (PEST) factors affecting it. Following this focus, the paper hopes to provide useful reference points and a clear direction for the promotion of optimization in the energy structure to policy makers. The structure of the paper is as follows. Section 2 provides an overview of the distribution of scattered coal in various regions across China and the status of policy implementation within them. Sections 3 and 4 analyze existing problems and the ways in which SEFSC in China could be improved, with reference to the PEST analysis. Section 5 presents the conclusions.

2. Current Situation

2.1. Distribution of Scattered Coal

Regarding the currently available data from China's National Bureau of Statistics [33,34], 2014 is the most recent year with detailed statistics in all areas. The direct combustion of coal amounts to approximately 600 million tons per year in China, of which country's residents using this for everyday living represent nearly 310 million tons, while the remainder is used for industrial fuel. Thinking about China's classifications of scattered coal, these mainly include rural life, agricultural production, urban life, commercial and public institutions, small industrial boilers, etc. The first four categories are collectively referred to as civil scattered coal, accounting for more than half of the total amount of scattered coal, which presents a key difficulty for governance [35], and will be discussed in this section. The classifications of scattered coal are shown in Figure 1.

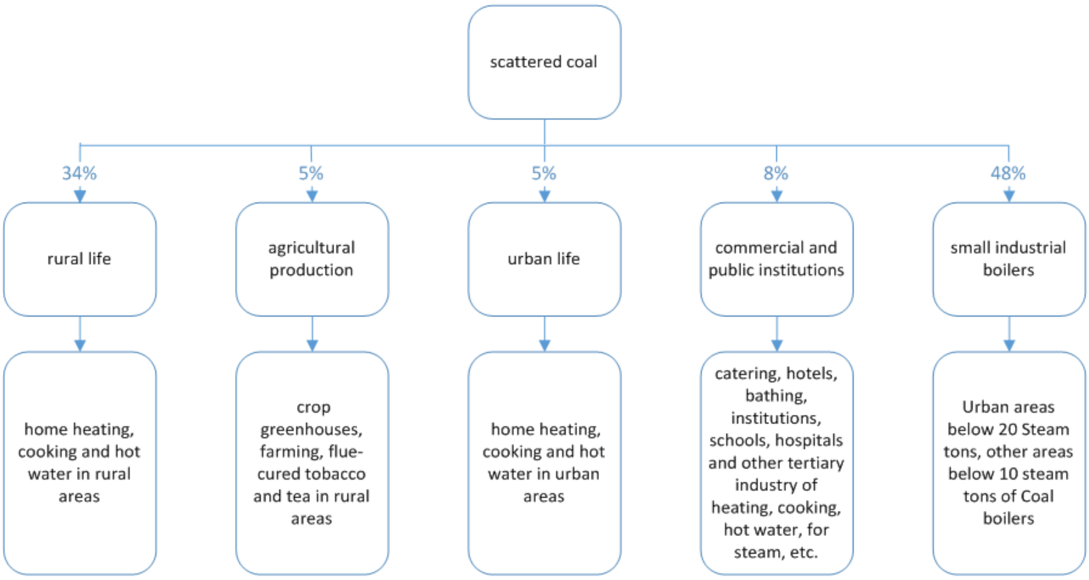

Figure 1. The classifications of scattered coal in China, 2014 (Data source: authors' calculation from Refs. [33,34]).

2.1.1. The Total Amount of Civil Scattered Coal

In terms of regions, North China ranks first in the country for its total amount of civil scattered coal, reaching 81.4 million tons and accounting for 26.1% of the total. Northeast region ranks second in the country, with its quantity of scattered coal reaching 73.6 million tons and accounting for 23.6% of the country's total. Central China and Northwest region are similar, ranking third and fourth at 63.1 and 40.8 million tons, respectively, and accounting for 20.3% and 13.1% of the total. South, East and Southwest regions of China rank last, accounting for 10.7%, 4% and 2.1% of the total, respectively. The total amount of civil scattered coal across China's provinces is shown in Figure 2.

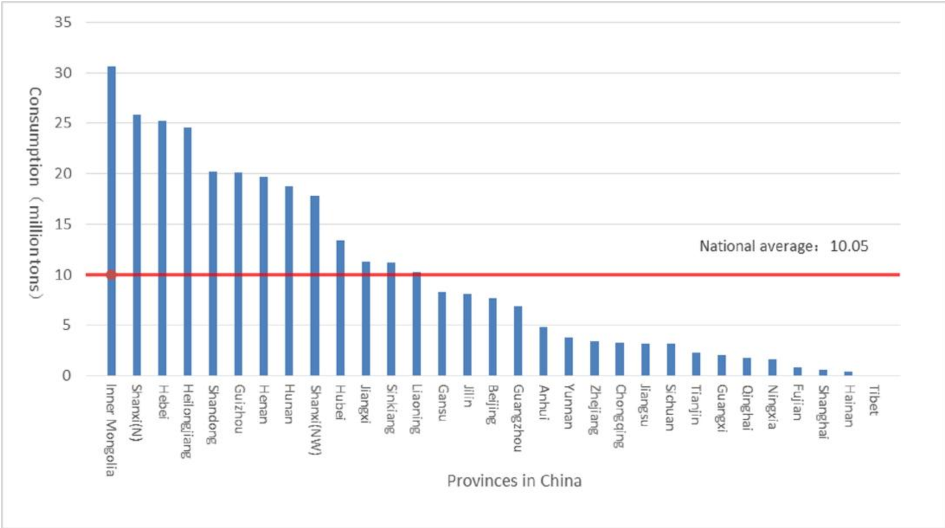

Figure 2. The total amount of civil scattered coal across China's provinces, 2014 (Data source: authors' calculation from Refs. [33,34]).

2.1.2. The Per Capita Distribution of Civil Scattered Coal

As the population of each province varies widely, this section takes the per capita value of every province to compare them. Examining the per capita volume of civil scattered coal across the country's regions, the largest belongs to Northeast China, and the lowest to Southwest and East China. Northeast, Northwest, North China, Central China, South, Southwest and East China have a per capita usage of 0.60, 0.37, 0.35, 0.24, 0.16, 0.05 and 0.05 tons. In the Southern area, the amount of scattered coal is equal for both rural and urban civilians, of which the coal used for rural living coal is the major factor and commercial catering coal is the second. The predominant scattered coal in other regions comes from rural civil sources, and is mainly found in the context of rural life demands. The per capita distribution of civil scattered coal in each province is shown in Figure 3.

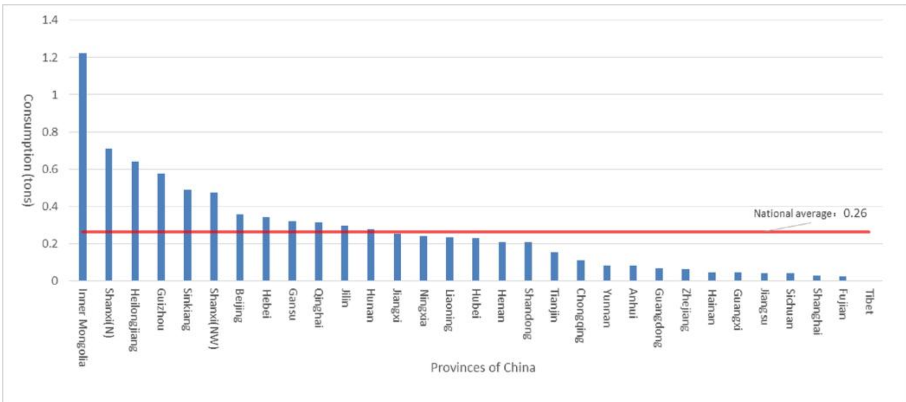

Figure 3. The per capita distribution of civil scattered coal across China's provinces, 2014 (Data source: authors' calculation from Refs. [33,34]).

2.1.3. Spatial and Temporal Distribution of Civil Scattered Coal

In terms of spatial distribution, provinces with a large amount of civil scattered coal are concentrated from the northeast to southwest through the main line of China, with the northeastern provinces generally being larger than the southwest ones. In terms of temporal distribution, the emissions from coal fired during the heating season far exceed those of the non-heating season in northern cities. The surrounding county air quality is generally worse than that in the city centers, with rural areas encircling the city in terms of air pollution. The demand for heating, coal supply capacity, climatic conditions, level of economic development, residents' everyday habits, fuelwood and gas resource endowments, and the population are all important factors affecting China's distribution of civil scattered coal.

2.2. Policy and Potential of SEFSC

2.2.1. Policy Formulation and Implementation

The Chinese government has developed a series of low-carbon development action programs aimed at vigorously reducing scattered coal consumption, which play a role in promoting the country's SEFSC strategy. The relevant policies are shown in Table 1.

Table 1. China's relevant policies of SEFSC (substituting electricity for scattered coal).

Year	Policy Name	Main Content	Reference
2013	The Action Plan for the Control of Air Pollution	Managing small coal-fired boilers with sub-annual task decomposition. Targeting by 2017, the concentration of respirable particulate matter in cities across the country fell by more than 10% from 2012.	[36]
2014	Interim Measures for Alternative Management of Coal Consumption Reduction in Key Areas	Replacing dispersed coal-fired boilers by combined heat and power, aiming to reduce the scattered coal gradually.	[37]
2014	The Treatment Agreement of Clean Coalification	Adhere to the reduction of scattered coal and clean alternative measures to achieve the clean civil scattered coal combustion in Beijing-Tianjin-Hebei areas by the end of 2017.	[38]
2015	Coal Clean and Efficient Use Action Plan (2015–2020)	Increasing the proportion of power coal in coal consumption and reduce amount of the direct dispersion coal gradually.	[39]
2016	Guidance on Advancing Electric Power Substitution	Regarding scattered coal users as the action target. Pointed out that the main application areas are northern residents of heating, manufacturing, transportation, electricity supply and consumption.	[40]
2016	Energy Work Guidance of 2016	Developing electric heating, electric boiler (kiln), electric storage and peaking projects and establishing SEFSC demonstration area to orderly substitute scattered coal.	[41]
2017	Energy Work Guidance of 2017	Promoting electric heating film, heat pump heating and other new models of electric heating to impel the control of scattered coal in Beijing-Tianjin-Hebei, Yangtze River Delta and other regions.	[42]

Thus far, the results of SEFSC have been significant. In 2015, China's coal consumption fell by 1.5% [43], which was the first net decline since 2005. Electricity accounted for the proportion of terminal energy consumption increasing from 10.9% in 2000 to approximately 22% in 2015, with more coal for power generation. The new power of the country's electricity is about 90 billion kWh, of which 90% have come from SEFSC [44]. As can be seen, the government has a firm determination to promote the SEFSC strategy.

2.2.2. Substitution Potential

The Chinese government has prioritized the expansion of renewable power plants as well as the electricity transmission system to connect more remote power sources to population centers [45]. It is estimated that China's SEFSC technology potential is huge, at around 1.8 trillion kWh, which is equivalent to the reduction of approximately 700 million tons of scattered coal theoretically. By 2020, the country is expected to have reduced its amount of scattered coal by 200 million tons through

SEFSC, amounting to 30% less than in 2015. Moreover, by 2030, China is estimated to have reduced a further 470 million tons of scattered coal through SEFSC, representing 70% less than in 2015 [46].

The main technologies behind SEFSC are decentralized electric heating, heat pumps and electric boiler heating, which amount to power potentials of 500, 500 and 300 billion kWh, respectively, accumulating over 70% of the total. In terms of spatial distribution, the power potential of SEFSC is mainly distributed in North China, East China and Northwest region, in which 655.6, 319.7 and 245.2 billion kWh, respectively, account for approximately two-thirds of the country's total, as shown in Figures 4 and 5 [46].

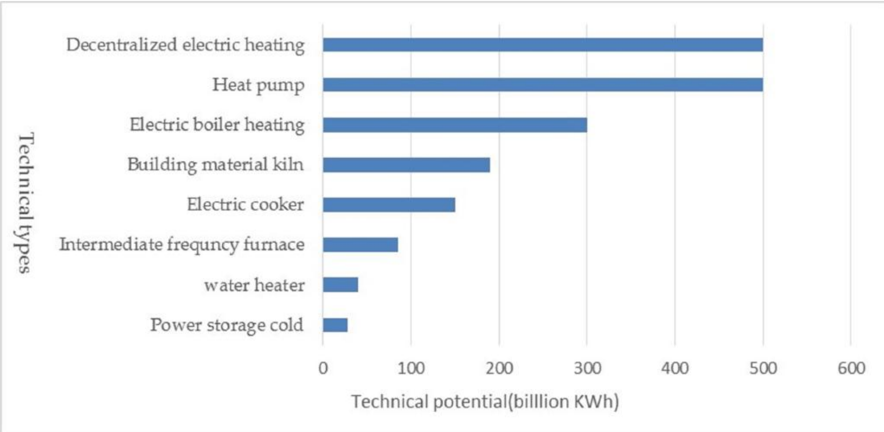

Figure 4. Potential distribution of technical types for SEFSC technologies (Data source: from Ref. [46]).

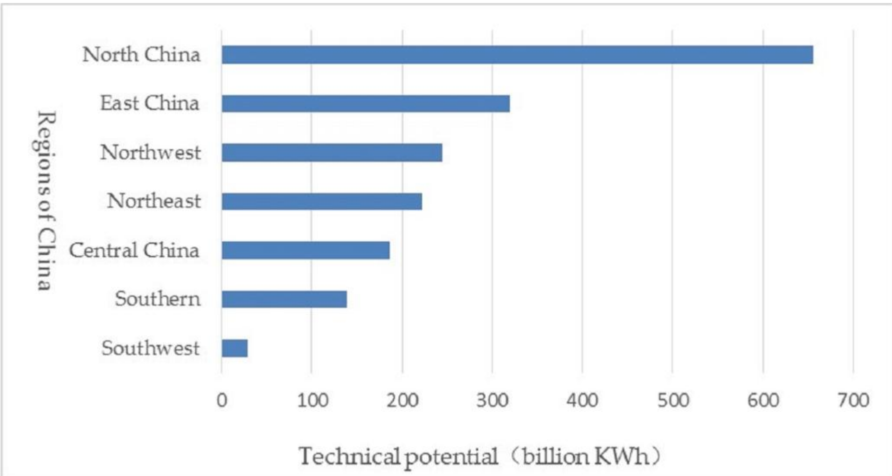

Figure 5. Potential distribution of areas for SEFSC technologies (Data source: from Ref. [46]).

As each region's economic development, industrial structure and environmental requirements vary, there is a diversity in the potential of SEFSC. In the economically developed but badly polluted areas, such as the Beijing-Tianjin-Tangshan, the Pearl River Delta and other southeast coastal areas, where there is an urgency to promote energy saving and emission reduction tasks, the potential for SEFSC can be fully harnessed in various fields. In areas whose industry is more developed but the environment dangerously polluted, such as Liaoning province and other central and western regions, the potential of SEFSC will be mainly reflected in the field of industrial work. In regions whose agriculture is more developed but there is a certain degree of pollution, such as Heilongjiang province, Henan province and other places, the potential of SEFSC will mainly be highlighted in the field of agriculture.

3. Existing Barriers to Substitute Electricity for Scattered Coal in China

3.1. Theoretical Framing Analysis

To analyze the challenges of implementing SEFSC, it is important to understand the external factors. This can be accomplished by performing PEST analysis, which examines the political, economic, social and technical issues that policy makers and developers should address in order to ensure sustainable diffusion [47]. Researchers such as Azzaoui (2013) [48], Chi (2014) [49], Nunes et al. (2015) [50] and Igliński et al. (2016) [51] have used this tool in the field of energy management and the application is remarkable. Based on this theoretical basis, we establish the framework of PEST analysis to analyze how the external factors mutually influence each other, as can be shown in Figure 6.

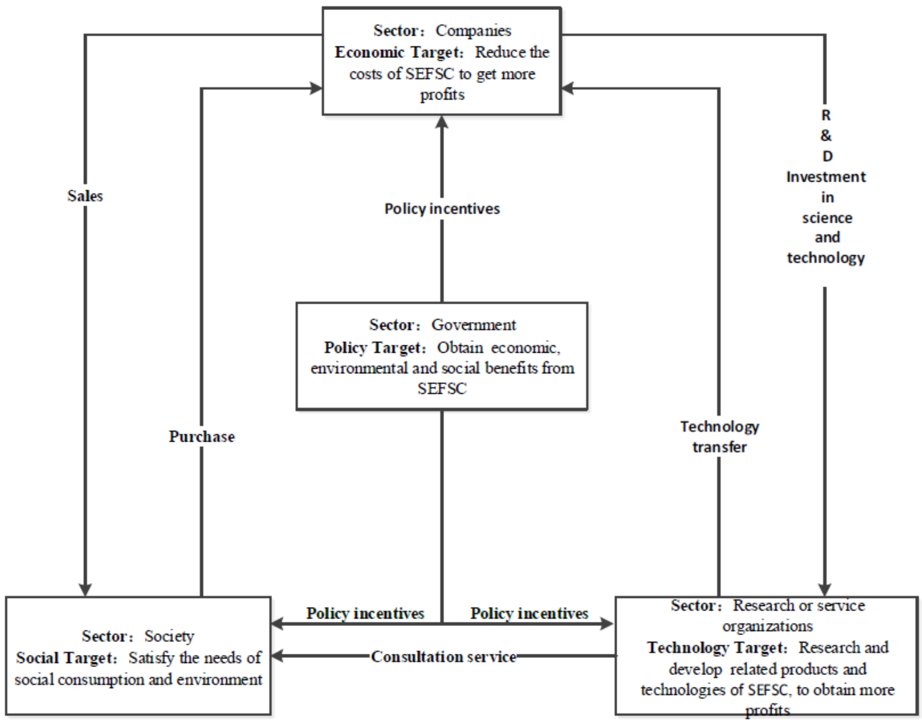

Figure 6. The theoretical framing of PEST (policy, economy, society and technology) analysis in SEFSC strategy.

We use questionnaire method which intends to present investigated factors on a point scale, depending on how much they affect the implementation of SEFSC. Within the used scale, particular points from 1 to 5 are defined as:

- 1: a least influential factor;
- 2: a poorly influential factor;
- 3: a neutral factor;
- 4: an influential factor; and
- 5: a highly influential factor.

It was decided to use the formula of the mean value of selected factors, assuming that the impact on the implementation of is as the following:

- Less than or equal to 2.00 points: a least influential external factor;
- 2.01~3.00 points: a poorly influential external factor;
- 3.01~3.50: a neutral external factor;

- 3.51~4.50: an influential external factor; and
- 4.51~5.00: a highly influential external factor.

The PEST analysis was conducted using the information provided by the sectors of government, companies, technology R&D department related to SEFSC and society (see surveys in Appendix A), literature sources data, and the strategy for the development of SEFSC as well as legal acts and regulations in China. Figure 7 represents the external factors of SEFSC in terms of their influence for implementation.

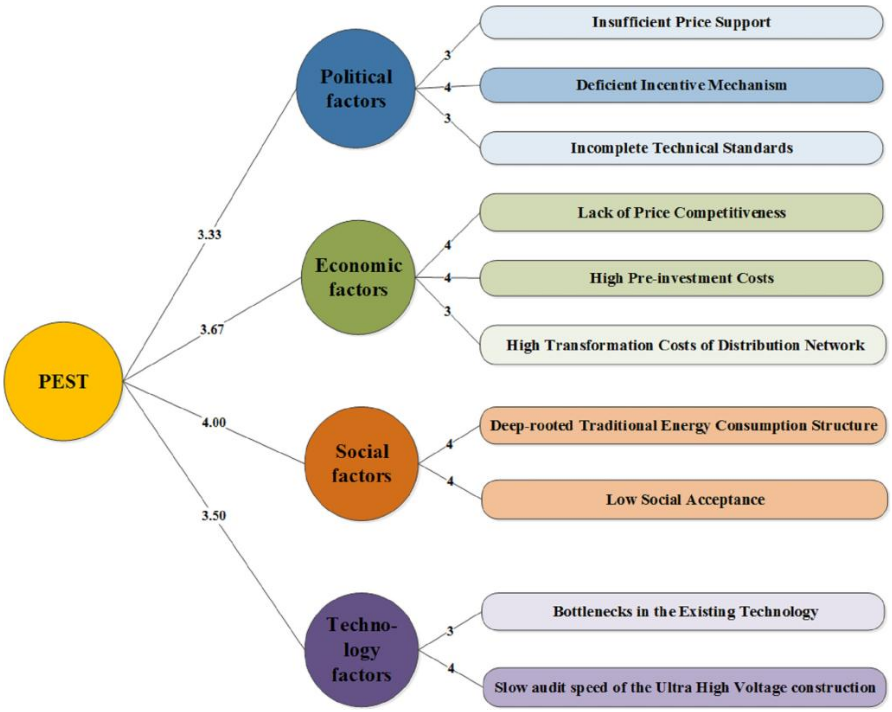

Figure 7. The external factors of SEFSC in terms of their influence on implementation.

3.2. Policy

As China's strategy on SEFSC is still in the early stages, government support for it has been insufficient, thus affecting the market development space.

3.2.1. Insufficient Price Support

The electricity tariff policy which promotes SEFSC is mainly classified into three categories: The first is adopting the peak-valley, time-of-day electricity price policy, which can promote the application of regenerative power equipment in particular. The second is abandoning the ladder price of residential electricity for heating and executing the table price instead. The third is implementing large industrial electricity prices for groundwater source heat pumps, which is powered by an independent transformer with a power capacity above 315 kVA. To date, some areas have introduced this special price policy; however, a clear comparative advantage is still not obvious, resulting in insufficient price support.

3.2.2. Deficient Incentive Mechanism

At present, the government's support for financial subsidies and tax relief policies is lacking. For most SEFSC technologies, there is no operational supporting policy. For example, in the face of a lack of necessary incentives for customers to choose energy saving devices, customers' enthusiasm and initiative for the latter will be reduced [52].

3.2.3. Incomplete Technical Standards

Given the non-uniformed market standards, non-standardized operations, and incomplete technical laws and regulations of SEFSC, there is no scientific basis and means for the Chinese government to assess the scope of SEFSC among enterprises. At the same time, a lack of relevant publicity, poor training and insufficient capacity among technical professionals are also not conducive to market development. Therefore, it is necessary to introduce more stringent restrictions or prohibitions to ensure that scattered coal is effectively reduced.

3.3. Economy

SEFSC can broadly be divided into the residential field and industrial field, which vary significantly in terms of their costs of the use of electricity, natural gas and coal. These differences are shown in Tables 2 and 3.

Table 2. Economic comparison of residential field (Data source: from Ref. [14]).

Equipment	Heating Cable	Carbon Crystal	Air Source Heat Pump	Regenerative Heater	Wall-Mounted Gas Furnace	Coal-Fired Heating Stove
Energy type	electricity	electricity	electricity	low electricity	natural gas	coal
Operating costs per year (Yuan/m^2)	25.1–34.3	16.4–22.4	8.2–11.2	14.4–19.2	low price areas: 12.7–21.2; high price areas: 23.3–41.3	11.0–22.0
Investment costs per year (Yuan/m^2)	2.2	6.5	11.0	7.3	5.5	1.6
Life cycle costs (Yuan/m^2)	27.3–36.5	22.9–28.9	19.2–22.2	21.7–26.5	low price areas: 18.2–26.7; high price areas: 28.8–46.8	12.6–23.6

Table 3. Economic comparison of industrial field (Data source: from Ref. [14]).

Equipment	Regenerative Electric Boiler	Ground Source Heat Pump	Gas Boiler	Coal-Fired Boiler
Energy type	low electricity	electricity	natural gas	coal
Operating costs per year (Yuan/m^2)	18.9–25.2	25.6–33.2	low price areas: 18.7–30.8; high price areas: 33.0–52.8	6.5–12.9
Investment costs per year (Yuan/m^2)	18.1	36.2	14.1	14.1
Life cycle costs (Yuan/m^2)	37.3–43.3	61.8–69.4	low price areas: 32.8–44.9; high price areas: 47.1–66.9	20.6–27.0

From a cost point of view, obstacles to the implementation of SEFSC mainly exist in terms of the following aspects: a lack of price competitiveness, high pre-investment costs and high transformation costs of the distribution network. These will now be discussed in further detail.

3.3.1. Lack of Price Competitiveness

The price of various terminal energy products is the primary consideration when users make energy choices [53]. On the one hand, because the current energy price mechanism in China does not contain environmental costs and results in price distortions, traditional energy prices seriously deviate from their true value, making it difficult for the market itself to play the role of allocating resources.

Thus, electricity presents no comparative advantage over coal [54]. On the other hand, natural gas has the same strength of convenience, cleanness and environmental protection as electricity. In China's northwest, southwest and other low gas price areas, natural gas price has a comparative advantage and thus engenders a broad market development space. Compared with coal and natural gas, electricity has insufficient price competitiveness, which hinders the rapid implementation of SEFSC.

3.3.2. High Pre-Investment Costs

Compared to coal, electricity not only has the need for large-scale investment in fixed assets, but also requires the payment of higher annual costs, exerting more economic pressure on the user and having only short-term economic benefits. At present, SEFSC has to rely on the subsidy policy for its implementation, lacking a long-term return on investment mechanism, which has become the bottleneck that restricts the development of SEFSC. How to use the market mechanism to reduce costs and normalize SEFSC is thus a key current dilemma.

3.3.3. High Transformation Costs of Distribution Network

With the rapid development of China's urban and rural economy, the electric load continues to grow, and the function and form of the electricity distribution network—which directly faces the end customers—are changing significantly. At present, the overall automation level of distribution in China is relatively low, the size of the distribution network is too large, and the required financial needs and technical support are high, thus making it difficult to complete the automation construction of an entire power network in the short term. With the requirements of supply security, reliability and adaptability of power supply becoming higher, more arduous efforts have to be made in constructing the distribution network, especially the rural power network.

3.4. Society

3.4.1. Deep-Rooted Traditional Energy Consumption Structure

From a macro level perspective, coal-based energy consumption has been a long-term issue in China, which is gradually developing according to national resource endowments and the needs of industrialization. Conversely, given the high cost of conventional fossil fuels, the technical lock will make it difficult to achieve a technical breakthrough of SEFSC in the short term, with the absence of scientific policy incentives and adequate supporting funds. In general, the country's dependence on traditional fossil fuels is still quite prominent at this stage.

3.4.2. Low Social Acceptance

From a micro level perspective, the market is influenced by the longtime spending habits of consumers. Users who live in economically undeveloped and information lagging areas are limited in terms of their access to information on SEFSC. Another concerns is that the inherent use of fossil fuels has given consumers a certain degree of dependence on them, whereby they pay more attention to economic benefits rather than environmental benefits, ultimately making it difficult to switch their choice of energy.

3.5. Technology

3.5.1. Bottlenecks in Existing Technology

Technology is the basis for effectively carrying out SEFSC, and the potential for an alternative to scattered coal is based on the development of electrical equipment and technology. The main technology behind SEFSC, such as decentralized heating, heat pumps, electric storage systems and electric kilns has made great progress. However, there are still some technical bottlenecks hindering the implementation of SEFSC. The advantages and disadvantages of the related technology are presented in Table 4.

From this, it can be seen that the afore-mentioned technical equipment has the advantages of high efficiency, energy saving and environmental protection. With the continuous progress of technology, their disadvantages will arguably gradually be compensated for, and the promotional scope of SEFSC expanded.

Table 4. Analysis on the advantages and disadvantages of SEFSC main technologies in China (Source: Ref.'[14]).

Technology	Advantages	Disadvantages	Scope of Application
electro thermal film	(1) Partitioned, time-sharing and temperature control; (2) long use time; (3) areas saving; (4) water saving, maintenance-free	Need electricity capacity, the region where the power should be more abundant	New buildings, laying on the roof or wall of the room
heating cable			New buildings, floor radiant heating
carbon crystal plate			New or renovation of buildings or tall space buildings
air source heat pump	(1) High efficiency of energy saving;(2) renewable recycling; (3) areas saving; (4) multi-usage	Performance attenuation in the case of low temperature, so in cold areas where under low temperature conditions, should be accompanied by electric auxiliary heat source	South of the Yangtze River
ground source heat pump		The heat exchange area is large	Larger open space for new buildings
water source heat pump		Water availability is limited	Building close to the city water trunk
electric thermal storage system	(1) High degree of automation, reliable operation; (2) realizing the mechanical and electrical integration; (3) using the valley electric heat storage, having strong economy; (4)balance of power load	(1) In the case of existing transformer load is full and needs to increase the capacity, distribution investment will increase; (2) difficult to produce high-quality steam to meet production needs	In the areas of where there is heat load demand in night and uses valley price
electric skin	(1) Furnace temperature uniformity, automatic temperature control; (2) temperature is easy to control	(1) Temperature can only reach about 1200 °C, so the product types are limited; (2) Sintering cross-section is narrow, which is difficult to burn large-size cross-section products	Ceramics, cement, glass industry

3.5.2. Slow Audit Speed of Ultra High Voltage Construction

As the supporting system of SEFSC, Ultra High Voltage (UHV) construction is desiderated to speed As can be seen in Table 5, There are more than 1/3 provinces throughout all regions of China facing lack of electricity except the Northwest. Therefore, the Chinese government has prioritized the connection of the UHV transmission system with more remote power sources to the economic centers [45]. This was proposed in 2013 and is still in the initial stages owing to the country's slow audit speed [55], which has become a potential obstacle to the implementation of SEFSC. Furthermore, because of serious historical reasons, a lack of capacity in the power supply has occurred in some area. In this case, strengthening the construction of the energy distribution network has become an urgent demand.

In addition, with the continuous improvement of technology and the rapid development of renewable energy, there have emerged new, alternative technologies, such as the direct thermal utilization of solar energy and geothermal energy, which will have a strong impact on the market share of electricity and, to some extent, create a challenge for the large-scale promotion of SEFSC. However, although competing with SEFSC, these renewable energy technologies still play an active role in coal substitution and energy structural adjustment.

Table 5. The status of electricity supply and demand by provinces in China, 2015 (Data source: authors' calculation from Ref. [56]).

Region	Supply–Demand Difference (billion KWh)	Provinces Where Demand Exceeds Supply (13)	Provinces Where Demand and Supply Are Roughly in Balance (7)	Provinces in Which Supply Exceeds Demand (11)
East China	−143.87	Jiangsu, Zhejiang, Shanghai	Fujian	Anhui
North China	−110.78	Hebei, Shandong, Beijing, Tianjin	-	Shanxi (N)
Central China	18.23	Henan, Hunan, Jiangxi	-	Hubei
South region	43.39	Guangdong	Guangxi, Hainan	Guizhou, Yunnan
Southwest region	96.39	Chongqing	Tibet	Sichuan
Northwest region	104.71	-	Qinghai	Shanxi (NW), Sinkiang, Ningxia, Gansu
Northeast region	115.01	Liaoning	Jilin, Heilongjiang	Inner Mongolia

4. Improvement Schemes for Substituting Electricity for Scattered Coal in China

In terms of the efficient promoting of SEFSC strategy, China requires sound institutional arrangements. This paper builds a policy framework to accelerate SEFSC development, as can be shown in Figure 8.

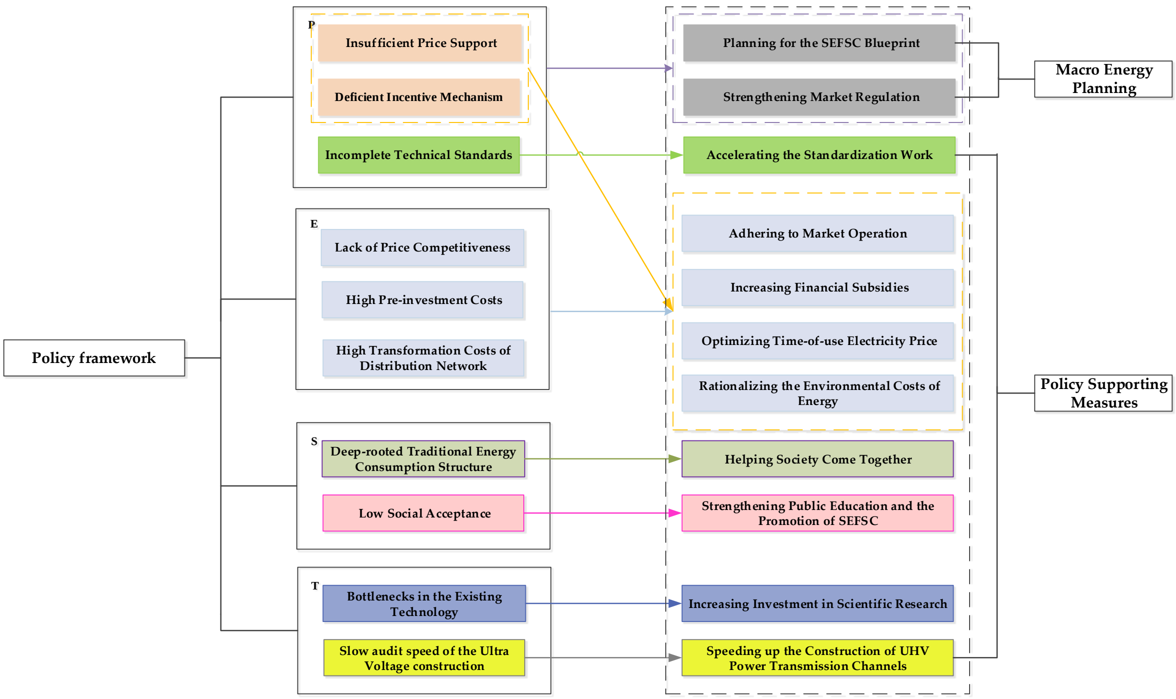

Figure 8. Institutional arrangement for SEFSC development.

4.1. Improvement of Externality Effects

4.1.1. Planning for the SEFSC Blueprint

A long-term step-by-step plan should be implemented. The proportion of power generating coal in China accounts for about 51% of the total coal, which is far from the proportion of the United States (93%), the EU (82%) and world average (78%) [57]. From this, it can be argued that more scattered coal should be transformed into power-generating coal at a macro policy level [58]. Next, further study of the connection between the terms of the One Belt One Road, air pollution control, global energy interconnection, the level of electrification and SEFSC, would arguably bring SEFSC strategy to the forefront of local development planning in accordance with the actual situation on the ground. Both the objectives of SEFSC and the central and local governments' responsibilities toward fulfilling them should be clearly spelled out. Thirdly, completing the qualitative and quantitative targets of SEFSC is crucial, as this would contribute to the rolling adjustment and regular release mechanisms of planning policy.

4.1.2. Strengthening Market Regulation

There are many participants in SEFSC, including buyers and sellers, third party service enterprises, rule makers, regulators, etc. It is thus necessary to regulate theses take holders' behavior and strengthen market supervision in order to prevent market manipulation, illegal transactions and other acts. The regulating body should form a strong department that fulfills the responsibility of imposing severe penalties on those not meeting their SEFSC quota obligations. In this way, the healthy and sustainable development of SEFSC in China could be ensured.

4.1.3. Accelerating Standardization Work

Most SEFSC technologies are emerging products still in the initial stages of development, resulting in non-unified market standards and non-standardized operation and leading to the exclusion and resentment of costumers. As a solution, new technical standards that have been introduced can be promoted within the grid company first and evaluated for their implementation to enable continuous improvements to take place. Filling in the gaps of those technical standards, which are still blank, is necessary in order to support SEFSC.

Every province in China could introduce the implementation of the SEFSC program's details and annual plans in accordance with the $PM_{2.5}$ annual average target decline in the Air Pollution Control Objectives Responsibility, thus breaking down this task by city, county and relevant department. Provinces that have not yet introduced the target of a coal reduction policy can draw lessons from other provinces such as Beijing, Tianjin, Hebei and Shandong. This target could then be introduced according to the results of the simultaneous precipitation scenario.

4.2. Reduction of Use Cost

4.2.1. Adhering to Market Operation

For the market to play a more decisive role of in resource allocation, a recommendation would be the encouragement of social capital investment, innovating on current business models and exploring the all-win, market-oriented project operation mode. For this to happen, manufacturers should first establish alliances to coordinate their efforts in the way of Energy Performance Contracting (EPC) to promote SEFSC. Secondly, energy-saving environmental protection investment and financing systems should be deeply reformed, encouraging private capital, social capital and other financing channels to enter the field of air pollution control. Finally, de-controlled competitive electricity pricing outside transportation and distribution could form the basis of China's reformed power system and power market to reduce the electricity costs for SEFSC users further.

4.2.2. Increasing Financial Subsidies

The electricity price subsidy is a short-term and immediate measure for increasing the economic benefits and social acceptance of SEFSC [56]. To strengthen financial support for this and a preferential tax policy, governments at all levels should make full use of the relevant environmental protection, air pollution control, demand side management and other special funds policies to support key projects, thereby decreasing the initial investment and operating costs. Furthermore, encouraging SEFSC projects to implement a separate measurement and execute a direct purchase price would arguably be beneficial for industrial boilers and kilns, which have broad prospects but poor economy.

4.2.3. Optimizing the Time-of-Use Electricity Price

Currently, China's time-of-use tariff policy is mainly implemented in industrial and commercial sectors, especially among large industrial users, but arguably needs to be implemented on a wider scale. In addition, the time-sharing price ratio should be adjusted based on the actual load needs of residents, expanding the price spread to the full competitive price at the lower limit, so as to fully mobilize the enthusiasm of electricity users to pinch the valley. This would then enable greater leverage in peak and valley electricity prices and improve energy competitiveness. The time division of the electricity price should also be more sophisticated in those areas where the load is high and the supply of electricity is tight in summer; in these cases, we would recommend the introduction of peak electricity price policy to achieve the aim of a more accurate peak load [59].

4.2.4. Rationalizing the Environmental Costs of Energy

China's current pricing system does not reflect the environmental costs of energy, meaning that, likewise, the comprehensive benefits of clean energy cannot be reflected properly either. It is suggested that the government internalize the external environmental damage costs by applying reasonable environmental taxes and fees for coal production and consumption to realize the adjustment and optimization of the energy structure [60]. Once the environmental costs are taken into account, it can be argued that the social benefits of electricity will be significantly enhanced. According to China's total terminal energy pollution emissions and environmental value, the environmental costs of coal, natural gas and electricity that produce 1 kWh of electricity are 0.037, 0.001 and 0 Yuan, respectively [61]. If coal ceases to be a cheap source of energy through carbon pricing or other policies, fuel substitution from coal to electricity could become an inevitable reality.

From this perspective, economic policy can be seen as a common tool used by the government in guiding the ways in which residents use energy. In China, residents' energy consumption behavior has changed in the direction of saving energy, improving energy efficiency, and using clean energy under the impetus of government policies such as subsidies, tax relief, price increases, energy tax and others. Among them, tax incentives and subsidies are part of the positive incentive policy, Enabling cost savings to stimulate residents to carry out energy-saving investment and energy-saving activities. Conversely, raising energy prices and levying an energy tax is a reverse incentive policy, designed to increase the cost of energy consumption to limit residents' energy demands [62,63].

4.3. Social Responsibility

4.3.1. Helping Society Come Together

In the fight for clean energy and a cleaner environment, it is essential to establish a whole society mechanism of air pollution control. In China, the public typically regards environmental protection as a government responsibility, government often attributes environmental problems to enterprises, and enterprises believe that local government should be responsible. Thus, a main body of responsibility is absent when real environmental issues arise and society's stakeholders effectively "pass the buck", so to speak [64]. In contrast to this, it can be argued that environmental protection is the common responsibility of the public, and each society part's subject should be made clear about its legal responsibility. This requires joint efforts between governments, professional energy services companies, suppliers, financial institutions and research institutes, in order to harness the combined force of the whole society.

4.3.2. Strengthening Public Education and the Promotion of SEFSC

Due to the external nature of energy products, information asymmetry and the uncertainty of future events generally induces the public to lack the initiative to participate in the work of SEFSC. Thus, it is necessary to strengthen promotional campaigns and education regarding this matter aimed at the public, alongside the implementation of demonstrable pilot projects. As for the acceptance of

SEFSC policy, which involves energy conservation and environmental protection, it is arguably more sustainable to aim for this via educational rather than economic means [65]. The role of promotion and education can be bolstered by providing more public information and knowledge directly related to residents' energy consumption [65–67].

4.4. Strengthening Technology Research and Development

4.4.1. Increasing Investment in Scientific Research

Earlier studies indicate that technology advancement might be a more effective way to conserve energy than increasing fuel prices alone [26]. Therefore, we recommend that the Chinese government open up the technology frontier and increase the collection and analysis of market information, as well as increase research and development efforts, and study various fields that can provide benchmarks and suggested standards as to the optimum designs by which to implement SEFSC. Key technology efforts could be concentrated on improving the energy efficiency of SEFSC products, which would then reduce the cost of purchasing equipment. At the same time, improving the capacity of the power grid to access large scale loads would be crucial to ensuring the implementation of SEFSC, by way of strengthening the distribution network planning and protecting the power supply [68].

4.4.2. Speeding up the Construction of UHV Power Transmission Channels

The distribution of coal resources (such as Northwest and Northeast regions) in China does not match energy demand in consumption-intensive regions (such as East and North China). The UHV system could be a solution to this, as it could replace coal transportation with the transportation of electricity, which could then be used to optimize the energy structure and improve environmental quality [69]. Therefore, through the construction of UHV transmission channels and supporting power supply facilities, cheap power from China's Northwest and Northeast regions could be transmitted to East and North China where the economy is developed but the environment is massively polluted. It would thus be reasonable for East and North China to replace scattered coal with the transmitted electricity, as this would then meet their demand for electricity [70]. At the same time, the resource advantages of the Northwest and Northeast regions could be transformed into economic advantages by expanding the power delivery markets, the latter action would, moreover, be conducive to the development of China's regional economy in general.

To sum up, the effect of administrative instruments is immediate due to their enforceability, however, the government should promote the introduction of these laws, as well as be responsible for their legal enforcement. The information tool for society is shown to be effective, but its impact takes longer to become evident. While economic means can act as a catalyst for change, they ultimately meet the same fate as information policy; namely, over the course of time, there emerges the need for continuous updates to raise concerns. Technological improvement can ultimately be achieved through the improvement of energy efficiency in energy equipment and buildings themselves, the effect of which will be significant if these changes are aligned with punitive tools implemented to enforce them [71].

5. Conclusions

In conducting the research and analysis for this paper, the following conclusions have been reached.

1. Through the analysis of the distribution of scattered coal in China and the current situation pertaining to SEFSC, it can be seen that provinces with a large amount of civil scattered coal are concentrated in the northern region of China, and that the use of scattered coal is mainly during the heating season. The Chinese government has formulated a series of policies to reduce the consumption of scattered coal, the results of which have been significant and have demonstrated the positive substitution potential of SEFSC in the future.

2. This paper used the PEST analysis to analyze existing problems in the implementation of SEFSC in China. In terms of policy, which can be categorized as a relatively neutral factor (3.33 points), the problem lies mainly in the lack of perfect policy guarantees. In terms of the economy, which can be considered an influential factor (3.67 points), the lack of price advantages, high initial investment costs and the costs associated with the necessary capacity expansion of the energy distribution network, hinder the further development of SEFSC. At the social level, where can be classed as quite influential factors (4.00 factors), the public perception of the traditional energy structure being dominated by coal is deep-rooted, while the social recognition of the potential for SEFSC is low, and thus limiting the implementation of SEFSC. From the point of view of technology, which can be considered neural (3.50 points), the existing technology bottlenecks and slow audit speed of UHV construction have engendered large-scale obstacles to the promotion of SEFSC.
3. This paper proposes several schemes to improve the implementation of SEFSC in China, from the perspectives of policy, economy, society and technology. The first is to formulate macro energy planning and strengthen market regulation to improve the externality effects relating to energy prices and incentives. Secondly, adhering to market operations, increasing financial subsidies and optimizing the time-of-use electricity prices would be key methods for reducing the use costs of SEFSC. Thirdly, it is recommended that the government promote SEFSC as part of everyone's social responsibility, introducing environmental protection policies and rationalizing/clearly explaining the environmental costs of energy. Finally, through increasing investment in scientific research, accelerating construction of UHV and unifying technical standards, there would emerge strong technical support for the implementation of SEFSC.

In conclusion, utilizing electricity to speed up the replacement of scattered coal in China can be seen as the only way to ease national pressure on China's energy and environment. Although there may be some challenges and bottlenecks in the future, they are not insurmountable and SEFSC holds very promising prospects for development.

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Appendix A

Appendix A.1. Government Sector-Surveys

Government staff working on energy policy research responded to the questionnaire. The government has issued a number of policies to promote the implementation of SEFSC, a good macroeconomic policy environment formed gradually. Among the investigators, the personnel are distributed as follows:

- National Energy Board: 10% of survey participants;
- National Development and Reform Commission: 10% of survey participants;
- Local energy management agency: 25% of survey participants;
- Environmental Protection agency: 30% of survey participants; and
- Coal Industry Administration: 25% of survey participants.

Relevant government personnel were investigated; the research is mainly for tariff policy, supporting financial subsidies, tax policy, and market management standards of SEFSC. The main problems of the implementation of SEFSC are:

- Lack of enough policy support, price advantage is not obvious;

- Weak in supporting financial subsidies and tax relief policy;
- Difficulties guiding customers to use energy-saving environmental protection equipment;
- Lack of scientific basis for the identification and assessment of coal to electricity generation; and
- Insufficient technical expertise.

The survey research showed that 75% of participants reflect the difficulty and urgency of the implementation of electricity price support, and 80% of participants reflect the importance of financial subsidies and tax relief policy on SEFSC. The government is gradually formulating relevant incentives. Meanwhile, it can be seen from the opinion of the investigators that the harmonization of technical standards is a strong guarantee for the effective reduction of the scattered coal.

Appendix A.2. Company Sector-Surveys

A thorough investigation of enterprises related to the implementation of SEFSC to reflect the economic problems was performed. Among the investigators, the personnel are distributed as follows:

- State Grid Corporation: 20% of survey participants;
- Professional energy services company: 25% of survey participants;
- Financial Institutions: 15% of survey participants; and
- SEFSC production enterprises: 40% of survey participants.

Compared to coal and natural gas, electricity has insufficient competitiveness for its deficiency in price advantage, which hinders the rapid implementation of SEFSC. The main obstacles that related enterprises facing are:

- Ignore environmental costs;
- Competition from natural gas price;
- Too high investment costs; and
- Difficult construction and transformation task of the distribution network.

The survey research showed that how to use the market mechanism to reduce the project construction costs and transformation costs is the current dilemma for the implementation of SEFSC.

Appendix A.3. Society Sector-Surveys

People who responded to the survey were mostly energy research experts, economists, sociologists, etc. Experts and scholars said that, at this stage of China, traditional fossil energy path dependence is still quite prominent, which is not conducive to improving the level of SEFSC technology. In addition, consumer spending habits of fossil fuels is difficult to change in the short term, especially in the economically underdeveloped areas.

Eighty-five percent of the respondents believe that the establishment of universal environmental protection responsibility, which takes environmental protection costs into account in the current price system, will effectively adjust the rationality of coal production and consumption.

Appendix A.4. Research and Service Institution-Surveys

Technology is the basis for the development of electricity generation, and the potential of mining is based on the development of electric equipment and technology. Most of the technical research objects are experts in electrical equipment technology, among them:

- Experts in decentralized heating: 30% of survey participants;
- Experts in heat pump: 25% of survey participants;
- Experts in electric storage system: 25% of survey participants; and
- Experts in electric kiln: 20% of survey participants.

According to the experts' feedback and opinions, SEFSC technology needs to overcome the existing technical bottlenecks in the development, along with the construction of electricity transmission system, which is the supporting system for the generation of electricity.

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