Sustainable Development of Smart Power Industry: Multi-level framework based on big data technology

Yanli Zhang[1], Zhuyun Yang[2], Huimin Zhu[2], Qi Lu[3], Xingqun Xue[4*]

[1] Panjin Institute of Industrial Technology, Dalian University of Technology, China

[2]Department of Economics, School of Business, Dalian University of Technology, China

[3]Dandong Dong Fang Measurement and Control Technology Co. Ltd., China

[4] Department of International Economics and Trade, School of Economics and Management, Dalian University, China

*Corresponding Author: xuexingqun@dlu.edu.cn

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ABSTRACT

This article integrates the traditional electric power business with smart surroundings, drawing on a survey of prior academics' research on smart grids to identify 15 elements that impact the sustainable growth of smart grids. With the Fuzzy-Dematel method, this investigation classifies the factors impacting the sustainable development of smart grid in the big data environment based on three frameworks, namely, smart society, smart economy, as well as smart environment, and eventually utilizes ISM theory to build a multi-level framework impacting the smart power industry development and establishes a system for the sustainable development of the smart grids. This article finds that power demand side management, smart microgrid systems, and smart low-carbon power are critical components for the sustainability of smart grids in the big data technology environment. The theoretical contribution of this investigation is considering the impact of the economy, society, and environment to establish a sustainable development framework for smart grid.

Keywords: Smart grid, Big data technology, Fuzzy-Dematel, ISM, Sustainable development.

1. Introduction

Power infrastructure has remained unchanged for more than 100 years, and the service life of hierarchical networks is almost completed, but the demand is gradually increasing. The current power network is complexly distributed, which is unsuited to the demand for electricity of the 21st century [1]. With the rise of population, the increase of energy demand, the change of global climate, aging equipment, the problem of energy storage, the shortage of fossil energy, and the capacity constraints on power supply [2], the greenhouse gas effect caused by the power sector and industry has become a significant problem [3]. The two major challenges of fossil energy exhaustion and environmental degradation are becoming more and more serious. With the rising electricity demand, the United States, the European Union, China, Japan, Canada, South Korea, Australia, and other countries have launched research into smart grid applications and technologies [1]. The goals of the

US government's energy policy are the security of energy supply, the sustainable low cost of energy, reduction of consumption by improving energy efficiency, the development of new energy, especially renewable energy and renewable fuels to protect the environment [4]. The EU has set a goal of 30% renewable energy in energy in 2030, with a 40% reduction in greenhouse gas emissions compared to 1990[5]. Smart grid development has emerged as a major national science and technology initiative in China and is outlined in the ‘12th Five-Year Plan’ of the Chinese government. Increased attention has been given by China towards the development and emergency response of smart grids. [6].

Smart grid (SG), for which there is no uniform definition, can store energy, facilitate communication with users, and utilize detection data to make decisions compared with traditional grids. The SG, according to the ‘National Institute of Standards and Technology’, is a grid system that combines digital and communication technologies with the power system's infrastructure. The detection of user power data, power supply, power transmission efficiency as well as stability, and cleanliness; all depend on SG. Smart grids are self-healing and hence enhance fault detection through data monitoring. Smart grid provides solutions for technological sustainability, like distributed power production and micro-grid [6]. In comparison to conventional grids, smart grid involves more power data [7]. Besides, the smart grid is equipped with more sensors and detection devices [8-9], which are analyzed by the data obtained from sensors and detection equipment [10].

Ths study aims to enhance the efficiency of smart grid energy usage and power demand user management by utilizing big data and smart grids together. This will help with smart power dispatching and power maintenance. At present, in the research on smart grids, some scholars have taken a distributed energy supply perspective on the process of integrating distributed renewable energy into the energy supply system is the most important challenge in energy informatics[11]. Renewable energy is a promising technology to reduce fossil fuel consumption and lower greenhouse gas emissions [12]. A few researchers approached this from the standpoint of communication technology, noting that communication technology has become an essential component of the smart grid and that it can be employed for intelligent detection and control. [13], [14]. Advanced measurement infrastructure (AMI) is a tool that power companies can use to connect equipment throughout the whole power grid, hence collecting consumer data more promptly, and providing electricity customers, with a structured communication network. [15]. Some scholars studied power demand side management (DSM): power companies tried to attract consumers’ attention to participate in the smart grid to improve service and efficiency [1]. Dynamic pricing of electricity at the demand side of electricity users converts fossil fuel generation into renewable energy generation (RERs) [16].

This paper finds the following shortcomings in the research on the sustainable development of smart grids: firstly, the existing research on smart grids is carried out from the aspects of power supply, transmission, and power demand, which lacks the perspective of sustainability and does not consider its impact on economy, society, and environment; secondly, the research on the smart grid has placed too much emphasis on the development of intelligent technology, without integrating smart technology with economy, society and environment. In addition, the existing scholars rarely study smart grid from the perspective of big data. In the end, the present study lacks a systematic framework for the sustainable development of SG, thus the practice of SG lacks theoretical framework guidance. In this paper, Fuzzy-Dematel method is applied for dividing the factors that impact the sustainable development of SG in big data environment by these three frameworks, namely, smart society, smart economy as well as smart environment. After that, ISM theory is applied to establish a multi-level framework affecting the development of smart power industry, and a systematic system for sustainable development of SG. Conclusively, based on stakeholder theory, sustainable application systems for SGs have been developed to provide theoretical support to the key players in smart grids.

This paper establishes a systematic system for the sustainable development of SG and divides these influencing factors into five different important levels. The sustainable development of solar energy in the context of big data technology is shown to be significantly influenced by power demand side management, smart microgrid systems, and smart low carbon power. SG companiesSG companiesSG companies can apply big data technology can apply big data technology can apply big data technology to improve the interaction between SG and power users and optimize the development of smart power dispatching and smart micro-grid systems. Also, smart grid enterprises can use block chain technology to make the current grid data public and transparent to reduce the information asymmetry among power users, and then effectively manage the power demand side. Finally, according to the stakeholder theory, application systems for the sustainability of SG is developed to provide theoretical support for the main participants of the smart grid. The sustainable development of SG requires the cooperation between government, smart grid enterprises, and users. A's smart social environment is a precondition for the SG's sustainable development. The government policy on the grid industry and the environment can be used as a guide for the development of SG. The government can formulate effective environmental policies based on its public data to promote the sustainable development of SG.

2. Literature Review

2.1 Riple Bottom Line and Big Data

The triple bottom line theory includes three dimensions: traditional methods to evaluate the company's earnings, corporate environmental responsibility, and corporate social responsibility. [17, 18, 19]. The current evaluation of a large-scale investment in science and technology through utility. The triple bottom line theory should be used to estimate the investment in a smart grid or smart city in terms of economic, social, and environmental benefits. Much of the triple bottom line theory concentrates on aspects of society, and the environment together with the economy, and innovative services (cloud computing, big data) that will drive the competitiveness and sustainable development of large enterprises [21]. Big data technology has extraordinary significance for the technical, social, and economic benefits of power grids in many ways [22]. This paper will discuss the multi-layer framework of smart grid sustainable development based on big data. Besides, utilizing the triple bottom line theory, it classifies the sustainability of the intelligent power sector into these three dimensions, including intelligent economy, intelligent society as well as intelligent environment. As shown in figure 1.

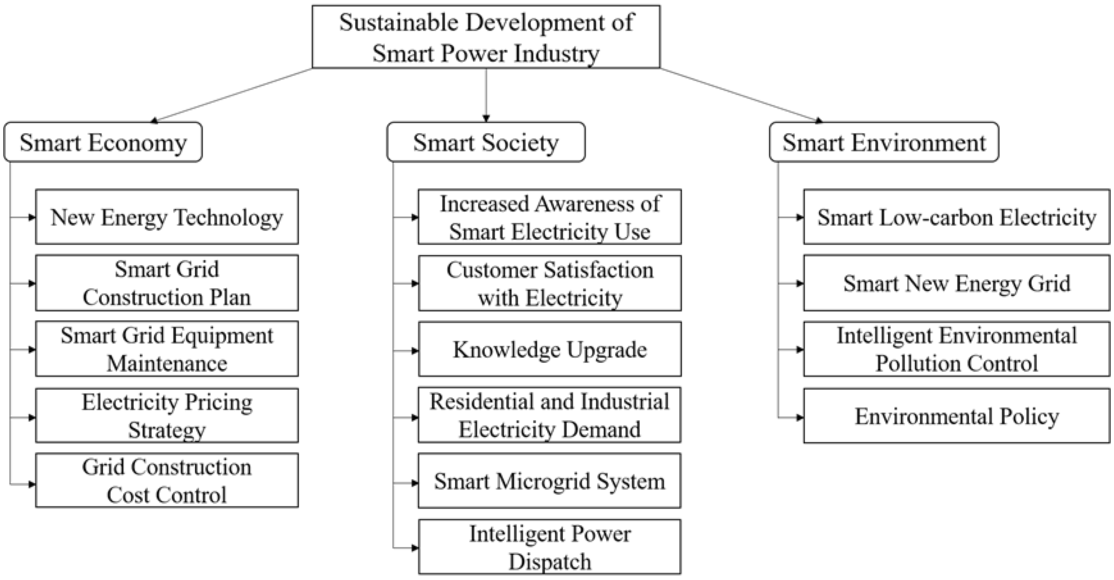

Figure 1. Structure of sustainable development factors in the smart power sector

Table 1. Explanation of sustainable development factors of the smart power industry

Index selection		Explanation
C1	New energy technology power generation (REMs)	Look for new and renewable energy generation to lower the marginal generation costs of the smart power sector.
C2	Smart grid construction location	Find the optimal location for smart grid construction, realize the intelligence of the entire grid in operation control, management and maintenance, and fulfill the optimal allocation of power resources.
C3	Smart grid equipment maintenance	Smart grids can reduce maintenance costs and improve operational efficiency by monitoring, analyzing, responding to and even recovering from abnormal operation of power progeny or local networks, utilize big data technology to assess potential problems and risks of equipment, and establish forward-looking intelligence equipment maintenance system.
C4	Electricity pricing strategy	A fair power pricing plan will be developed to influence the demand for electricity in homes and businesses, taking into account the power grid's capacity to supply power as well as the environmental effects of energy production.

C5	Smart grid construction cost control	The natural monopoly characteristics of the power industry are conducive to reducing organizational costs, building a modern energy comprehensive transportation system, changing the traditional energy transportation development model, utilizing data mining techniques, and comprehensively analyzing the limits of different factors for smart grid transmission power.
C6	Increased awareness of smart electricity use	Power Demand Side Management (DSM) encourages users to use surplus energy and recover power generation to reduce the power and electricity drawn from the power system, facilitate the sustainability of smart power sector, and build a resource-saving and environment-friendly society
C7	Customer satisfaction with electricity	Implement differential pricing of power quality; power customers feedback the power industry services, use big data technology to improve power pricing strategies, and increase customer satisfaction with electricity.
C8	Knowledge upgrade	The building of smart power industry infrastructure, upkeep and repair of newer equipment, and the distribution of smart grid electricity; all contribute towards the creation of jobs in society and help lower the rate of social unemployment.
C9	Power demand side management (DEM)	Through the analysis of customer electricity consumption data, we can obtain electricity consumption patterns and electricity consumption behaviors of customers in different regions and industries, subdivide customer electricity consumption types, and accurately design demand-side management (DEM) solutions for electricity consumption to improve electricity efficiency.
C10	Smart microgrid system	With big data technology, smart microgrid system is built to realize the interaction between a complete set of energy generation from a small house to a large power grid; smart grid distributed power generation resources that can accommodate many different types of power sources including centralized power generation.

C11	Intelligent power dispatch	In the principle of economic dispatch, low-carbon constraints are added to smart grid dispatch, and monitoring data obtained from the smart power system, such as environmental monitoring, power dispatch, and substation monitoring, are used to improve the safety level of smart grid operations, and the smart grid’s disaster warning and response capabilities.
C12	Smart low-carbon electricity	Smart low-carbon power is a method of comprehensive resource strategic planning, which requires a change in the traditional planning model, utilize big data technology to promote the growth of clean energy generation in the supply of electricity, and on the power demand side, reduces carbon emissions from certain power consumption; In the past, power supply and demand growth and power structure planning were restricted by resources.
C13	Smart new energy grid	The construction of smart new energy grids uses renewable energy sources for power generation, for instance, photovoltaic and nuclear power generation. Reduce the dependence of grid power generation on fossil energy and change the proportion of energy supply on the power supply side.
C14	Intelligent environmental pollution control	Build an intelligent detection system that integrate advanced sensing and monitoring control technology, information processing and communication technology, etc., to detect environmental problems such as acid rain caused by traditional fossil energy power generation. Big data technology is used to detect the emission of pollution source gas and carry out intelligent environmental pollution gas control.
C15	Environmental policy	The government's environmental policies, for example, government tax carbon emissions and issue permits for carbon emissions; lowering the high threshold status of the power industry, preventing improper government intervention in the power industry; imposing "carbon dioxide" taxes at appropriate times and establishing carbon trading market.

2.2 Proposal Attributes

The influencing factors and explanations for the sustainable development of the smart power industry are described in Table 1. New energy technology power generation (REMs) (C1) can reduce greenhouse gas emissions and generate economic benefits for consumers and power enterprises [23]. Smart grid construction location (C2) is the employment of big data technology to find the optimal location of smart grid construction, to achieve the intelligent operation control and management maintenance of the whole power grid, and to fulfill the optimal allocation of power resources. Smart grid equipment maintenance (C3) is the monitoring, analysis, response and even recovery of abnormal operation of local networks or electrical components through big data technology, reduce maintenance costs and improving operational efficiency. The power distribution network can be reasonably detected and controlled using the power grid's ideal electrical components. [24]. The power pricing strategy (C4) is to develop a reasonable power pricing strategy that affects residential electricity demand and industrial electricity demand. From the perspective of the residential power demand side, Sibo Nan proposes the optimal smart grid demand residents reflect scheduling model to reduce consumer costs and peak power pressure, which also provides a theoretical basis for power pricing strategy (C4) [25]. To deal with excessive electricity demand, the peak pricing approach may allow consumers to reduce their demand [26]. From the perspective of cost control of smart grid construction, smart grid can lower investment costs (C5). The inherent monopolistic nature of the power sector makes it advantageous to lower organizational costs and construct a cutting-edge energy-transportation system that employs data mining technology to thoroughly examine the constraints imposed by various factors on the transmission power of smart grids.

Power demand side management (DSM) encourages users to engage in waste energy and recycled power generation, improve the awareness of smart electricity (C6), promote the sustainable development of the smart power industry, and build a resource-saving and environment-friendly society. Using consumer data and big data technology to improve power pricing strategy and customer satisfaction (C7). Demand side response (DR) has been extensively applied in the past several years. DR is the main communication mode between power grid companies and consumers in power grid development [25]. The sustainable development of the smart power industry bears major social responsibilities: increasing the employment rate (C8), investing in infrastructure construction of the smart power industry, maintenance of equipment in the later stage, and dispatching power from the smart grid to provide jobs for the society and reduce social unemployment. Power Demand Side Management (DSM) (C9) is based on the analysis of customer electricity data, drawing customer electricity laws and behavior in different regions and different industries to improve power efficiency. The implementation of DSM (C9) requires the analysis of smart grid data to determine the most appropriate policy for each type [7].

Using big data technology, the smart microgrid system (C10) is constructed to realize the interaction between the whole energy generation from small to housing and the large grid. This paper provides an economic benefit evaluation model that cooperation can be provided to users and power suppliers, which includes market environment and load scheduling [27]. Microgrids can be cooperated for commercial companies or retailers and consumers [28]. With the development of the social economy, electricity demand has been rising. Intelligent power dispatching (C11) is beneficial to the growth of a low-carbon economy and the prevention of potential risks. The optimal operation of thermal power units integrated with distributed generation is an important issue in smart grid [29].

Smart low-carbon electricity (C12) is a comprehensive resource strategic planning method, which requires changing the traditional planning mode, utilizing big data technology, promoting the growth of clean energy generation in electricity supply, and reducing carbon emissions of certain power consumption in the power demand side to change the resource-constrained power supply and demand growth and power structure planning of the past. A grid of low-carbon power has formed. Overstimulation of the economy and technology will hinder the growth of smart grid low-carbon economy, and users will encourage this development. [30]. Smart new energy grid (C13), the generation of electricity from renewable energy sources, for example photovoltaic and nuclear power. Reduce the dependence of power generation on fossil energy and change the energy supply ratio of power supply side. There is a global trend to change power supply systems by shifting from fossil fuels to renewable energy based on the hazards presented by many traditional fossil energy sources [31]. Intelligent environmental pollution control (C14) is an intelligent detection system, which integrates advanced sensing and monitoring control technology, information processing, and communication technology to detect environmental problems such as acid rain caused by traditional fossil energy power generation. Environmental policy (C15) is the formulation of environmental policies by the Government, such as taxing carbon emissions and issuing carbon emission permits [33], [34].

3. Method

3.1 Fuzzy-Dematel

Step1：In view of the researched problem, a systematic system of prevention methods is constructed, set as M1, M2…Mn.

Step2：Fuzzy-Dematel determines the influence relationship among various factors through expert scoring, which is finally expressed in matrix form. Expert access to the language operators, including "N", "VL", "L", "H" and "VH" in Table 2 to evaluate the relationship among the factors. The raw expert assessment is transformed into the appropriate triangular fuzzy numbers using a semantic table, and its meaning is the degree to which the m-th expert believes that the factor i influences factor j, as illustrated in Table 2.

Table 1 Semantic variable interpretation table

Semantic variable	Corresponding triangular fuzzy number (TFN)
N（No Influence）	（0,0,0.2）
VL（Very Low Influence） L（Low Influence）	（0,0.2,0.4）
H（High Influence）	（0.2,0.4,0.6）
VH（Very High Influence）	（0.4,0.6,0.8）

The formula for conversion from semantic variables to triangular fuzzy numbers is：

$$w_{ij}^{m} = \left(a_{ij}^{m}, b_{ij}^{m}, c_{ij}^{m}\right) = \left(\max\left\{\frac{i-1}{n}, 0\right\}, \max\left\{\frac{i}{n}, 0\right\}, \max\left\{\frac{i+1}{n}, 0\right\}, \right) \quad i \in \{1, 2, 3 \ldots n\}$$

Step 3: CFCS (Converting the Fuzzy data into Crips Scores) is applied for fuzzing the starting values of the expert scores, and the direct influence matrix is denoted as Z. In detail, these four steps：

1）Standardize the triangular fuzzy number.

$$xa_{ij}^{m} = \left(a_{ij}^{m} - \min a_{ij}^{m}\right) / \Delta_{\min}^{\max}$$

$$xb_{ij}^{m} = \left(b_{ij}^{m} - \min b_{ij}^{m}\right) / \Delta_{\min}^{\max}$$

$$xc_{ij}^{m} = \left(c_{ij}^{m} - \min c_{ij}^{m}\right) / \Delta_{\min}^{\max}$$

2）Standardize the left value (LS) and the right value (RS).

$$xLS_{ij}^{m} = xb_{ij}^{m} / \left(1 + b_{ij}^{m} - a_{ij}^{m}\right)$$

$$xRS_{ij}^{m} = xc_{ij}^{m} / \left(1 + c_{ij}^{m} - b_{ij}^{m}\right)$$

3）Calculate deblurred clarity values.

$$x_{ij}^{m} = \left[xLS_{ij}^{m}\left(1\text{-}xLS_{ij}^{m}\right) + xRS_{ij}^{m} xRS_{ij}^{m} \right] \Big/ \left[1 - xLS_{ij}^{m} + xRS_{ij}^{m}\right]$$

$$Z_{ij}^{m} = \min a_{ij}^{m} + x_{ij}^{m} \Delta_{\min}^{\max}$$

4）Calculate the average clarity value.

$$Z_{ij} = \left(Z_{ij}^{1} + Z_{ij}^{2} + \cdots + Z_{ij}^{m}\right) / m$$

Step4：The direct impact matrix is standardized to give a standardized direct impact matrix f $\mathbb{Z}$

$$\alpha = 1 \Big/ \max_{1 \le i \le n} \sum_{j=1}^{n} Z_{ij}, \ \mathbb{Z} = \alpha Z$$

Step5：Calculate the comprehensive influence matrix Field, where E is the unit matrix of the same order as G.

$$\mathrm{T} = G\left(E - G\right)^{-1}$$

The comprehensive influence matrix is calculated and the connections between the internal influence factors are explained. The comprehensive influence matrix is summed by rows and denoted as D_i , which means that the factor affects the comprehensive value of other factors; the comprehensive influence matrix is summed by columns and denoted as R_i, this implies that the factor is influenced with other factors.

$$D_i = \sum_{j=1}^{n} \mathrm{T}_{ij} \text{ , } j \in \{1,2,3\cdots,n\}$$

$$R_i = \sum_{i=1}^{n} \mathrm{T}_{ij} \text{ , } i \in \{1,2,3\cdots,n\}$$

The aggregate of the degree of being influenced R_i and the degree of influence D_i is referred to as centrality C_i, which reflects the factor's position in the system and the magnitude of its role. The difference between the degree of being influenced R_i and the degree of influence D_i is referred to as the degree of cause N_i, which describes the causal connection between the factors. If the degree of cause is more than zero, the factor has a strong influence on the other factors and is known as the cause factor; otherwise, the method is influenced by other factors. A high degree of influence is called a result factor, and its calculation formula is as follows:

$$C_i = D_i + R_i \text{ , } i \in \{1,2,3\cdots,n\}$$

$$N_i = D_i - R_i \text{ , } i \in \{1,2,3\cdots,n\}$$

Step7：Create a Cartesian coordinate system based on the causality and centrality of the study factors as horizontal and vertical coordinates, analyze the importance of each factor and the mechanism system of each factor's mutual influence, and propose targeted suggestions for practical problems.

3.2 ISM

With the ISM method, fuzzy connections can be transformed into intuitive structural correlations. Such a method applies to the analysis of systems with many variables, ill-defined structures, and complex relations. The fundamental steps of ISM include the following：

Step1：Calculate the overall impact matrix with the following formula:

$$F = I + T = \left[q_{ij} \right]_{n \times n}$$

Step2：Introduce the threshold value ϕ and propose redundant information to obtain a simplified matrix. The formula of threshold value calculation in this paper is as follows, where δ^2 and μ are the variance and mean of the comprehensive influence matrix T respectively.

Step3：A threshold is applied for the removal of redundant factors from the overall influence matrix to give a judgment matrix Ψ . 1 and 0 denote the presence and absence of a direct relationship between two factors respectively.

$$\Psi = \begin{cases} 1 \text{ , } & q_{ij} \geq \phi \\ 0 \text{ , } & q_{ij} < \phi \end{cases} \text{ , } i, j \in \{1,2,3\cdots,n\}$$

Step4：Hierarchical processing of reachable set A_i and antecedent set B_i, the calculation formula is：

$$\mathrm{A}_i = \left\{ M_j \in M \text{ , } \phi_{ij} \neq 0 \right\}, i \in \{1,2,3\cdots,n\}$$

$$\mathrm{B}_i = \left\{ M_j \in M \text{ , } \phi_{ji} \neq 0 \right\}, i \in \{1,2,3\cdots,n\}$$

Step5：For the factors belonging to the same area, find the set Γ, and divide the rows and columns that correspond to the factors in the intersection of set A_i and set Γ in the matrix.

$$\Gamma = \mathrm{A}_i \cap \mathrm{B}_i$$

Step6：Repeat Step4 and Step 5 until the set of factors of each layer $\Pi_q \left(q \in \{1,2,3\cdots,n\} \right)$ is obtained, at this time all factors of the judgment matrix Ψ are deleted.

Step7：Based on the matrix resulting from step 6, a hierarchy of impact factors is drawn in the order of the underscores.

4. Results

To get the original data for analysis, 7 experts were chosen to design the questionnaire. Two of them are from the public utilities authority in a city in northeast China, and five of them are from State Gird with a minimum of 10 years working experience. After reviewing and analyzing the literature, the authors first designed the questionnaire, then it was sent to 7 experts. If any of the experts do not agree with the suggested measures in the questionnaire, the authors will revisit the points of contention until the seven experts agree. Several iterations of this process took place. Subsequently, individual interviews were conducted to collect the data for greater accuracy and to prevent cross-fertilization.

In this paper, through the review of literature, the factors of sustainable development of smart grid in a big data environment are divided into 15 indicators according to the Dematel method, and the 15 indicators are scored by smart grid experts, and the raw data are processed by using CFCS method. The direct influence matrix can be acquired, as displayed in Table 3 below.

Table 3 Direct influence matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C1	0.000	0.405	0.430	0.214	0.405	0.024	0.037	0.214	0.011	0.024	0.405	0.011	0.405	0.024	0.290
C2	0.011	0.000	0.329	0.367	0.341	0.227	0.202	0.379	0.037	0.037	0.011	0.037	0.011	0.189	0.392
C3	0.011	0.329	0.000	0.367	0.341	0.265	0.202	0.379	0.024	0.037	0.024	0.062	0.011	0.189	0.379
C4	0.024	0.049	0.062	0.000	0.011	0.354	0.354	0.379	0.011	0.011	0.011	0.024	0.024	0.354	0.405
C5	0.011	0.341	0.341	0.367	0.000	0.189	0.202	0.379	0.049	0.037	0.011	0.024	0.011	0.202	0.379
C6	0.024	0.024	0.011	0.037	0.024	0.000	0.405	0.011	0.011	0.024	0.024	0.024	0.011	0.405	0.011
C7	0.011	0.024	0.011	0.024	0.011	0.405	0.000	0.011	0.011	0.024	0.011	0.011	0.024	0.379	0.011
C8	0.011	0.024	0.011	0.379	0.011	0.379	0.379	0.000	0.011	0.011	0.024	0.011	0.011	0.354	0.405
C9	0.430	0.202	0.202	0.049	0.189	0.214	0.202	0.037	0.000	0.456	0.379	0.405	0.456	0.214	0.037
C10	0.417	0.202	0.214	0.011	0.202	0.214	0.202	0.011	0.392	0.000	0.417	0.456	0.430	0.214	0.011
C11	0.405	0.405	0.405	0.214	0.405	0.011	0.011	0.214	0.024	0.011	0.000	0.011	0.405	0.011	0.214
C12	0.392	0.202	0.214	0.037	0.214	0.214	0.202	0.024	0.392	0.405	0.405	0.000	0.405	0.214	0.024
C13	0.367	0.367	0.341	0.214	0.354	0.037	0.037	0.214	0.011	0.011	0.405	0.011	0.000	0.037	0.214
C14	0.011	0.024	0.024	0.024	0.024	0.379	0.405	0.011	0.011	0.011	0.011	0.049	0.011	0.000	0.011
C15	0.024	0.011	0.024	0.354	0.011	0.354	0.379	0.379	0.011	0.011	0.075	0.011	0.024	0.379	0.000

The direct influence matrix is in Table 3, and the comprehensive influence matrix according to the formula $\mathrm{T} = G\left(E - G\right)^{-1}$ as shown in Table 4.

Table 4 Comprehensive influence matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C1	0.051	0.211	0.217	0.202	0.208	0.156	0.158	0.203	0.021	0.025	0.161	0.024	0.158	0.151	0.227
C2	0.025	0.048	0.134	0.191	0.135	0.194	0.188	0.194	0.024	0.026	0.028	0.028	0.026	0.182	0.201

C3	0.027	0.136	0.049	0.192	0.136	0.206	0.190	0.195	0.022	0.026	0.033	0.035	0.027	0.184	0.198
C4	0.021	0.036	0.038	0.052	0.024	0.193	0.194	0.149	0.011	0.012	0.020	0.017	0.021	0.192	0.157
C5	0.025	0.138	0.137	0.191	0.045	0.185	0.187	0.194	0.027	0.026	0.028	0.025	0.026	0.184	0.198
C6	0.016	0.021	0.017	0.026	0.020	0.047	0.152	0.019	0.008	0.012	0.016	0.014	0.013	0.151	0.019
C7	0.012	0.018	0.015	0.021	0.015	0.148	0.044	0.016	0.008	0.012	0.012	0.010	0.015	0.142	0.017
C8	0.017	0.026	0.022	0.146	0.021	0.195	0.197	0.046	0.010	0.011	0.022	0.013	0.017	0.189	0.152
C9	0.228	0.206	0.206	0.164	0.200	0.233	0.228	0.160	0.051	0.172	0.220	0.162	0.238	0.228	0.168
C10	0.224	0.205	0.208	0.153	0.202	0.229	0.224	0.152	0.152	0.055	0.228	0.173	0.231	0.224	0.159
C11	0.155	0.210	0.210	0.197	0.207	0.146	0.145	0.199	0.023	0.022	0.055	0.023	0.157	0.141	0.205
C12	0.213	0.200	0.203	0.156	0.200	0.227	0.222	0.152	0.150	0.157	0.220	0.055	0.220	0.222	0.159
C13	0.143	0.193	0.187	0.188	0.187	0.145	0.144	0.189	0.019	0.020	0.157	0.022	0.049	0.140	0.195
C14	0.013	0.020	0.019	0.022	0.019	0.144	0.151	0.018	0.009	0.010	0.013	0.020	0.013	0.045	0.018
C15	0.022	0.027	0.029	0.142	0.024	0.190	0.197	0.146	0.010	0.012	0.036	0.013	0.023	0.195	0.050

By the comprehensive influence matrix, the degree of influence, degree of being influencing, centrality and degree of cause between the 15 factors influencing the sustainability of the SG can be calculated, as illustrated in Table 5 below.

Table 5 Comprehensive influence Matrix Analysis table

	D_i	R_i	C_i	N_i
C1	2.174	1.192	3.367	0.982
C2	1.624	1.695	3.319	-0.071
C3	1.655	1.692	3.347	-0.037
C4	1.138	2.043	3.181	-0.905
C5	1.616	1.644	3.260	-0.028
C6	0.552	2.640	3.192	-2.088
C7	0.503	2.622	3.125	-2.119
C8	1.084	2.032	3.116	-0.948
C9	2.864	0.543	3.407	2.321
C10	2.820	0.598	3.418	2.222
C11	2.096	1.249	3.345	0.846
C12	2.757	0.633	3.390	2.123
C13	1.978	1.235	3.213	0.743
C14	0.535	2.569	3.104	-2.035
C15	1.117	2.124	3.241	-1.007

This paper ranks the factors that influence the sustainability of smart grids in order of centrality, C10 (smart microgrid system), C9 (power demand side management), C12 (smart low-carbon power), C1 (new energy technology power generation), C11 (Smart power dispatch), C3 (smart grid equipment maintenance), C13 (smart new energy grid), C2 (smart grid construction location), C5 (smart grid construction cost control), C15 (environmental policy), C4 (power pricing strategy), C7 (customer power consumption satisfaction), C8 (knowledge upgrade), C6 (increasing awareness of smart power use) and C14 (intelligent environmental pollution control). Among them, factors such as smart microgrid system, smart low-carbon power, new energy technology power generation and smart power dispatching is vital to the sustainability of smart grids, which can give priority to these factors.

In this paper, the degree of influence and the degree of being influenced in Table 5 are plotted as the abscissa and ordinate respectively as shown in Figure 2. It can be observed that the causal factors influencing the sustainability of smart grid are: C1 (new energy technology power generation), C9 (power demand side management), C10 (smart microgrid system), C11 (smart power dispatch), C12 (smart low-carbon power) and C13 (smart new energy grid), indicating that these six factors will affect other factors; ranked according to degree of influence that from by comprehensive influence matrix, the degree of influence of C9, C10, C12, C1, C11 and C13 are 2.85, 2.80, 2.74, 2.11, 2.07 and 2.03 respectively, indicating the data-based smart social development and the power generation of new energy technologies are essential for the sustainable development of SG, thus the sustainable development of smart grids can be emphatically considered in terms of new energy technology and smart society. As can be seen from Figure 1, factors that contribute to the sustainability of smart grids are: C2 (location of smart grid construction), C3 (smart grid equipment maintenance), C4 (power pricing strategy), C5 (smart grid construction cost control), C6 (increased awareness of smart electricity use), C7 (customer satisfaction with electricity), C8 (knowledge upgrade), C14 (intelligent environmental pollution control), and C15 (environmental policies), indicating that these 9 factors will be affected by other factors. The effect on the sustainability of smart grid is comparatively weak, but it is more susceptible to other factors. Therefore, we should be aware of the variations of these factors in order to optimize the sustainable development of SG.

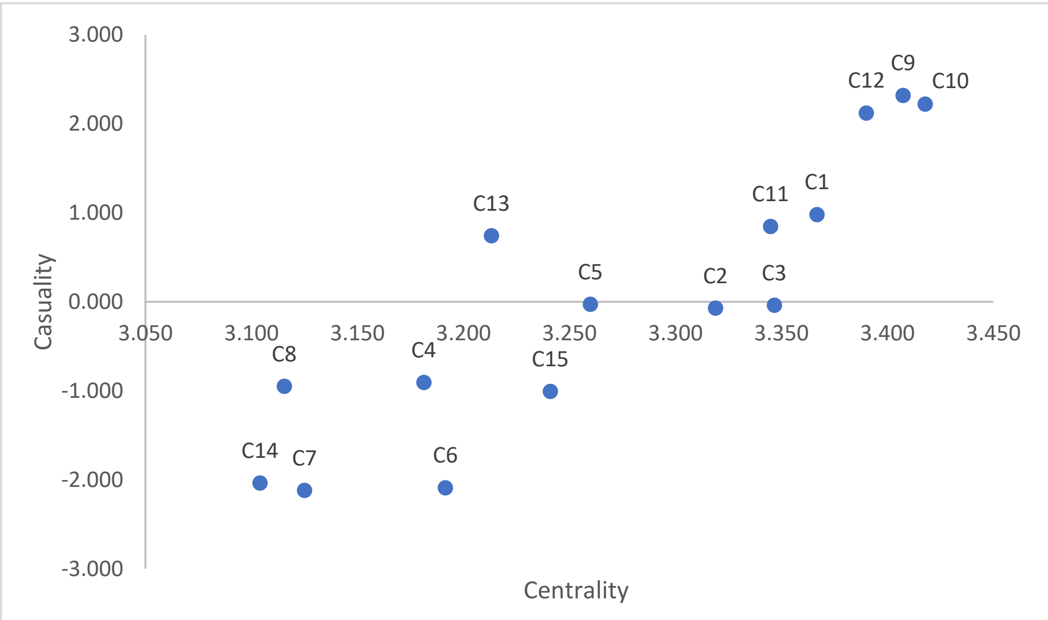

Figure. 2. Cause and result graph

From the comprehensive influence matrix, $\phi=0.12$ can be calculated, so the reachable matrix in Table 6 can be calculated, where 1 indicates that there is a strong correlation between the two factors, and 0 denotes that there is a weak correlation or no correlation between the two factors. Through the calculation in Table 6, the primary breakdown structure of ISM can be obtained, as shown in Table 7.

Table 6 Reachable matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C1	1	1	1	1	1	0	0	1	0	0	0	0	0	0	1
C2	0	1	0	0	0	1	0	1	0	0	0	0	0	0	1
C3	0	0	1	1	0	1	0	1	0	0	0	0	0	0	1
C4	0	0	0	1	0	1	1	0	0	0	0	0	0	1	0
C5	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1
C6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
C7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
C8	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0
C9	1	1	1	0	1	1	1	0	1	0	1	0	1	1	0
C10	1	1	1	0	1	1	1	0	0	1	1	0	1	1	0
C11	0	1	1	1	1	0	0	1	0	0	1	0	0	0	1
C12	1	1	1	0	1	1	1	0	0	0	1	1	1	1	0
C13	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1
C14	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
C15	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1

Table 7 shows that the intersection of A_i and Γ is 6, 7, and 14, so the first-level node N_1={C6,C7, C14}. Removing these three rows and three columns from the reachable matrix, and so on, the set of five levels of ISM decomposition can be obtained, denoted as Nq(q=1,2,...,5), the specific nodes are as follows: Node, N_1={C6,C7, C14}; second-level node N_2={C4,C8,C15}; third-level node N_3={C2,C3,C5},fourth-level node N_4={C1,C11,C13},five-level nodeN_5={C9,C10,C12}, high-level node factors affect low-level node factors, and same-level node factors can also affect other factors of same-level nodes.

Table 2 Primary breakdown structure

	A_i	B_i	Γ
1	C1,C2,C3,C4,C5,C8,C15	C1,C9,C10,C12	C1
2	C2,C6,C8,C15	C1,C2,C9,C10,C11,C12,C13	C2
3	C3,C4,C6,C8,C15	C1,C3,C4,C9,C10,C11,C12	C3
4	C4,C6,C7,C14	C1,C3,C4,C11	C4
5	C5,C8,C15	C1,C5, C9,C10,C11,C12	C5
6	C6	C2,C3,C4,C6,C8,C9,C10,C12	C6
7	C7	C4,C7, C8,C9,C10,C12,C15	C7
8	C6,C7,C8	C1,C2,C3,C5,C8,C11	C8
9	C1,C2,C3,C5, C6,C7,C9,C11,C13,C14	C9	C9
10	C1,C2,C3,C5, C6,C7,C10,C11,C13,C14	C10	C10
11	C2,C3,C4,C5,C8,C11,C15	C9,C10,C11,C12	C11
12	C1,C2,C3,C5, C6,C7, C11,C12,C13,C14	C12	C12
13	C2,C13,C15	C9,C10,C12,C13	C12,C13
14	C14	C4, C9,C10,C12,C14,C15	C14

15	C7,C14,C15	C1,C2,C3,C5,C11,C13,C15	C15

The five level node sets and reachable matrix obtained from the ISM model are drawn into the hierarchical ISM structure diagram shown in Figure 3. The red arrows indicate the influence between nodes at the same level, and the black arrows indicate the influence of higher-level nodes on lower-level nodes. The blue arrows indicate cross-level influence. Figure 3 reveals that power demand side management, smart microgrid systems, and smart low-carbon power are the keys to the sustainable development of SG. Smart grid companies can use big data technology to improve the interaction between power users and smart grids, optimize the construction of smart power dispatch and smart microgrid systems; smart grid companies can also use blockchain technology to make the current grid data open and transparent, reduce information asymmetry with power users, and then effectively perform power demand side management. The government can also formulate effective environmental policies based on its public data to promote the sustainability of the smart grids.

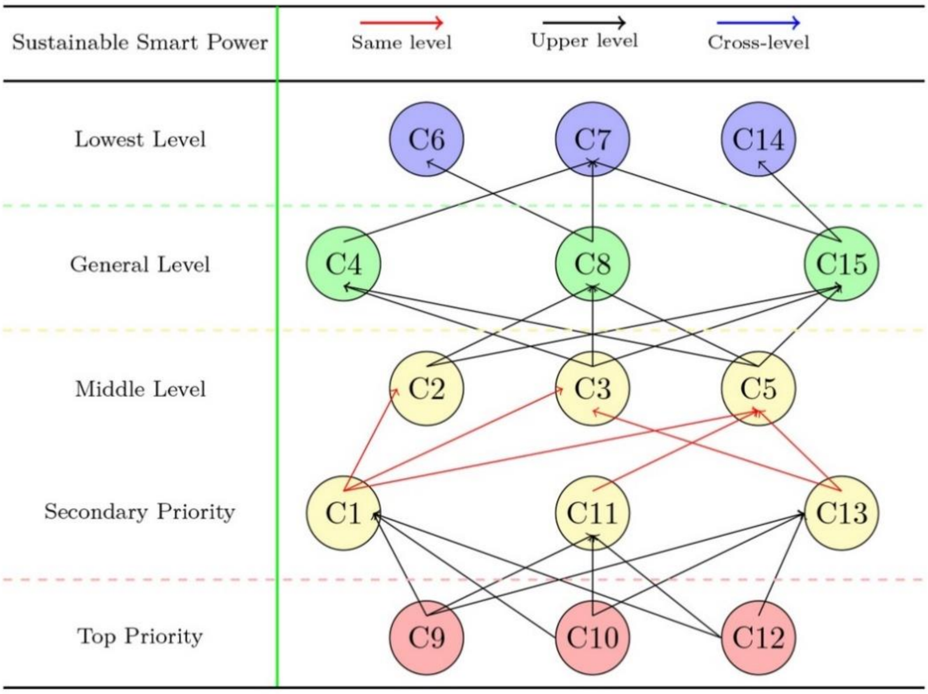

Figure. 3. ISM structure hierarchical diagram

It can be seen from Figure 3 that the establishment of a smart grid sustainable development system has been affected by multiple factors. This article utilizes the Fuzzy-Dematel-ISM method to categorize the factors influencing the sustainable development of SG into smart economy, smart society as well as smart environment, the expert opinions are then fuzzed. The degree of influence and degree of being influenced of each factor shows the intensity of the role of each factor in the sustainable development of the smart grid. based on the environment of big data technology, the factors impacting the sustainable development of the smart grid are processed in a multi-level framework, and each factor affects the sustainable development of the SG by the relationship between the hierarchical frameworks, so that a systematic multi-level framework for the sustainable development of SG can be built upon the foundation of a big data environment.

5. Discussion

Currently, there are research on the systematic framework of the sustainable development of SG. Through combing previous scholars' research on smart grids, this paper identifies 15 factors influencing the sustainability of smart grids by combining the traditional power industry with the smart environment. Besides, in this study, the Fuzzy-Dematel approach is applied to categorize the factors that influence the sustainable development of smart grids in the big data environment based on the three frameworks of smart economy, smart society together with smart environment, the ISM theory is eventually applied to build a multi-level framework influencing the development of the intelligent power sector and establish a systematic system for the sustainability of the smart grids.

The sustainable development of smart grids starts with improving the three factors of C9 (power demand side management), C10 (smart micro-grid system), and C12 (smart low-carbon power). C9, C10 and C12 are ranked in the top three in terms of influence, indicating that the three factors have a stronger influence on other factors.C9, C10, and C12 are at the highest level in the systematic framework for the sustainable development of SG. Since these three elements are all part of the smart society dimension, establishing a smart society in line with big data technology will have a significant impact on SG's ability to develop sustainably. Advanced measurement infrastructure is necessary for power demand side management, which is conducive to power detection, data collection, and evaluation information between power companies and users [35]. Smart grid companies can use big data technology to classify users by region, customs and other characteristics, understand the power distribution curve of each user, and then optimize power demand side management, improve the efficiency and quality of power distribution, and realize low-carbon smart grid. Smart grid firmsSmart grid firms can use blockchain technology to eliminate information asymmetry associated with power customers, making the current grid data more transparent and open, and hence managing power demand efficiently. Laura Antonia Faerber et al proposed an innovative grid pricing strategy to promote the low-carbon economic transformation of smart grids [36]. Smart grid companies can also use new energy technologies for power generation and smart grid distributed power generation to build smart micro-grid systems that effectively reduce power generation costs and promote the development of low-carbon smart power, which is conducive to the construction of social environmental friendliness and social harmony.

C1 (new energy technology power generation), C11 (smart power dispatch) and C13 (smart new energy grid) are at the second level of a sustainable system framework for smart grids. SG companies utilize big data technologies to search for new and renewable energy generation and to lower the marginal cost of generation in the intelligent power sector. Traditional electricity grids are being transformed into new smart grids to support humanity's rapid progress. The introduction of modern smart grids has had a significant impact on power dispatching. [37]. Smart grid companies extract the characteristics of each type of user's electricity consumption based on the massive amount of electricity consumption data of users and then optimize the dispatching of smart electricity, and improve the efficiency of electricity consumption of electricity customers. Alessandra Pieroni et al proposed the use of smart energy grids based on block chain technology to improve the energy distribution capabilities between cities and residents and enhance the quality of life and service for residents of smart cities [38]. The development of smart new energy networks, which incorporate renewable energy sources such as photovoltaic and nuclear power, has the potential to have a significant spillover effect. Its externalities can be manifested in reducing the dependence of grid power generation on fossil energy, changing the proportion of energy supply on the power supply side, and promoting the reform of the traditional power industry.

C2 (smart grid construction location), C3 (smart grid equipment maintenance), and C5 (smart grid construction cost control) are the third level of the system of the systemic framework for smart grid sustainability, all located in the smart economy dimension. Smart grid enterprises serve a crucial role in the sustainable development of SG. Third-level considerations play a significant role in lowering the cost of smart grid companies building smart grids. Smart grid companies use big data technology to find the optimal location for global smart grid construction, realize the intelligence of the entire grid in operation control, management and maintenance, reduce the cost of smart grid construction, and achieve optimal allocation of power resources [39]. To achieve technical and economic efficiency standards, it is essential to focus on the maintenance of SG equipment. Smart grid can apply big data technology for the monitoring, analysis, response, and even recovery of abnormal operation of the original electric power or local network, reduce maintenance costs and improve operation efficiency, use big data technology to evaluate potential problems and risks of equipment and establish a forward-looking system of smart equipment maintenance to reduce the risk potential in the process of the sustainable development of SG, and strengthen the protection of the life and property safety of smart grid users. The power industry's natural monopoly reduces organizational expenses, and the sustainability of smart grids allows for the construction of a contemporary integrated energy transportation system and the transformation of the conventional energy transportation development model. Smart grid companies utilize data mining technology to comprehensively analyze the limits of different factors for smart grid transmission power, which can effectively control the construction cost of smart grids.

C4 (power pricing strategy), C8 (knowledge upgrade), and C15 (environmental policy) are located at the fourth level of the SG sustainability systematic framework. Smart grids can open electricity price data to users through blockchain technology, and users can control their electricity load according to real-time electricity prices [40]. Smart grid companies and governments can formulate reasonable power pricing strategies based on the power supply capacity of smart grids in different regions and the effect of energy generation on environment, which further affects residential power demand and industrial power demand, and management of power demand side. The development of the smart grid has shown great spillover effects. The investment in infrastructure construction in the smart power industry, the repair and maintenance of later equipment, and the dispatching of smart grid power provide jobs for society, reducing the social unemployment rate, and promoting the upgrading of social group knowledge. The government's environmental policies can be regarded as a compass for the development of smart grids. For example, the government imposes taxes on carbon emissions and issues carbon emission permits; lowers the high threshold status of the power industry and prevents the government from improper intervention in the power industry; introduces a "carbon dioxide" tax and establishes a carbon trading market.

C6 (improvement of smart power awareness), C7 (customer power utilization satisfaction), and C14 (smart environmental pollution control) are at the last level of the SG sustainability systematic framework. Factors at this level indicates that the sustainable development of the SG can be realized from the smart grid user side. Anders Nilsson et al found that customer awareness of power consumption management can affect customers’ awareness of power consumption [41]. On the power demand side management, users are encouraged to use surplus energy and recover power generation to reduce the power and electricity drawn from the power system and to facilitate the sustainable development of the intelligent power sector to build a resource-saving and environment-friendly society. Smart grid companies can implement differential pricing of power quality. Smart grid customers feedback smart grid services, and smart grid companies use big data technology to improve power pricing strategies and increase customers’ satisfaction with power consumption. The government can detect smart grid companies and smart computer users. The government's detection department can develop a smart detection system that combines advanced sensing and monitoring control technology, information processing, and communication technology, and can detect environmental issues such as acid rain caused by traditional fossil fuel power generation. In this way, big data technology can be used to detect the emission of pollution source gas and carry out smart environmental pollution gas control.

The sustainable development of the smart grid requires cooperation among the government, smart grid companies, and users. This article shows the behavioral relationship among the three in Figure 4. The model can be categorized into three levels, namely, the government, the enterprise, and the user levels. The electric power regulatory department, environmental management department, and energy management department constitute the first layer. For the successful energy transition of the smart grid, it is crucial to consider optimizing the dynamic interaction between the government and the market to create conducive conditions [42]. The government regulatory department supervises smart power companies, and the environmental regulatory department monitors environmental pollution. The British government regards smart measurement as an important promoter of low-carbon smart grids and has set user-oriented goals in the United Kingdom [43]. The energy department manages the energy supply and authorizes distributed generation of smart grids. The enterprise layer includes smart power companies, power distribution departments, distributed power generation departments, insurance departments, and power maintenance departments. As the centrepiece of the sustainable development of SG, smart power companies can use blockchain technology and big data technology to manage the power demand side and build a smart micro-grid system. Power distribution departments can distribute power based on their clients' power usage characteristics. The development of the distributed power generation departments can improve the energy supply structure and recommend a low-carbon process for the sustainable development of SG.

The power maintenance departments and the power distribution departments cooperate to dispatch the smart grid, and the insurance departments can provide guarantee certificates for unexpected accidents during the sustainable development of smart grid. Mian Hu et al regards each user as a smart energy management system [44]. The user layer includes customers of power consumption and power consumption characteristics of customers. As the demand side of the smart grid, the user's power consumption satisfaction has always been the pursuit of the sustainable development of the smart grid. Smart grid companies can complete the data interaction with customers according to the customer's power distribution curve.

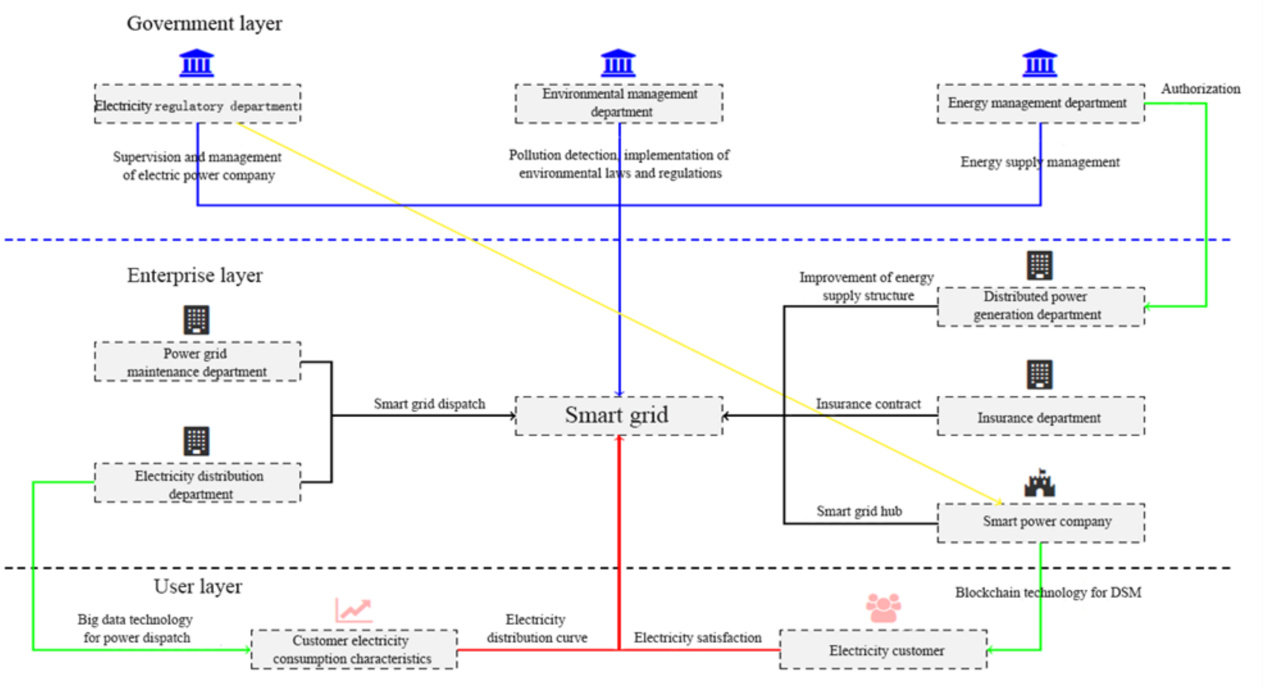

Figure. 4. Application of sustainable development system of smart grid

6. Conclusions

Current scholars have mostly focused on customer demand management, distributed power generation, power transmission, etc., and lacks a systematic framework for the sustainable development of SG. In contrast to previous research, this article divides the elements impacting SG's sustainable growth into three categories: smart economy, smart society, and smart environment, based on the triple bottom line theory. Fuzzy-Dematel theory is used to construct the theoretical system of sustainability of smart grids, and clarify the influence path and mechanism framework among various factors based on the environment of big data by the ISM approach, and eventually develop an application system for the sustainable development of SG according to stakeholder theory.

This paper adopts the integration approach of FUZZY-DEMATEL-ISM for analyzing the interaction between the numerous factors of the SG based on the environment of big data and determines the degree of influence and the degree of being influenced of each factor. Power demand side management, smart microgrid systems, and smart low-carbon power are important factors for the sustainable development of SG. This article combines the traditional power industry with current technologies. Smart grid firms can employ big data and blockchain technologies to communicate with electricity customers and successfully regulate demand. A smart social environment is a precondition for the sustainability of smart grids. The government policies for power grid industry and environment can serve as a compass for SG development. New energy technology power generation can improve the proportion of energy supply structure of smart grids and promote the low-carbonization of smart grids. Eventual development of an application system on smart grid sustainability in this article can provide theoretical support for stakeholders.

The research in this article still has some shortcomings. Although this article has built a organised system for smart grid sustainability, the affecting aspects may alter qualitatively as the sector evolves, necessitating additional research and development. In this paper, the association and degree of influence between the 15 indicators are treated and analyzed according to the information and data filled in the questionnaire by the experts. Despite the utilization of fuzzy set theory to address the subjective bias of experts, there remain systematic errors that are hard to eliminate and may result in some bias to the study results.

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