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Research on Power Demand Side Information Quality Indicators and Evaluation Based on Grounded Theory Approach

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Abstract: High-quality power demand side information is necessary for scientific decision-making of power grid construction projects. Literature research shows that the current demand side management (DSM) information quality theories and methods need to be improved, and the information quality indicators and evaluation work are essential. In this paper, based on the grounded theory, about 250 copies of relevant literatures and interview records are reviewed. Through open coding, spindle coding, and selective coding, 105 initial concepts are finally extracted to 35 categories and 10 main categories. On this basis, four information dimensions including load extraction, monitoring, management, and government planning are summarized. An index system containing 34 indicators for DSM information quality evaluation on the power demand side is constructed. Finally, using matter-element extension evaluation method, a case study in China is performed to verify the feasibility and scientificity of the indexes. The results show that DSM information quality evaluation indexes are effective, and the evaluation method is also applicable. The establishment of DSM information quality indicators and the evaluation methods in this paper can provide a reference for similar information quality evaluation work in power systems.

Keywords: power demand side; DSM; information quality; grounded theory; comprehensive extension evaluation

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1. Introduction

1.1. Background

Demand Side Management (DSM) is to allow enterprises and users to manage their own electricity consumption by building a refined power management platform. Over the past 10 years, the development of DSM has achieved abundant energy conservation and emission reduction effects and formed a certain scale. For example, the State Grid Energy Research Institute of China counts that the generation capacity of DSM project is 640.7 billion kWh in China for 2011–2015, and estimates for 2016–2020, it is 1.3254 trillion kWh. It can reach 1.9661 trillion kWh during the period 2010–2020, equivalent to a reduction of 22,598 kWh in generation capacity, and nearly 57 billion USD in investment compared with the conventional power plants [1].

With the increase of DSM project scale, many problems in management have been exposed [2]. Among them, information quality is an important factor affecting the development and implementation of energy projects [3]. An important element in fully developing demand-side resources for electricity is the scientific management of demand-side information. Electricity demand-side information is not only information from the electricity user side but also information that directly or indirectly affects electricity demand, such as government policy information, grid construction and planning information, commercial information (e.g., energy efficiency service companies), etc. Power demand-side information management includes information collection, analysis, storage, processing and application with the aim of providing a sound information base for nurturing and supporting future projects and project decisions. The issue of information quality is a difficulty and a key point in electricity demand-side information management efforts. The quality of information on the demand side of electricity often has an important impact on the economic and social benefits of grid investment projects, and poor information quality seriously disturbs scientific decision-making on grid construction projects, making them unable to serve local socio-economic development well and causing serious waste.

1.2. Literature Review

In recent years, information quality has become a research hotspot in the field of information management. Different information quality evaluation indexes and methods are put forward by scholars and widely used in the field of enterprise management and information management. For example, Corbets et al. [4] used an information quality assessment system to assess the team's performance. Dilruba et al. [5] applied dynamic data maintenance to study data quality. And Yeganeh et al. [6] developed a query collaboration framework to solve the problem of data quality-aware query system. Meanwhile, information quality is also widely used in other interdisciplinary fields, such as surgery [7], medical [8], nursing [9], emergency care [10], chemistry [11], and finance and accounting [12–14].

However, even if the quality of information is an important factor, most scholars prefer to focus on other aspects of DSM, such as in the economic field, billing [15], pricing [16] and cost-benefit analysis [17]; in the field of mathematics, such as scheduling [18] and planning [19], energy efficiency [20–22]; in the field of technology, such as renewable energy [23], smart distribution system [24] and others [25]. Some literatures considered the information quality of power information (energy information). Petushkov et al. [26] described intermodulation distortion influence on a transmitted information quality and examined an analog predistortion linearizer for TWTA that lowers third-order intermodulation distortion by 9.5 dB. Peng and Zhang [27] analyzed the basic principles of IEC series standard (IEC 61850, IEC60870-5-104, IEC60870-6, IEC 61970, etc.) based on IEC 62361-2 and domestic electric power industry standard (DL476) on information quality code from the perspective of interactive information quality of control data. Tie and Liu [28] defined all aspects of the domain software to be inspected by establishing an attribute model, obtained basic data on evaluation by analyzing and measuring evidence, tailor-made the computing logic of quality evaluation score by establishing an evaluation model, and classified domain software quality by establishing level model. Chang and Choi [29] suggested a research model which would explain the relationship among the bargaining power, partnership, information quality, and SCM features. Ciftcioglu et al. [30] focused on the time-varying nature of the observation quality of the environment in practical networks, which leads to uncertainty in satisfying QoI requirements specified by end users. However, the literature that studies the information quality of power demand side (user side) urgently needs to be supplemented. Therefore, this study of DSM information quality in this paper is innovative and of practical value.

2. Theories and Methods

2.1. DSM Information

With the rapid development of information technology, the power industry has also entered the era of big data, the main content of DSM is load management for end-users, which narrowly refers to the electricity consumption information of enterprises and other users, while the demand side of electricity information, which in a broad sense includes all the information that affects the demand for electricity such as government policies, regulations, documents, power load fluctuations, the speed of socio-economic development, natural disasters, and even the dictation of the person in charge, etc., will have an effect on electricity demand [31].

We summarize the previous discussion on electricity demand-side information and propose the framework and main contents of electricity demand-side information from two aspects: internal information and external information, as shown in Figure 1.

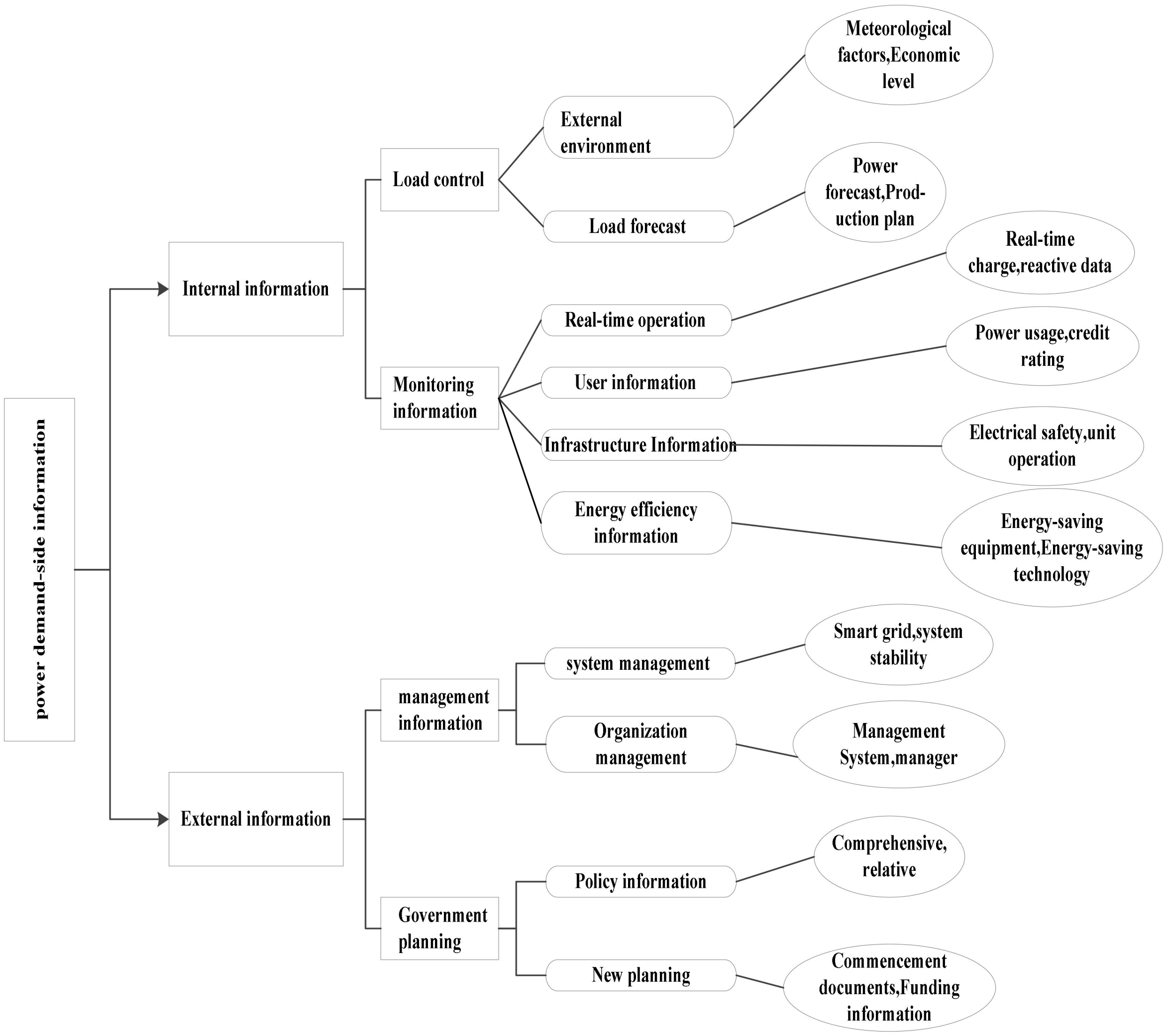

Figure 1. Main content of demand side management (DSM) information.

(1) Internal information. Internal information refers to information related to management operations and is selected to be reflected in two aspects, "load control" and "monitoring information". Load control information mainly refers to information that affects load forecasts, mainly including external environment information and load forecasting techniques and methods; monitoring information mainly focuses on the real-time monitoring status of power operation, users, infrastructure, and other information.

(2) External information. External information refers to objective environmental information that has an impact on demand-side management of electricity and is reflected in two parts, "management information" and "government planning". "Management information" can generally be divided into systems and organizations. In addition to this, there is a need to consider the impact of relevant government planning on grid development. "Government planning information" also includes information on regional policy releases and new planning documents.

2.2. Grounded Theory Approach

Grounded theory (short for GT) approach, proposed by Anselm Strauss and Barney Glaser [32] from Columbia University, is a well-known theory building method in the study of qualitative research, whose main purpose is to build a theory based on empirical information. Grounded theory approach is the process of continually starting from theoretical facts and then forming entity theories and then evolving from practice to formal theory; it is a theory and method based on accumulating scientific knowledge. Grounded theory approach is a process of moving from the concrete to the abstract, and its operative keywords include "coding", "constant comparison", "theoretical sampling", "theory saturation", "memo", and "word for word" (Figure 2).

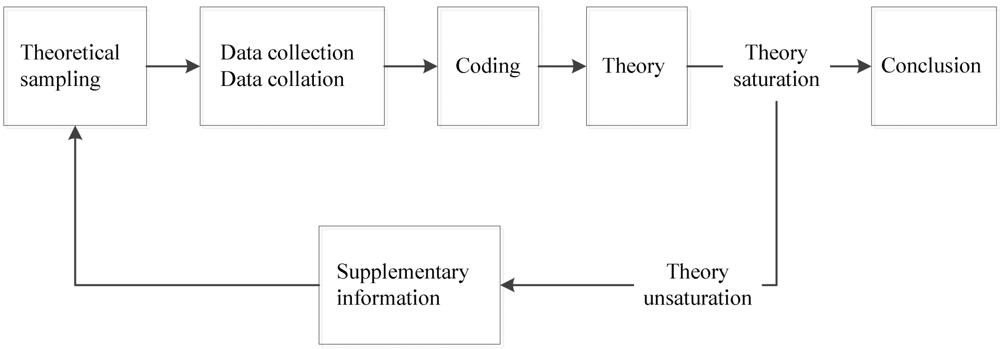

Figure 2. Grounded theory approach research process.

"Coding" is an important element of the Grounded Theory Approach, and coding is the formation of more categories, features, and conceptualized information in the context of different concepts, as well as in the contrast between different events and events. This phase is divided into three stages (Figure 3), and the questions that the researcher needs to keep asking in response to the information are the following: What is the study about which the data are collected? Which category is this incident pointing to? What is really happening in the data?

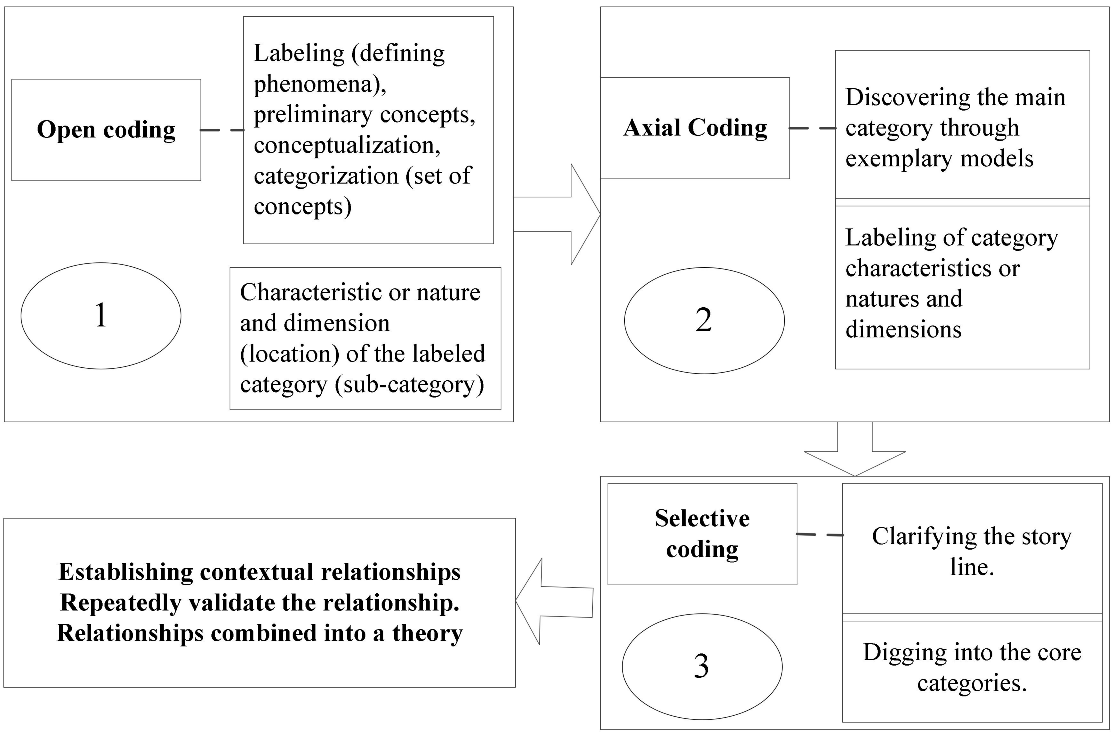

Figure 3. Coding process.

Open coding is the process of decomposing the original data and endowing the original data concepts and recombining them with new ones (Figure 4). The purpose of axial or mainline coding is to clarify concepts and the relationship between them. By thinking about and analyzing the relationships between concepts, higher levels of abstract categories can be integrated. Selective core coding, also known as axial core coding, is also present in the development of many general conceptual relationships through the principal category of core coding. The final step in grounded theory approach is to perform a theoretical saturation test.

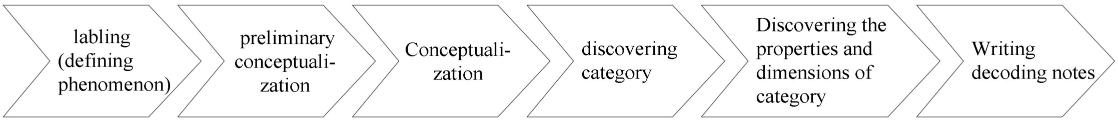

Figure 4. Process of open coding.

2.3. Matter-Element Extension Evaluation Method

Extenics theory builds models with matter elements as primitives to describe paradoxical problems [33], uses matter element transformations as a means of resolving paradoxical problems, and quantitatively describes the quantitative and qualitative changes in things by building correlation functions in the extensible set, that is, quantitatively describes the process of quantitative and qualitative changes in things using extensible domains and critical elements. Therefore, the extension comprehensive evaluation can not only obtain the final evaluation results but also determine the specific position of the evaluation results at what level, which has a natural advantage for the direction of improvement of the evaluation results and analysis of the results.

The theoretical pillars of extenics are matter-element theory and extension set theory, whose logical cells are primitives, including matter-elements, affair-elements, etc. Extension comprehensive evaluation method is an evaluation method based on extension set by building a matter-element model and transforming the evaluation indicators into compatible problems, which leads to conclusions that combine both qualitative and quantitative aspects. Its evaluation model can be briefly described as follows:

In extension comprehensive evaluation, matter elements are expressed as ordered triples. If the thing N has n features, and the m matter-elements to be evaluated have the same feature C, then the object R with the same feature can be expressed as

$$R = \begin{bmatrix} N & N_1 & N_2 & \cdots & N_{\mathrm{m}} \\ c_1 & v_{11} & v_{12} & \cdots & v_{1m} \\ c_2 & v_{21} & v_{22} & \cdots & v_{2m} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ c_n & v_{n1} & v_{n2} & \cdots & v_{nm} \end{bmatrix}$$

where N_i represents the element to be evaluated; N represents the whole element $N_1, N_2, \ldots N_m$ to be evaluated; and v_{ij} represents the value of the ith feature of the jth element to be evaluated.

After forming the object to be described or evaluated, each feature, and the quantitative value of the object about the feature into an matter-element whole, using the relational degree of extension, set to describe the relationship between each feature and the object to be studied, so as to extend the qualitative description to quantitative description.

(1) The correlation degree function of the ith index number range belonging to the jth level is the following:

$$K_j(x_i) = \begin{cases} \rho(x_i, x_{ji}) / [\rho(x_i, x_{pi}) - \rho(x_i, x_{ji})] & x_i \in x_{ji} \\ -\rho(x_i, x_{ji}) / \left| xji \right| & x_i \notin x_{ji} \end{cases}$$

where:

$$\rho(x_i, x_{ji}) = \left| x_i - \frac{a_{ji}+b_{ji}}{2} \right| - \frac{1}{2}(b_{ji} - a_{ji})$$
$$\rho(x_i, x_{pi}) = \left| x_i - \frac{a_{pi}+b_{pi}}{2} \right| - \frac{1}{2}(b_{pi} - a_{pi})$$

(2) The correlation degree of matter P_0 to be evaluated with respect to grade j is as follows:

$$K_j(P_0) = \sum_{i=1}^{n} w_{ij} K_j(x_i) \tag{1}$$

where w_{ij} is the corresponding weight of its correlation function.

Finally, the evaluation grade of the matter to be evaluated is $K_j = \ \max K_j(P_0) \quad (j = 1, 2, \ldots, m)$, after verifying the evaluation results, illustrating the relative accuracy of extension comprehensive evaluation results.

3. Results

3.1. Building DSM Information Quality Evaluation Indexes Based on the Grounded Theory

3.1.1. Data Sources

Research on demand-side information quality should not only consider users but also the current social environment and economic development trend, that is, pay attention to the social interactivity of the textual material, which fully demonstrates that the collected textual material is an objective material that can fully reflect the quality of demand-side information.

The published papers and documents are basically the secondary processing of existing original materials. In order to ensure the validity of the research process of grounded theory approach and to be more faithful to the original material, on the basis of research topics and situations, the material of this research sample, in addition to the research paper literature, also includes objective data such as online news, national power official website and newspaper news (including the full-text database of important Chinese newspapers (CNKI)), comments on "Zhihu" (a very famous question and answer community platform in China), national power grid, international power network, and Sina Weibo (China's most widely used micro blogs).

Firstly, we searched the above repository with the keywords "power demand side management", "power demand side information quality", "power demand side response", "power/grid information quality", and "power load", with a total time frame of 168 qualitative materials after 2013; secondly, the materials obtained were screened by initial reading, and the screening criterion is the evaluation of electricity demand information quality by users or professionals. The evaluation can best reflect the influence degree of power demand side information. Finally, 114 qualitative materials were obtained, including 15 research papers, 9 newspaper reports, 18 speeches at power grid expert meetings, 22 reports on the official website, 38 expert comments and 12 "Zhihu" comments. Second, we invited a total of 15 experts from grid companies, universities, research institutes, experts, enterprise users, residents, and third-party energy service companies; interviewed them about DSM information quality evaluation index system; made the interview records of more than 90 copies; deleted contradiction or expression of 8 questionnaires, and made 82 copies of effective interview records. The data and records of DSM information quality evaluation index are formed by the collection of two aspects of materials.

3.1.2. Data Coding and Analysis

Open Coding

Preliminarily, 105 free nodes (a1–a105) were obtained after excluding simple and ambiguous descriptions according to the qualitative analysis software NVivo11 and reserving 10 copies of the material for theoretical saturation tests. Through the screening of the frequency of occurrence of statements and the comparative analysis of the library and information professional group discussion, 34 categories (A1–A34) were formed. The specific coding results are shown in Table 1.

Table 1. Results of open coding.

Category	Initial Concept
A1 daily load data	a1 social event, a2 holiday, a3 workday
A2 geo-environmental information	a4 geographical position, a5 regional differences, a6 terrain differences
A3 meteorological information	a7 temperature, a8 rainfall, a9 season change, a10 weather
A4 economic development data	a11 urbanization level, a12 industrialization level, a13 population resources, a14 economic status
A5 power price information	a15 power price reform, a16 time-of-use power price, a17 peak-valley power price
A6 rate of deviation from power forecast	a18 load forecasting method, a19 data mining analysis techniques, a20 forecast model
A7 production load information	a21 production plan, a22 production law, a23 sustained and stable power consumption
A8 traceability of large power users	a24 power for large industrial users, a25 high-power mechanical electricity, a26 large user equipment operating status, a27 high energy user, a28 small hydropower management
A9 reliability of data sources	a29 original data, a30 data availability
A10 power collection information	a31 electrical energy collection, a32 terminal power efficiency
A11 deviation rates of real-time monitoring	a33 abnormal power consumption, a34 power theft monitoring, a35 monitoring of metering unit operation, a36 distribution monitoring, a37 grid quality monitoring, a38 energy efficiency assessment
A12 authenticity of user information	a39 regularity of life, a40 power consumption habits, a41 consumer behavior, a42 power consumption mode
A13 confidentiality	a43 user information collection security, a44 user privacy
a14 timeliness of user response	a45 perceived risk, a46 power price budget, a47 power consumption adjustment
A15 user service interactivity	a48 user warranty, a49 user complaints, a50 message reply, a51 online state grid app
A16 electrical safety	a52 safety protection technology, a53 safety management
A17 conditions of unit operating	a54 line loss, variable loss, power loss, a55 aging of equipment, a56 telecommunications equipment for grids
A18 energy consumption information	a57 equipment utilization, a58 energy information
A19 effectiveness of energy-saving equipment	a59 eco-friendly appliances, a60 energy-saving inverters, a61 energy storage equipment
A20 availability of energy saving technology	a62 renewable energy, a63 power substitution
A21 universality of energy saving promotion	a64 promotion of energy-saving lamps, a65 publicity efforts
A22 smart grid systematic	a66 automatic collection system, a67 terminal collection system, a68 automatic meter reading
A23 stability of load management	a69 voltage control systems, a70 reactive power compensation system

Table 1. *Cont.*

Category	Initial Concept
A24 ease of use	a71 collection of fundamental data, a72 power transmission and transformation equipment ledger
A25 rate of system upgrades	a73 internal update, a74 service system update, a75 work procedures update
A26 frequency of database maintenance	a76 safe operation, a77 low-level maintenance, a78 oracle database
A27 rationalization of the management system	a79 attribute management, a80 contract management, a81 oversight mechanisms, a82 festive care
A28 professionalism of managers	a83 managerial talent, a84 professional talent, a85 professionalism of employees
A29 personnel assessment system	a86 skills assessment, a87 power simulation training, a88 system of rewards and penalties, a89 team performance assessment
A30 relevance and comprehensiveness	a90 industry policy, a91 technical standard, a92 scientific and technical planning
A31 directional accuracy	a93 power gap, a94 consumption structure, a95 power market development
A32 correctness of interpretation	a96 brief analysis of power reform, a97 guideline, a98 restrictive measures
A33 status of start-up documents	a99 new projects, a100 annual development report, a101 enterprise credit evaluation
A34 fund information	a102 bank-enterprise direct connect, a103 budget management, a104 specific investment, a105 economic calculation

Axial Coding

The axial coding is based on the formation of open coding to clarify the interconnection of each category. According to the characteristics of power demand-side information, this study fully considers the application scenarios, and through repeated combing and refining, and through repeated inductive clustering by means of NVivo group function to form 10 main categories (B1–B10), which are finally loaded into the four dimensions of information quality, monitoring information quality, management information quality, and government planning information quality, as shown in Table 2.

Table 2. Results of axials coding.

Dimensions	Main Categories	Categories	Category Connotation
load information quality	B1 environmental information quality	A1 daily load data	Daily load type is categorized into weekdays, holidays, and public holidays, with obvious cyclicality.
		A2 geo-environmental information	Differentiated and complex development across regions and provinces, varying levels of electricity access, and whether the geographic information of the area under their jurisdiction is documented

Table 2. *Cont.*

Dimensions	Main Categories	Categories	Category Connotation
		A3 meteorological information	Weather affects the demand and delivery of electricity, consideration of meteorological factors can improve load forecasting accuracy, and whether meteorological factors in the area under jurisdiction are well documented
		A4 economic development data	GDP, industrial structure and other economic development data is the reference basis for power load forecast, and the load curve also reflects the development of the economy to a certain extent.
		A5 power price information	Flexibility in power price adjustments is prompting customers to change their electricity consumption structure, e.g., Off-peak power price, time-of-use power price
	B2 load forecasting information quality	A6 rate of deviation from power forecast	The accuracy of power system load prediction is related to the stability and safety of power system operation
		A7 production load information	There are many different types of production processes, plans and rules
		A8 traceability of large power users	Power load of large users changes violently and stochastically, which can reflect historical experience and processing capacity
monitoring information quality	B3 real-time operating information quality	A9 reliability of data sources	Only authentic and reliable data content has the value of analysis; the data source of collection must be true and reliable
		A10 power collection information	Electric energy collection information includes data collection, analysis of electricity consumption, automatic settlement of electricity bills, assessment optimization, etc.
		A11 deviation rates of real-time monitoring	The efficiency information mined in real-time dynamic monitoring data and its utilization degree affect the lean level of power enterprises
	B4 user information quality	A12 authenticity of user information	Different types of residents, business locations, resident loads, and industrial loads have different degrees of impact on the load
		A13 confidentiality	Theft of electricity information and data mutations caused by incorrect data can lead to poor data quality and loss of user benefits
		A14 timeliness of user response	Electricity consumption of electricity users is directly related to the price of electricity, region, temperature, lifestyle and the psychology of the consumer.

Table 2. *Cont.*

Dimensions	Main Categories	Categories	Category Connotation
		A15 user service interactivity	To provide business support and services for users, to provide data basis for intelligent power consumption work, and to serve the information system of power users.
	B5 infrastructure information quality	A16 electrical safety	Mainly includes the user's power imbalance, voltage flicker and other safe operations of the power grid.
		A17 conditions of unit operating	Device problems can lead to economic loss of power, real-time monitoring is good for efficient and economical electricity consumption.
		A18 energy consumption information	Analysis of the energy consumption information of the power equipment and the energy saving potential of the equipment can improve the terminal power consumption rate and carry out scientific energy efficiency management
	B6 energy efficiency information quality	A19 effectiveness of energy-saving equipment	Advanced, high-efficiency power-saving devices to achieve lower power consumption, more efficient power use and lower emissions from improved user-side power efficiency.
		A20 availability of energy saving technology	Can the development of renewable energy represented by wind and solar power replace coal, oil, and other energy sources and reduce pollution?
		A21 universality of energy saving promotion	Energy conservation and environmental protection propaganda efforts to influence users' awareness of energy conservation and environmental protection and users' constant pursuit of consumption reduction and efficient electricity consumption behavior.
management information quality	B7 system information quality	A22 smart grid systematic	The smart grid is a combination of power grid and information technology for reliable, safe, economical, efficient, and environmentally friendly operation.
		A23 stability of load management	Making full use of modern remote telemetry and other technical equipment, in-depth load management is the only way to modernize and refine power demand-side management.
		A24 ease of use	Mainly reflected in the system is easy to use and operate, flexible, and accurate response, etc.
		A25 rate of system upgrades	The system needs to be upgraded in time, and the 100% update rate of the system can guarantee the compatibility and normal operation of the system.
		A26 frequency of database maintenance	Regular maintenance of the system improves system functionality and solves problems that occur during system operation.

Table 2. *Cont.*

Dimensions	Main Categories	Categories	Category Connotation
	B8 organization information quality	A27 rationalization of the management system	It includes the scientificity, rationality, operability and management efficiency of the management system.
		A28 professionalism of managers	The power demand side management, technology research and development team, and the professional team of power demand side management, which are related to the scientific nature of demand management.
		A29 personnel assessment system	Organizational management should be based on the principle of objectivity and fairness, and implement a multi-level, multi-channel, comprehensive, and institutionalized evaluation system
government planning information quality	B9 policy information quality	A30 comprehensive	Macro power purchase policy is a guide to ensure normal and orderly production and life of citizens, key enterprises, and cities
		A31 correctness of interpretation	Policies often reflect industry trends, and the policies included in the power information database can provide direction to business users.
		A32 correctness of interpretation	Good power policy interpretation helps users and enterprises to better understand national policies and helps the implementation of national policies.
	B10 new planning information quality	A33 status of start-up documents	This specifically includes the acceptance and audit of new plants and new projects.
		A34 fund information	Investment attraction and capital implementation of enterprise projects is a key part of the enterprise's ongoing projects.

Selective Coding

Selective coding is to further sort out the relationship between categories on the basis of the formation of the main category, and to systematically depict the relationship between the core category and other categories. The typical relationships among the main categories are shown in Table 3, which focuses on the core category of "demand-side information on electricity".

Table 3. Typical relationships structure of main categories.

Typical Relationship	Relationship Structure	Connotation
Environmental information quality→ power demand side information quality	Causal relationship	Power load forecast is sensitive to weather, temperature, and season. Different factors such as temperature, weather, and season will have a significant impact on the power load. Even slight weather and temperature changes will cause fluctuations in power load forecast data.

Table 3. *Cont.*

Typical Relationship	Relationship Structure	Connotation
Load forecast information quality→ power demand side information quality	Causal relationship	The production plan of the enterprise obviously affects the power load, and timely and accurate load forecast for large users can optimize the supply and distribution structure, improve the efficiency of the power grid and reduce the destructive impact of power load changes on the grid.
Real-time information quality→ power demand side information quality	Causal relationship	Information on grid operation, electricity consumption, real-time data and residential power consumption helps provide a comprehensive technical solution for lean metering and lean management of the demand-side grid.
User information quality→ power demand side information quality	Causal relationship	Electricity data from electricity consumers is the basis for effective management of the demand side of the power supply, and information should be collected from all customers, and the quality of customer information has an important impact on the quality of management.
Infrastructure information quality→ power demand side information quality	Causal relationship	By comparing the theoretical line loss and variable loss rate of power grid lines with the actual line loss and variable loss rate calculated from the power voltage, load current, and other data on the terminal equipment on the demand side, the actual line loss can be calculated for the variable loss statistics.
Energy efficiency information quality→ power demand side information quality	Intermediary Relationships	Energy efficiency management, which has an indirect impact on the amount of losses in households and society through the upgrading of power consumption equipment and the R&D and use of renewable energy technologies and power equipment, increasing the efficiency of the use of available energy and the users' awareness to save electricity.
System information quality→ power demand side information quality	Intermediary Relationships	Power demand-side professional information management and application systems can reasonably allocate power resources, while reducing power demand, alleviating environmental pressures, realizing energy conservation and consumption reduction, and achieving economic operation on the premise of ensuring grid security.

Table 3. *Cont.*

Typical Relationship	Relationship Structure	Connotation
Organization information quality→ power demand side information quality	Intermediary Relationships	The science of the system set up in the power company, the professionalism of the managers, and the reasonable division of work all affect the demand side of electricity management process. Optimizing the organization and management of electric power enterprises and building a modern and reasonable organization and management model are conducive to the formation of a unified and coordinated whole.
Policy information quality→ power demand side information quality	Intermediary Relationships	Implementing demand-side management systems to achieve power plant construction, power grid construction, short- and medium- and long-term planning of power grid operation, which improves the quality of the lines and ensures the power safety for the masses, and indirectly affect the stability of demand-side management.
New planning information quality→ power demand side information quality	Intermediary Relationships	Demand-side management of electricity requires high-quality expertise in a wide range of areas. It requires not only professional equipment and technology but also a large amount of human resources and investment. In the current situation, the lack of long-term and stable policy support in the power market environment makes it difficult for demand-side management and large-scale demand response business. Both enterprises and government agencies need to expand their professional teams to meet management needs and set up special management funds at the same time.

3.1.3. DSM Information Quality Evaluation Indexes

By coding the 10 data set aside, the coded labels can all be included in the above coded concepts, and no new categories or associations are found, which satisfies the principle of theoretical saturation; to this point, it is considered that the theoretical saturation verification passes. The purposes of power demand side management are to reduce energy consumption and load, to reduce air pollution from power plants, and to maintain energy service levels and achieve economic and social benefits. Therefore, it is crucial to understand what factors affect the quality of information on the demand side of e power. In this paper, the storyline formed by coding points out that the quality of information on the demand side of electricity is influenced by 10 main categories, which are environmental information quality, the load forecasting information quality, real-time operation information quality, user information quality, infrastructure information quality, energy efficiency information quality, system information quality, organization information quality, policy information quality, and new planning information quality. Based on this, the structural model of the relationship between the influencing factors is shown in Figure 5.

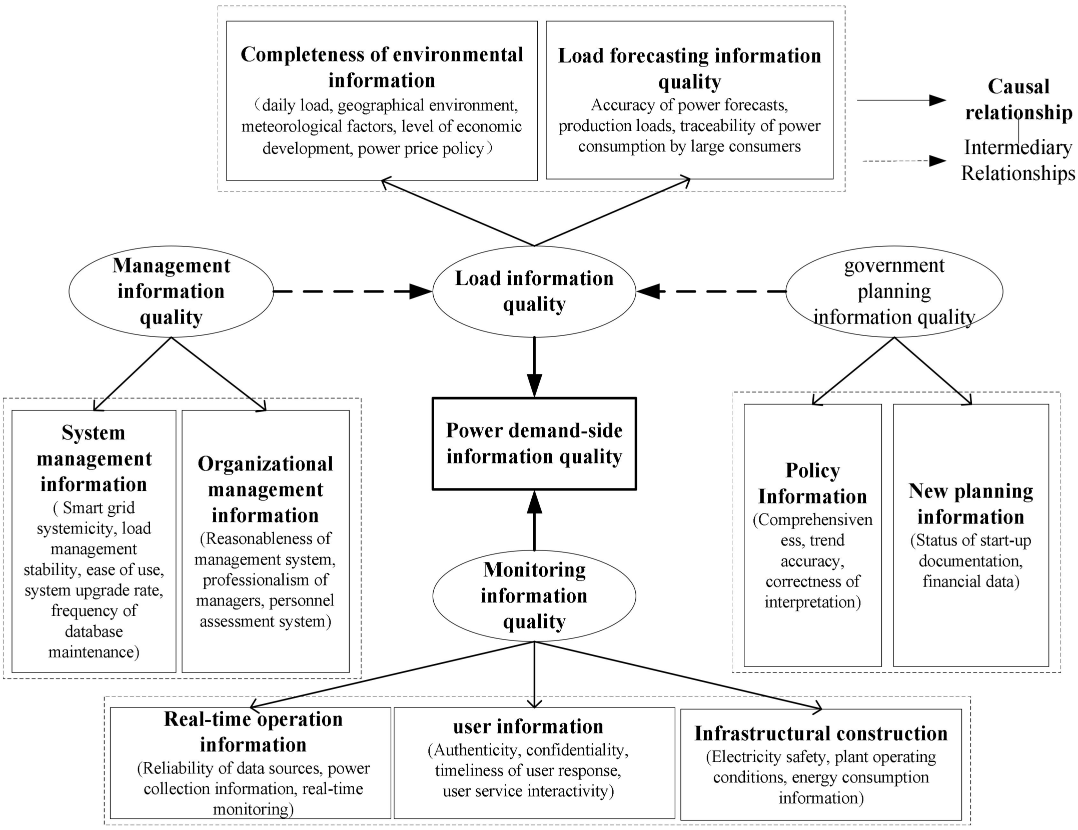

Figure 5. Relational structure model of influencing factors of power demand side information quality.

The model of factors influencing the power demand-side information quality shows 10 main categories that have been researched through grounded theory approach, which include 5 Causal and 5 intermediary relationships, forming 4 dimensions of load information quality, monitoring information quality, management information quality, and government planning information quality. Each of these 4 dimensions has its own characteristic mechanism for influencing the quality of information on the demand side of electricity.

Based on the above study, an indicator system for evaluating the power demand side information quality can be constructed, as shown in Table 4.

Table 4. Design table of evaluation index of DSM information quality.

Primary Indictors	Secondary Indictors	Tertiary Indictors	Type of Indictors	Interpretation
load information quality C_1	external environment information quality C_{11}	daily load informationC_{111}	qualitative	Whether daily load data is recorded and whether there is significant cyclicality
		geo-environmental informationC_{112}	qualitative	Whether geo-environmental information under its jurisdiction is recorded?
		meteorological informationC_{113}	qualitative	Whether the meteorological factors in the area under their jurisdiction are well documented
		economic development information C_{114}	qualitative	Whether GDP, industrial structure, and other economic development data and their data records are complete
		information of flexibility of power price C_{115}	qualitative	Whether the recorded power price has certain flexibility, whether the peak and valley power prices and real-time power prices are recorded.

Table 4. *Cont.*

Primary Indictors	Secondary Indictors	Tertiary Indictors	Type of Indictors	Interpretation
	load forecasting information quality C_{12}	rate of deviation from power forecast C_{121}	quantitative	Whether power system load forecasts reflect power load trends
		production load informationC_{122}	qualitative	Whether the data on the enterprise's production process, planned categories, and production laws are recorded.
		traceability of large power usersC_{123}	qualitative	Whether the data recorded by large power users reflect historical experience and processing capacity
monitoring information quality C_2	real-time operation information quality C_{21}	reliability of data sourcesC_{211}	qualitative	Whether the source of the collected data is reliable and whether the data is available
		power collection informationC_{212}	qualitative	Whether the collected data is comprehensive and accurate
		deviation rates of real-time monitoringC_{213}	quantitative	Whether the information record is real-time monitoring
	users information quality C_{22}	authenticityC_{221}	qualitative	Whether the user information such as the address of residents and enterprises and the type of work is true or not
		confidentialityC_{222}	qualitative	Whether the user data is secure
		timeliness of user response C_{223}	qualitative	Whether user response and information feedback are timely
		user service interactivityC_{224}	qualitative	Whether there is feedback from users' complaints, and whether users are satisfied with business support and service capabilities
	infrastructure information quality C_{23}	electrical SafetyC_{231}	qualitative	Whether infrastructure equipment can ensure the safe operation and safe use of electricity
		plant operating conditionsC_{232}	qualitative	Whether the operating condition of the device is recorded and whether the data is complete.
		energy consumption informationC_{233}	qualitative	Whether energy consumption information is recorded and well documented.
	energy efficiency information quality C_{24}	effectiveness of energy-saving equipmentC_{241}	qualitative	Whether energy-saving devices reduce power consumption and emissions
		availability of energy-saving technologiesC_{242}	qualitative	Whether renewable energy is useful and can replace energy sources such as coal and oil.
		universality of energy-saving promotionC_{243}	qualitative	whether energy saving publicity efforts can influence users' awareness of energy saving and power consumption behavior
management information quality C_3	system information quality C_{31}	smart grid systematicC_{311}	qualitative	Whether the power grid is deeply integrated with information technology and whether the smart grid is systematically complete
		system stabilityC_{312}	qualitative	Whether load management is stable and whether it meets the requirements of refined management of power demand side

Table 4. *Cont.*

Primary Indictors	Secondary Indictors	Tertiary Indictors	Type of Indictors	Interpretation
		ease of useC_{313}	qualitative	Ease of use of the system and variety of search paths
		system upgrade rateC_{314}	quantitative	The system software should be the latest version and meet the standard
		frequency of database maintenance C_{315}	quantitative	Whether the system is routinely maintained and whether the frequency of maintenance meets the operational requirements of the system
	organization information quality C_{32}	reasonableness of the management systemC_{321}	qualitative	Whether the power demand-side information management system meets management requirements.
		professionalism of managersC_{322}	qualitative	Whether power demand-side information managers can handle specialized work
		personnel assessment systemC_{323}	qualitative	The existence of a fair and scientific assessment system for managers
government planning information quality C_4	policy information quality C_{41}	comprehensivenessC_{411}	qualitative	Whether the policy covers all aspects of power management
		relevanceC_{412}	qualitative	Whether the collected policies are relevant to grid planning, and whether there is irrelevant policy information
		accuracy of directionC_{413}	qualitative	Whether the collected policies are correct and consistent with power development trends
		correctness of interpretationC_{414}	qualitative	Whether the interpretation of the power policy is correct and easy to understand
	new planning information quality C_{42}	status of start-up documents C_{421}	qualitative	Whether the audit and review comments of the new project of the enterprise are collected and whether there is a report on the commencement.
		fund informationC_{422}	qualitative	Whether the project funds of the enterprise are implemented, and whether the investment information is grasped

The following is an explanation of the indicators in Table 4:

(1) Load information quality

Load control consists of two main categories, environmental factors and load forecasting, and is an indispensable link in power demand-side management. Load management requires the power supply department to do a good job in power consumption management, improve power consumption efficiency, and reduce power consumption cost by using scientific load forecasting. Therefore, from the point of view of power demand-side management practices, the first step is to improve the accuracy of power load control, which is not only related to the stability and safety of power system operation but also related to the scientific nature of power demand side management.

(2) Monitoring information quality

Power demand side information management is inseparable from the support of monitoring technology. The dimension of monitoring information includes three main categories: real-time operation, user, and infrastructure. In the process of power demand side management, there has not been enough attention to the power quality of the demand side power grid. Problems such as voltage flicker and unbalanced power supply often affect users' power consumption, and even pose a threat to the safe operation of the power grid, which requires power demand-side management and technical personnel to fully capture the data information of the line and can provide suggestions and requirements for technical transformation and other aspects for enterprise users who do not meet the requirements.

(3) Management information quality

The management dimension includes two main categories, system management and organizational management, which can indirectly influence the demand side of electricity by having an impact on the load Quality of information. On the one hand, through the management of each information system, the efficiency and effectiveness of power information collection is improved, which not only reduces costs but also improves the data authenticity. On the other hand, the organization and management model of the company also affects the information quality on the demand side of power to some extent. The more advanced the grid company system is, the more it can integrate into the market environment and meet customer needs, and the more professional and visionary its employees are, the more excellent performance will be created.

(4) Government planning information quality

The scientific management of power demand side is inseparable from the joint efforts of the government and enterprises. A benign grid environment, coupled with scientific power station planning and layout, can realize the relative stability of power station construction cost and electricity price. Therefore, DSM should be taken as an important part of energy planning to establish a higher level of DSM, as well as short- and long-term planning for power plants and power grids. At the same time, the construction planning of the enterprise affects the work arrangement of the electric power enterprises. In the early stage of the construction, whether the audit documents of each link are complete is related to the continuity and stability of the electric power of the enterprise, and power enterprises need to understand and collect this information.

Among the above indicators, qualitative indicators can be scored by experts to determine the specific grading and scale of indicators, such as accuracy standards, real-time time standards, and so on, which requires a lot of practical research and deliberation, due to space limitations; this part is not discussed in this paper.

3.2. Case Study of DSM Information Quality Evaluation Based on Matter-Element Extension Evaluation Method

3.2.1. Case Introduction

The author made a field investigation on the Nanchang Power Supply Company (in Nanchang City, Jiangxi Province, China) and investigated its power demand side information collection, analysis, system management, and utilization mechanism. The main investigation conclusions are as follows:

The power supply company covers an area of about 20,000 square kilometers and is responsible for the electricity needs of about 1.6 million households and 4.8 million people in 10 counties and 1 district and 1 economic development zone in Nanchang. Currently, there are 2500 kV substations, 13,220 kV substations, and 37,110 kV substations under construction. There are 42,220 kV lines/1222 km and 68,110 kV lines/1274 km. In recent years, the economy continues to develop, and the demand for electricity is on a straight upward trend. The last five years have sustained a high annual growth rate within the scope of power supply. The electricity consumption of the primary industry grows rapidly, while the demands of the tertiary industry and non-residents also show an expanding trend. The continuous popularization of the use of household appliances has also led to a great increase in household electricity consumption. In the implementation of demand-side management, Nanchang Power Supply Company clarified the responsibilities of each organization (as shown in Figure 3): adherence to market-oriented, service-oriented, and efficiency-centered organization of power production and operation activities to ensure that all aspects of electricity demand are covered.

The power demand side management of the power supply company mainly includes the following parts:

(1) The large industrial power consumption in the power supply area of the company has always accounted for more than 60% of the total power consumption, so the implementation of DSM and load management for large industrial users will bring significant economic benefits and social significance.
(2) The power company emphasizes regulating peak and flat loads, incentivizing underestimated power consumption, focusing examining on power consumption of underestimated periods, and adhering to hierarchical management and electricity conservation programs.
(3) The Power Supply Company and relevant units in the city jointly carry out the publicity work of power demand side management and publicize the power demand side management project through media publicity, publicity activities, and rules and regulations.
(4) The power supply company applies load control technology to ensure the safe and stable operation of the power system, to guarantee the basic electricity consumption of the community, and, through administrative and regulatory measures, to improve the load rate of the power grid.
(5) In order to ensure the orderly power supply of the power grid, the power supply enterprises improve the security, reliability, and economic operation of the grid; strengthen the supervision and management; optimize the organizational management; scientifically and reasonably allocate and determine the power consumption indicators; and formulate corresponding assessment methods.

3.2.2. Index Weight

In order to evaluate the current power demand side information quality of the power supply company, the author invited more than 10 experts and professors from power supply companies, universities, and energy consulting companies to weigh the evaluation system and apply it to the evaluation language set of extension evaluation. The quantitative data are all from Nanchang Power Supply Company.

Questionnaires were issued to experts to investigate the mutual importance of secondary indicators, using analytic hierarchy process (AHP) to determine the weights of the evaluation index; using the 1–9 scale method to obtain the judgment matrix for each index; and using Yaahp software to calculate the maximum characteristic root λmax, deviation consistency index $CI(CI = \frac{\lambda \max - m}{m-1})$, random consistency ratio $CR(CR = \frac{CI}{RI})$, and weight vector of the judgment matrix, as shown in Table 5.

Table 5. Judgment matrix consistency and index weight table.

Judgment Matrix	λmax	CI	CR	Weight Vector
G	4.2343	0.0781	0.89	(0.5556,0.3000,0.0940,0.0504)
A_1	2.0000	0	0	(0.2500,0.7500)
A_2	4.0687	0.0229	0.89	(0.5628,0.1079,0.2671,0.0622)
A_3	2.0000	0	0	(0.8889,0.1111)
A_4	2.0000	0	0	(0.2500,0.7500)
B_{11}	5.3328	0.0831	1.12	(0.2100,0.0646,0.4853,0.1002,0.1399)
B_{12}	3.0387	0.01935	0.52	(0.2605,0.6333,0.1062)
B_{21}	3.0542	0.0271	0.52	(0.1822,0.1149,0.7028)
B_{22}	4.1923	0.0641	0.89	(0.6366,0.1267,0.1404,0.0963)
B_{23}	3.0948	0.0474	0.52	(0.5321,0.3661,0.1018)
B_{24}	3.0658	0.0329	0.52	(0.7235,0.1932,0.0833)
B_{31}	5.3915	0.0979	1.12	(0.5490,0.1892,0.0800,0.0527,0.1291)
B_{32}	3.0387	0.0193	0.52	(0.2605,0.6333,0.1062)
B_{41}	4.2013	0.0671	0.89	(0.5011,0.2630,0.0768,0.1591)
B_{42}	2.0000	0	0	(0.6667,0.3333)

It can be seen from the above table that the random consistency ratios CR are all less than 0.1, and the judgment matrix has satisfactory consistency.

3.2.3. Evaluation Process

Evaluation Set Identification

By referring to relevant literature and combining with expert suggestions, we classify the quality of electricity demand-side information into five levels from high to low: excellent, good, general, poor, and very poor; the score intervals are shown in Table 6. The range of qualitative indexes from excellent to very poor values is 90~100, 80~90, 70~80, 60~70, 0~60. The qualitative indicators range from excellent to very poor scores are 90–100, 80–90, 70–80, 60–70, 0~60, and the quantitative indexes score ranges are shown in Table 6.

Table 6. Score intervals of quantitative indexes.

Quantitative Indexes	Level				
	Excellent	Good	General	Poor	Very Poor
Deviation rate of power forecasts	(0.5%)	(5%,10%)	(10%,20%)	(20%,30%)	(30%,100%)
Power collection information	(30%,100%)	(20%,30%)	(10%,20%)	(5%,10%)	(0,5%)
deviation rates of real-time monitoring	(0.5%)	(5%,10%)	(10%,20%)	(20%,30%)	(30%,100%)
System upgrade rate	(30%,100%)	(20%,30%)	(10%,20%)	(5%,10%)	(0,5%)
Database maintenance rate	(30%,100%)	(20%,30%)	(10%,20%)	(5%,10%)	(0,5%)

After asking experts to familiarize themselves with the index system, the content of the indexes and the evaluation criteria constructed in this study, the qualitative indicators were judged and scored, and quantitative indexes were calculated. The average score for each indicator is shown in Table 7.

Table 7. Indexes scores.

Tertiary Indexes	Variables	Average Scores
daily load data	C_{111}	88
geo-environmental information	C_{112}	76
meteorological information	C_{113}	92
economic development information	C_{114}	86
information of flexibility of power price	C_{115}	83
rate of deviation from power forecast [%]	C_{121}	3
production load information	C_{122}	82
traceability of large power users	C_{123}	78
reliability of data sources	C_{211}	94
power collection information [%]	C_{212}	90
deviation rates of real-time monitoring [%]	C_{213}	2
authenticity	C_{221}	92
confidentiality	C_{222}	93
timeliness of user response	C_{223}	78
user service interactivity	C_{224}	76
electrical safety	C_{231}	88
plant operating conditions	C_{232}	92
energy consumption information	C_{233}	82
effectiveness of energy-saving equipment	C_{241}	75
availability of energy-saving technologies	C_{242}	78
universality of energy-saving promotion	C_{243}	76
smart grid systematic	C_{311}	92
system stability	C_{312}	94
ease of use	C_{313}	86
system upgrade rate [%]	C_{314}	95
frequency of database maintenance [%]	C_{315}	85

Table 7. *Cont.*

Tertiary Indexes	Variables	Average Scores
reasonableness of the management system	C_{321}	85
professionalism of managers	C_{322}	82
personnel assessment system	C_{323}	77
comprehensiveness	C_{411}	88
relevance	C_{412}	92
accuracy of direction	C_{413}	86
correctness of interpretation	C_{414}	82
status of start-up documents	C_{421}	75
fund information	C_{422}	78

Correlation Function and the Calculation of Comprehensive Correlation Degree

According to the calculation formula of correlation function in extension theory, the value of correlation function $K_j(\overline{v}_i)$ and comprehensive correlation degree $K_j(P0)$ of information quality level on the power demand side are obtained after calculation, as shown in Table 8.

Table 8. Correlation function value of information quality level on the power demand side.

Indexes	Grade				
	Excellent	Good	General	Poor	Very Poor
daily load dataC_{111}	−0.143	0.2	−0.4	−0.6	−0.7
Geo-environmental informationC_{112}	−0.368	−0.143	0.4	−0.2	−0.4
meteorological informationC_{113}	0.2	−0.2	−0.6	−0.733	−0.8
economic development informationC_{114}	−0.222	0.4	−0.3	−0.533	−0.65
information of flexibility of power priceC_{115}	−0.292	0.3	−0.15	−0.433	−0.575
rate of deviation from power forecastC_{121}	0.4	−0.4	−0.76	−0.867	−0.9
production load informationC_{122}	−0.308	0.2	−0.1	−0.4	−0.55
traceability of large power usersC_{123}	−0.353	−0.083	0.2	−0.267	−0.45
reliability of data sourcesC_{211}	0.4	−0.6	−0.8	−0.867	−0.9
power collection informationC_{212}	0.4	−0.6	−0.84	−0.911	−0.933
deviation rates of real-time monitoringC_{213}	0.895	0.889	−0.879	−0.862	0.143
authenticityC_{221}	0.2	−0.2	−0.6	−0.733	−0.8
confidentialityC_{222}	0.3	−0.3	−0.65	−0.767	−0.825
timeliness of user responseC_{223}	−0.353	−0.083	0.2	−0.267	−0.45
user service interactivityC_{224}	−0.368	−0.143	0.4	−0.2	−0.4
electrical safetyC_{231}	−0.143	0.2	−0.4	−0.6	−0.7
plant operating conditionsC_{232}	0.2	−0.2	−0.6	−0.733	−0.8
energy consumption informationC_{233}	−0.308	0.2	−0.1	−0.4	−0.55
effectiveness of energy-saving equipmentC_{241}	−0.375	−0.167	0.5	−0.167	−0.375
availability of energy-saving technologiesC_{242}	−0.353	−0.083	0.2	−0.267	−0.45
universality of energy-saving promotionC_{243}	−0.369	−0.144	0.4	−0.2	−0.4
smart grid systematicC_{311}	0.2	−0.2	−0.6	−0.73	−0.8
system stability C_{312}	0.4	−0.4	−0.7	−0.8	−0.85
ease of useC_{313}	−0.222	0.4	−0.3	−0.533	−0.65
system upgrade rateC_{314}	0.947	0.944	−0.934	−0.931	0.071
frequency of database maintenanceC_{315}	0.842	0.833	−0.818	−0.793	0.214
reasonableness of the management systemC_{321}	−0.25	0.5	−0.25	−0.5	−0.625
professionalism of managersC_{322}	−0.308	0.2	−0.1	−0.4	−0.55
personnel assessment systemC_{323}	−0.361	−0.115	0.3	−0.233	−0.425
comprehensivenessC_{411}	−0.143	0.2	−0.4	−0.6	−0.7
relevanceC412	0.2	−0.2	−0.6	−0.733	−0.8
accuracy of directionC_{413}	−0.222	0.4	−0.3	−0.533	−0.65
correctness of interpretationC_{414}	−0.308	0.2	−0.1	−0.4	−0.55
status of start-up documentsC_{421}	−0.375	−0.167	0.5	−0.167	−0.375
fund informationC_{422}	−0.353	−0.083	0.2	−0.267	−0.45

Evaluation Results Analysis

Combining the correlation function values and the weight values of the indexes at all levels, the evaluation result of information quality on power demand-side of this power enterprise can finally be obtained, as shown in Table 9.

Table 9. Evaluation result of information quality on power demand-side.

	Excellent	**Good**	**General**	**Poor**	**Very Poor**	**Result of Extension Evaluation**
overall assessment	0.0763	0.0431	−0.2947	−0.7345	−0.7751	excellent

The greater the correlation degree is, the higher the probability of the object belonging to a certain rank is. The largest correlation degree of the overall information quality on power demand-side of Nanchang Power Supply Company is 0.0763, which corresponds to excellent, that is, the overall power demand-side information quality of the power supply company is excellent. However, through the analysis and evaluation process, the power demand side information quality of the power supply company can still be improved in detail. Specifically, in the process of managing the power demand side information, the power supply company needs to focus on improving the services related to user interaction in B22 and increasing the development and promotion of energy-saving equipment technology in B24, in order to minimize energy consumption in the power supply area. On top of this, more attention needs to be paid to the availability of information in the B42 enterprise planning documents information, so as to reduce the correlation degree between each index and the lower level and increase the correlation degree with the higher level, so as to improve the comprehensive correlation degree of the level information quality, thus effectively improving the level of information quality on power demand side.

4. Discussion

In this paper three important contents are put forward:

Firstly, we downloaded 168 copies of valuable materials from academic journals, news reports, and professional forums about DSM information quality; invited a total of 15 experts out of different stakeholders; and collected more than 90 interview records. These materials provide substantial and reliable data for the grounded process of DSM information quality indicators.

Secondly, we used grounded theory approach to build DSM information quality indicators. Through open coding, spindle coding, and selective coding, a total of 34 indicators from four dimensions were constructed.

Finally, we put forward the case study of Nanchang Power Supply Company (in Nanchang City, Jiangxi Province, China) based on matter-element extension evaluation method. The case study results show DSM information quality evaluation indexes are effective, and the evaluation method is also applicable.

Compared with previous studies, we have made some innovations or progress in this paper.

Compared to a previous study [34] about information and communication technology in the energy field, we propose a more explicit technical path, that is, to improve energy efficiency by improving the quality of information. Compared to literatures [35–37] mainly about economic and technical evaluation of DSM projects, we innovatively propose information quality evaluation. Compared to Vasco et al. [38] about evaluation indicators of DSM, we use the grounded theory to construct the index system and demonstrate the effectiveness of the index system through empirical analysis, which makes our research more grounded and logical.

5. Conclusions

As a capital-intensive industry, power grid construction projects have the characteristics of large investment amount, long payback period, and high risk. The information quality evaluation on the power demand side is of positive significance for ensuring the investment benefits of power grid construction projects, reducing risk losses, and promoting socio-economic development. The main work and conclusions of this paper are as follows:

(1) Using the grounded theory to study the method of evaluating the information quality on the power demand side, the index system for evaluating the information quality on the power demand side was constructed, which is a beneficial supplement of the power demand-side management. The index system covers 4 dimensions (load information quality, monitoring information quality, management information quality, and government planning information quality) and includes 10 main categories (environmental information quality, load forecasting information quality, real-time operating information quality, user information quality, and infrastructure information quality, energy efficiency information quality, system information quality, organization information quality, policy information quality, and new planning information quality). The relationship between environment information, load forecasting information, real-time operating information, user information, infrastructure information, and power demand side information quality is causal; the relations between energy efficiency information, system information, organization information, policy information, new planning information, and power demand side information quality are intermediary relations. Through the interaction of factors, the evaluation index system of power demand side information quality is constructed. On this basis, the empirical analysis based on the extension comprehensive evaluation proves that the index system is feasible in theory and method. It is of practical significance to understand the current level of information quality on the demand side and point out the direction for improving information quality to the next higher stage.

(2) The issue of power demand-side information quality is a complex and dynamic problem that cannot be solved entirely by a set of indicator systems and evaluation methods. Although we have done some work on the establishment of the index system and evaluation methods, there are still shortcomings. relevant research and the verification of specific cases can be further detailed, and the index system and evaluation methods can be further enriched and expanded. However, the original research on power demand side information evaluation can serve as a reference for future related research.

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