

Postprint of Implicit Feature Analysis of Exogenous Warning Sources in Regional Energy Security Based on Multi-dimensional Association Rules

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Abstract

Addressing the frequent occurrence of regional energy security emergencies in China at the current stage, this study investigates the implicit characteristics of exogenous warning sources for regional energy security. Through case extraction from regional energy security incidents, we construct attribute sets and datasets for energy security exogenous warning sources. Based on the characteristics of the dataset, a multi-dimensional association rule mining model for energy security exogenous warning sources is designed. This model first adopts a multi-dimensional attribute fusion approach, mapping the multi-dimensional attributes of exogenous warning sources to one dimension by partitioning attributes into transaction items, and then performs rule mining utilizing the fundamental principles of the Apriori algorithm. On this basis, the model is applied to the analysis of implicit features of energy security exogenous warning sources to investigate the association relationships among warning source attributes and achieve output of strong association rules. The research results demonstrate that the multi-dimensional association rule method can discover patterns hidden within exogenous warning source data. Through inductive analysis of the mined rule set, it is concluded that regional energy security exogenous warning sources exhibit common characteristics including derivability, seasonality, harmfulness, and persistence when they erupt.

Full Text

Preamble

Title: Analysis on Implicit Characteristics of Regional Energy Security Exogenous Sources Based on Multi-Dimensional Association Rules

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Abstract: In response to the frequent occurrence of regional energy security emergencies in China, this paper investigates the implicit characteristics of regional energy security exogenous sources. Through case extraction of regional energy security incidents, we construct an attribute set and dataset for energy security exogenous sources. Based on the characteristics of the dataset, we design a multi-dimensional association rule mining model for energy security exogenous sources. This model first maps multi-dimensional attributes to one dimension by dividing attributes into transaction items based on the idea of multi-dimensional attribute fusion, and then mines rules using the basic principles of the Apriori algorithm. On this basis, the model is applied to analyze the implicit characteristics of energy security exogenous sources, examining the relationships among source attributes to output strong association rules. The research results demonstrate that the multi-dimensional association rule method can discover patterns hidden in exogenous source data. Through inductive analysis of the mined rule set, we conclude that regional energy security exogenous sources exhibit common characteristics of derivativeness, seasonality, harmfulness, and durability when they erupt.

Keywords: regional energy security; exogenous source; multi-dimensional association rules; Apriori algorithm; implicit characteristics

0 Introduction

In recent years, frequent regional energy security emergencies have seriously impacted economic development and social stability across China. For example, in early 2008, natural disasters caused by blizzards severely affected power grid operations, resulting in large-scale power rationing and outages in 19 provinces. Since 2011, Chongqing has experienced tight coal supplies for power generation due to sudden strict controls on coal sales and transportation imposed by coal-producing regions such as Guizhou and Sichuan. In November 2013, more than ten provinces in North and Southwest China experienced a sudden large-scale “gas shortage.” The triggers for these incidents were primarily sudden changes in external factors to the energy system. However, China’s current energy security system cannot effectively analyze the exogenous sources that trigger regional energy security events, leading to frequent regional energy supply-demand gaps. Therefore, deeply mining the implicit characteristics of regional energy security exogenous sources is of great significance for effective early warning research on regional energy security.

Existing research on regional energy security primarily focuses on macro-level studies. Vlado [?] established a novel and expanded conceptual energy security assessment tool that fully considers quantitative and qualitative attributes of energy security and policies for each country or region, evaluating energy security across 11 dimensions. Andreas et al. [?] explored the composition of

energy security indicator systems in depth, arguing that energy security metrics include predictive indicators and outcome indicators. Liu Litao et al. [?] systematically constructed a regional energy security evaluation index system for China and conducted empirical analyses of energy security in Guangdong and Shaanxi as representatives of energy input and output regions. Zhao Chunfu et al. [?] proposed building a chain-based early warning system from the perspective of supply chains, considering interactions among internal energy system factors and external factors. Fan Qiufang [?] analyzed specific energy security early warning problems and constructed a petroleum security monitoring and warning method and model based on BP neural network principles, conducting empirical application analysis. Guo Jindong et al. [?] constructed a coal safety measurement index system from three subsystems of coal safety pressure, status, and response to evaluate coal safety levels. Su Fei et al. [?] quantitatively assessed the conventional energy supply vulnerability of 30 Chinese regions based on a regional energy security vulnerability evaluation model and indicator system. Wu Chuguo et al. [?] defined energy security standards and calculated evaluation index weights using comprehensive scoring and entropy weight methods to assess China's energy security under different scenarios. Hu Jianbo et al. [?] constructed nine indicators from three aspects of pressure, status, and response to evaluate China's energy security status. Zhang Qiang [?] used integrated complex system research methods to build an energy security early warning system, detailing the system's design and implementation. Zhou Dequn et al. [?] used Hilbert-Huang transform to construct oil price fluctuation warning components for grading research on historical oil price fluctuation processes. Guo Lingling et al. [?] used system dynamics theory to build a system dynamics model of China's energy security, simulating three development patterns. Hao Ping et al. [?] established a regional energy consumption early warning system using data warehouses and association rule mining methods for monitoring and warning. However, few studies relate to regional energy security exogenous sources. Only scholar Chi Chunjie [?] proposed the concept of energy security exogenous sources, while Wei Yiming et al. [?, ?] analyzed key external factors inducing regional energy security events.

Through reviewing the above literature, we find that existing regional energy security systems have not studied the root elements that induce energy security events. Therefore, this paper defines the main external factors affecting regional energy security events as exogenous sources from an external perspective and clarifies their connotation. We extract exogenous source attributes through cases and construct an exogenous source dataset. Combining the characteristics of the exogenous source dataset, we use multi-dimensional association rule methods to deeply mine the implicit characteristics of regional energy security exogenous sources, aiming to provide decision-making references for regional energy security early warning.

1 Connotation and Characteristic Attributes of Energy Security Exogenous Sources

1.1 Connotation of Regional Energy Security Exogenous Sources

Regional energy security early warning refers to the predictive evaluation of future evolution trends of an energy system in a certain region to identify potential problems in advance, analyze their causes, and provide decision-making basis for warning analysis, formulation of preventive measures, and alleviation of energy supply-demand contradictions. Specifically, early warning is the process of measuring the degree of deviation from a warning line and issuing warning signals, essentially evaluating the stability of regional energy security operations, with the purpose of recognizing dangers in advance and implementing pre-control.

Regional energy security exogenous sources refer to external influencing factors that change in regional energy systems, such as energy price fluctuations, energy policy adjustments, and sudden natural disasters, causing disturbances in regional energy systems and triggering chain reaction events that threaten regional energy security. This paper defines these external elements affecting regional energy system security as exogenous sources. Exogenous sources are important external roots for analyzing sudden regional energy security warnings and are the source of regional energy security warnings. Therefore, studying regional energy security exogenous sources is a new logical starting point for regional energy security early warning, with the key being how to effectively identify regional energy security exogenous sources and their formation mechanisms.

1.2 Types of Regional Energy Security Exogenous Sources

Many external factors trigger regional energy security issues, including macroeconomic, energy policy, environmental, and sudden factors. This paper collected typical regional energy security events and found that the root causes of most regional energy security events were external factors to the energy system. Based on summarizing the causes and evolution processes of regional energy security events and according to the above external influencing factors, we classify exogenous sources from the perspective of their formation mechanisms as follows:

- a) Energy price fluctuations. Since China's energy prices are government-controlled and the pricing mechanism is not determined by market supply and demand, energy price disturbances break the local energy supply-demand balance, forming exogenous sources that interfere with regional energy security and ultimately inducing regional energy security events. Taking refined oil as an example, the domestic energy pricing mechanism allows wholesale enterprises to adjust prices flexibly within government-regulated ranges. When wholesale enterprises suddenly raise prices, retail enterprises, constrained by strict government pricing mechanisms, adjust prices relatively slowly in response to market supply-demand changes, resulting in purchase prices higher than sales prices and seriously affecting

profit margins. This energy price disturbance element becomes an exogenous source of regional energy security, and when it accumulates to a certain degree, it will inevitably trigger regional energy security events such as energy supply stoppages or rationing.

- b) Inappropriate regional energy policy interventions. Some regions, for their own economic development or constrained by national-level policies, will forcibly intervene in energy policies during specific periods, causing local energy supply-demand and allocation imbalances and inducing regional energy security events. For example, in November 2010, power security events erupted in Zhejiang, Jiangsu, Hunan, and other regions because local governments conducted sudden power rationing to meet emission reduction targets. In 2011, Chongqing experienced tight coal supplies for power generation due to sudden strict controls on coal sales and transportation imposed by Guizhou coal-producing regions.
- c) Changes in external environment. Changes in the external environment as exogenous sources of regional energy security are more likely to induce sudden changes in local energy demand and supply, leading to regional energy security events. Through analysis of the causes of sudden regional energy security events in various regions in recent years, we divide the external environment affecting regional energy security into seasonal changes, transportation capacity constraints, natural disasters, and emergencies in energy production and transportation. For example, in 2008 and 2009, sudden snowfall in winter across many regions for two consecutive years hindered energy transportation, resulting in “coal shortages” and “power shortages.”

1.3 Exogenous Source Characteristic Attributes

Through collecting regional energy security events such as “coal shortage,” “oil shortage,” “power shortage,” and “gas shortage,” we comparatively analyzed the formation mechanisms of various energy security exogenous sources. Based on relevant literature, we extracted common characteristics of various energy security exogenous sources and divided them into descriptive attributes and status attributes, as shown in Figure 1 [Figure 1: see original paper]. The specific attribute divisions are shown in Table 1 .

1.4 Exogenous Source Characteristic Attribute Classification

Since regional energy security exogenous source attributes have multi-dimensional characteristics, classical single-dimensional rule methods cannot mine implicit features. Therefore, by consulting experts in energy security, referencing relevant literature on classification levels, and conducting in-depth analysis of the formation mechanisms and impact degrees of regional energy security exogenous sources, we first quantitatively classify status attributes and convert multi-dimensional exogenous source characteristic attributes into

transaction items.

2 Multi-Dimensional Association Rule Mining Model Construction

Through exogenous source characteristic attribute classification, exogenous source cases are converted into a set of transaction items $I=\{i_1,i_2,\dots,i_m\}$. This paper uses the basic principles of the Apriori algorithm to mine rules hidden in exogenous source data. This method mainly includes two processes: first, finding all frequent itemsets from the transaction item set; second, generating strong association rules from frequent itemsets.

2.1 Basic Principles of the Apriori Algorithm

The Apriori algorithm is one of the most influential algorithms for mining Boolean association rule frequent itemsets. The algorithm's name is based on the fact that it uses prior knowledge of frequent itemset properties. Apriori uses a layer-by-layer search iterative method, where k -itemsets are used to explore $(k+1)$ -itemsets. First, find the set of frequent 1-itemsets, denoted as L_1 . L_1 is used to find the set of frequent 2-itemsets L_2 , which is then used to find L_3 , and so on, until no frequent k -itemset can be found. Finding each L_k requires one database scan.

- 1) **Generating Frequent Itemsets:** First find the set of frequent 1-itemsets, denoted as L_1 . L_1 is used to find the set of frequent 2-itemsets L_2 , which is used to find L_3 , and so on, until no frequent k -itemset can be found. Finding each L_k requires scanning the database once. The steps are as follows:
 - a) Find frequent 1-itemsets. Scan the transaction database, where $\text{Sup}_{\{\text{count}\}}(A)$ represents the number of times transaction itemset A appears, and $\text{Count}(T)$ represents the number of transactions. Equation (1) defines the support of frequent itemsets, and individual transaction items that meet the minimum support are called frequent 1-itemsets.
 - b) **Connection Step:** Generate candidate k -itemset sets by connecting L_{k-1} with itself. This candidate set is denoted as C_k . Let l_1 and l_2 be itemsets in L_{k-1} , where $l_i[j]$ represents the j -th item of l_i . For convenience, assume transaction items are sorted in order of appearance. Perform connection $L_{k-1} \times L_{k-1}$, where elements of L_{k-1} are connectable if their first $(k-2)$ items are identical. That is, when the condition in Equation (2) is satisfied, elements l_1 and l_2 of L_{k-1} are connectable, and connecting l_1 and l_2 produces the resulting itemset $l_1[1]l_1[2]\dots l_1[k-1]l_2[k-1]$.
 - c) **Pruning Step:** C_k is a superset of L_k ; its members may or may not be frequent, but all frequent k -itemsets are contained in C_k . Scan the database to determine the count of each candidate in C_k , and determine L_k according to Equation (1) for minimum support. However, C_k may be

large, making the computation involved considerable. Any non-frequent (k-1)-itemset cannot be a subset of a frequent k-itemset. Therefore, if a (k-1)-subset of a candidate k-itemset is not in L_{k-1}, the candidate cannot be frequent and can be deleted from C_k.

- 2) **Generating Strong Association Rules:** After generating frequent itemsets, strong association rules are output through confidence. If A and B are transaction itemsets, then confidence is defined as:

$$\text{confidence}(A \Rightarrow B) = \frac{\text{Sup_count}(A \cup B)}{\text{Sup_count}(A)}$$

If $\min\{\text{conf}\}$ represents the minimum confidence threshold, for each frequent itemset l, generate all non-empty subsets of l. For each non-empty subset S, if Equation (4) is satisfied, output the rule:

$$\frac{\text{Sup_count}(l)}{\text{Sup_count}(S)} \geq \min_conf$$

2.2 Apriori Algorithm Flow

The Apriori algorithm flow is shown in Algorithm 1.

Algorithm 1: Apriori uses a level-wise iterative approach based on candidate generation to find frequent rules.

Input: Transaction database D; minimum support threshold $\min\{\text{sup}\}$.

Output: Frequent itemsets L in D.

- 1) Scan database D to find frequent 1-itemsets;
- 2) for (k=2; L_{k-1} ≠ ∅; k++) {
- 3) C_k = apriori_{gen}(L_{k-1}, $\min\{\text{sup}\}$); // Generate candidate sets and prune
- 4) for each transaction t ∈ D { // Scan database for counts
- 5) C_t = subset(C_k, t); // Get subsets of t that are candidates
- 6) for each candidate c ∈ C_t
- 7) c.count++;
- 8) }
- 9) L_k = {c ∈ C_k | c.count ≥ $\min\{\text{sup}\}$ }
- 10) }
- 11) return L = ∪ L_k // All frequent sets;

procedure apriori_{gen}(L_{k-1}: frequent (k-1)-itemsets; $\min\{\text{sup}\}$: minimum support threshold)

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1) for each itemset l1 Lk-1
2) for each itemset l2 Lk-1
3)   if (l1[1]=l2[1]) (l1[2]=l2[2]) ... (l1[k-2]=l2[k-2]) (l1[k-1]<l2[k-1]) then {
4)     c = l1 l2; // Connection step: generate candidates
5)     if has_{{infrequent}}_{{subset}}(c, Lk-1) then
6)       delete c; // Pruning step: remove non-frequent subsets
7)     else add c to Ck;
8)   }
9) return Ck;

**procedure has_{{infrequent}}_{{subset}}(c: candidate k-itemset; Lk-1:
frequent (k-1)-itemset)**

// Use prior knowledge 1) for each (k-1)-subset s of c 2) if s Lk-1 then 3) return
TRUE; 4) return FALSE;

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3 Case Application of Implicit Feature Mining for Exogenous Sources

3.1 Data Acquisition and Preprocessing

Through literature review, website searches, expert interviews, and field research, we collected information on regional energy security exogenous source events that occurred in various regions of China in recent years. After data extraction, analysis, and preprocessing, we constructed a regional energy security exogenous source transaction database. We use five typical exogenous source cases from Table 2 as transactions to illustrate the application process of the multi-dimensional association rule method and verify its feasibility.

From Table 2, we can see that transactions are described by multi-dimensional attributes, i.e., composed of multiple predicates. Therefore, we use multi-dimensional association rule methods to mine patterns hidden in transactions. First, we use Table 1 to classify transaction characteristic attributes, converting multi-dimensional attributes into transaction items, thereby constructing the transaction database. The conversion results are shown in Table 3.

3.2 Frequent Itemset Generation

For convenience in scanning the transaction information table, we assume items in transactions are stored in attribute order, with five transactions in the transaction database. We set the minimum support threshold $\min_{\text{sup}}=60\%$, meaning the support count threshold is 3. Figure 2 [Figure 2: see original paper] shows the frequent itemset generation process.

- a) In the first iteration, each transaction item in Table 3 is a candidate set. We scan the transaction database, record the occurrence count of each transaction item in transactions, and select transaction items with counts greater than or equal to the support count threshold as frequent 1-itemsets L1.
- b) To discover frequent 2-itemsets, we perform connection L1 L1 to obtain candidate sets for frequent 2-itemsets. We scan the transaction database, record the occurrence count of each candidate itemset, and select candidate itemsets with counts greater than or equal to the support count threshold as frequent 2-itemsets L2.
- c) Perform connection L2 L2, where two frequent 2-itemsets satisfying Equation (2) can be connected to obtain candidate sets for frequent 3-itemsets. For example, $\{Td, Pa\}$ and $\{Td, Pb\}$ satisfy the condition, and their connection yields the frequent 3-itemset candidate $\{Td, Pa, Pb\}$. Simultaneously, we use the pruning step to delete impossible itemsets. For instance, when connecting $\{Td, Pa\}$ and $\{Td, Ic\}$, $\{Pa, Ic\}$ does not belong to frequent itemset L2, so the connected result $\{Td, Pa, Ic\}$ cannot be a frequent 3-itemset and must be deleted. After obtaining the frequent 3-itemset candidate set, we scan the transaction database, record the occurrence count of each candidate itemset, and select candidate itemsets with counts greater than or equal to the support count threshold as frequent 3-itemsets L3. Similarly, frequent 4-itemsets and 5-itemsets are generated using the same method as step c).

3.3 Strong Association Rule Generation

After obtaining frequent itemsets, we generate association rules according to Equation (4), setting the minimum confidence threshold $\min_{\{conf\}}=100\%$. A total of 187 rules were mined from the frequent itemsets of exogenous source data, forming a rule set. We excerpt some rules from the rule set and interpret them, as shown in Table 4 .

By analyzing the mined rule set, we systematically summarize the common characteristics hidden in the five typical cases of regional energy security exogenous sources:

- a) **Derivativeness of Regional Energy Security Exogenous Sources:** Regardless of the nature and scale of regional energy security exogenous source eruptions, they will spread to other regions to varying degrees in a short time, breeding more serious and widespread energy security events. Through analysis of the regional energy security exogenous source rule set, we find that among 187 rules, 12 rules support the derivativeness characteristic, such as Rule 16, where energy security events erupting in East China spread to Central China. Analysis results based on such derivativeness characteristics help reduce the spread range of regional energy security events induced by exogenous sources, because when an exogenous

source erupts in one region, warning signals will be transmitted to adjacent regions, enabling them to quickly formulate effective energy security early warning plans to reduce the probability or degree of energy security risk occurrence.

- b) **Seasonality of Regional Energy Security Exogenous Sources:** Based on inductive analysis of the mined rule set, regional energy security exogenous sources show strong seasonality, with most regional energy security events erupting in winter. Among 187 rules, 124 rules support this temporal characteristic, such as Rules 47 and 124. The main reason is that during seasonal transitions, energy demand in most regions increases sharply in winter, and the frequency of sudden events such as snow disasters is higher in winter, which affects energy production and supply to some extent. Based on analysis of such seasonal characteristics, regions can prepare energy reserves according to seasonal variation patterns and conduct real-time early warnings for sudden energy events induced by seasonal factors, reducing the probability of regional energy gap risk occurrence.
- c) **Harmfulness of Regional Energy Security Exogenous Sources:** Based on analysis of the mined rule set, after regional energy security exogenous sources erupt, the induced energy gap hazard level is large. Among 187 rules, 26 rules support the harmfulness characteristic, such as Rule 75. The reason is that energy, as the main cornerstone of regional economic development, once a gap occurs, will inevitably adversely affect regional production and life, thereby hindering regional economic development. Based on analysis of such harmfulness characteristics, it helps warn various regions to actively allocate energy through various channels after exogenous source eruptions to reduce energy gaps and thereby lower the hazards brought by exogenous source eruptions.
- d) **Persistence of Regional Energy Security Exogenous Sources:** After regional energy security exogenous sources erupt, they generally last for a long time. Analysis of the rule set shows that the duration after exogenous source eruptions is generally 1-3 months, with 20 rules among 187 supporting the persistence characteristic, such as Rule 11. Based on analysis of such persistence characteristics, it helps warn various regions to prepare for protracted battles in advance, so that once exogenous sources erupt, they can effectively cope with the adverse effects brought by the persistence of exogenous sources.

3.4 Application Effect on Large-Scale Data

To verify the application effect of the multi-dimensional association rule mining algorithm on large datasets, we collected over 100 regional energy security exogenous source events occurring from 1999 to 2015, conducted data extraction, analysis, and preprocessing, and constructed a regional energy security exoge-

nous source transaction database. We used the multi-dimensional association rule mining algorithm for rule mining, with results shown in Figure 3 [Figure 3: see original paper]. Figure 3 shows that when the number of regional energy security exogenous source events is large, the multi-dimensional association rule mining algorithm is feasible. The setting of minimum support determines the number of mined association rules, and as minimum support increases, the number of mined association rules gradually decreases.

4 Conclusion

Through research on the basic theory of regional energy security exogenous sources and multi-dimensional rule mining methods, we analyzed patterns hidden in exogenous source cases and obtained the following conclusions:

- a) We defined the connotation of regional energy security exogenous sources, extracted common characteristics of various exogenous sources through analysis of typical cases, and constructed characteristic attributes of exogenous sources.
- b) We designed a multi-dimensional rule mining method for exogenous sources, classified exogenous source characteristic attributes, and converted multi-dimensional exogenous source attributes into transaction items. On this basis, we proposed methods for generating frequent itemsets and strong association rules.
- c) We excerpted five typical cases from the exogenous source case set to verify the feasibility of the multi-dimensional association rule method. Mining results proved the method feasible and discovered patterns hidden in exogenous sources.

Since regional energy security exogenous source events have characteristics of suddenness and complexity, the following issues remain to be solved in future research: First, many rules are mined from exogenous source data, and future focus should be on how to prune them; second, rule interpretation efficiency is low, requiring domain knowledge to enhance understanding of cases.

References

- [1] Vlado V. Evaluating energy security in the Asia-Pacific region: a novel methodological approach [J]. *Energy Policy*, 2010, 38 (9): 5258-5263.
- [2] Löschel A, Moslener U, Rübhelke D. Indicators of energy security in industrialized countries [J]. *Energy Policy*, 2010, 38 (4): 1665-1671.
- [3] Liu Litao, Shen Lei, Zhang Yan. Regional differences in energy security of china: a case study of guangdong and shanxi provinces [J]. *Resources Science*, 2011, 33 (12): 2386-2393.
- [4] Zhao Chunfu, Liu Gengyuan, Chen Bin. *Advances in theories and methods*

of energy forecasting and early warning [J]. *Acta Ecologica Sinica*, 2015, 35 (7): 1-19.

[5] Fan Qiufang. Research on China oil security pre-warning based on BP neural networks [J]. *Operations Research and Management Science*, 2007, 16 (5): 100-105.

[6] Guo Jindong, Wang Enyuan. Measurement indicator system & comprehensive appraisal for coal energy security in China [J]. *China Safety Science Journal*, 2010, 20 (11): 112-118.

[7] Su Fei, Zhang Pingyu. Vulnerability analysis of regional energy security supply in china [J]. *China Population, Resources and Environment*, 2008, 18 (6): 94-99.

[8] Wu Chuguo, He Xianjie, Sheng Changming, et al. Comprehensive method for evaluating energy security [J]. *Journal of Natural Resources*, 2011, 26 (6): 964-970.

[9] Zhang Jianbo, Wu Hangjian, Hu Xiao. Construction of China's energy security evaluation index system based on PSR model [J]. *Statistics & Decision*, 2016 (8): 62-64.

[10] Zhang Qiang. National energy security research based on complex giant system [J]. *Forum on Science and Technology in China*, 2011 (2): 95-99.

[11] Zhou Dequn, Ju Keyi, Zhou Peng, et al. Early-warning grading system for oil price shocks based on Hilbert-Huang transform [J]. *System Engineering Theory and Practice*, 2013, 33 (3): 585-592.

[12] Guo Lingling, Wu Chunyou, Yu Jingtao. A study on simulating energy security system of China [J]. *Science Research Management*, 2015, 36 (1): 112-119.

[13] Hao Ping, Ni Guohua, Yu Yuqing. The research of regional energy consumption EWS based on OLAP analysis and association rules [J]. *Journal of Zhejiang University of Technology*, 2013, 41 (5): 534-538.

[14] Chi Chunjie. Research on energy security monitoring and early warning in China [M]. Shanghai: Shanghai Jiao Tong University Press, 2011.

[15] Wei Yiming, Wu Gang, Liang Qiaomei, et al. China energy re-port (2012): energy security research [M]. Beijing: Science Press, 2012.

[16] Wei Yiming, Liao Hua, Wang Ke, et al. China energy re-port (2014): energy poverty research [M]. Beijing: Science Press, 2014.

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