Supply Chain Perspective Oriented Business Mode of Renewable Energy Cloud and Its Data Factors Application

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***Abstract*— In the future, renewable energy source (RES) plays a main role in energy supply and demand system, which has become the consensus. The Energy Internet (EI) with deep integration of information is an important way to realize the transformation of energy operation structure. Based on the analysis theory of inventory, logistics, price and user demand of supply chain management, this paper analyzes the data factors of renewable energy cloud (REC) platform and established renewable energy cloud supply chain. Combined with data elements involved in the economy operation of REC, the value chain of renewable energy cloud is established and its business application mode is analyzed. Different market roles of supplier, operator and distributor were considered carefully to analyze the causality of data elements of REC. After the energy supply and demand system dynamics model was constructed. The regional load power data was tested in the model, and the anti-Bullwhip effect under the steady-state economic operation mode was verified and its suppression strategy and application value were discussed.**

Keywords—Energy Internet, supply chain of RES, REC, value chain, anti-Bullwhip effect

I. INTRODUCTION

With the increasing of climate change, carbon neutralization and high-quality developing demand of domestic economy, these status quo forces the civil energy revolution and developing transformation and further prompts the accelerating construction of EI [1-3]. On one side, the generating of renewable energy source RES like wind, photovoltaic and biomass will gradually become the main strength of power supply, its intermittent character decides that it needs the match of deep producing equipment, storage equipment and high precision forecast and dispatch control system, to suppress the disadvantage effect of RES penetration to achieve reliable operating of the grid [4]. On the other side, more and more distributed autonomous micro grids change the role from traditional passive consumers to active energy prosumers, with the expectation of earning additional profit by the real time electricity price [5]. As the basic operation mode in the regional EI, source-net-load-storage collaborating needs the basic support of comprehensively utilizing information and communication and control technologies, and value distribution theory, which can realize the high effective collaborating of energy stream, information stream and value stream [6]. Drawing on the experience of the design idea of IaaS and PaaS in cloud computing, the infrastructure network of distributed energy micro grid should be integrated into micro grid cloud, which uniformly provides energy management services at the platform layer, and will become the basic dispatch mode of cloud in EI [7-8].

As the main power of electric providing sources, RES in EI will also spawn new business modes. The Internet thinking of treating user as the center, taking the information as the bond, and taking data mining as the value force, will act as the core function in the economic developing formation of EI [9]. Paper [10] identifies the effect of the policy factors, market mature extent and techniques developing and application, to the spreading of business mode in EI, and further proposes the B2C, C2C, and agent mode based on open market trading. Storage will act as the function of "cache" and "memory" of computers in EI operation scenes. Paper [11] researches the cloud storage by analyzing the function embodied in "source-network-load" collaborating, and analyzes the economic sharing business model based on cloud storage. Paper [12] introduces the canvas theory into the business model design of generalize energy services, which promotes the scientific property of business model design. The researchers focus on analyzing and modeling of RES supply chain, as it can not only promote the operation efficiencies and obtain considerable profits [13][14]. As the new type of producing key factors, data is gradually gained attentions by education sectors and industry producing sectors, which take their researches on the application scene and trading scheme design [15-17], and preliminary resolves the problem of establishing energy data utilization and trade methodology. But it is rarely considering the effect of data key factors on the operation value of EI with high proportional RES accessing at the system layer.

This paper first defines the concept of REC. Taking trade data as the core, it decouples the cloud from the view of supply chain, and constructs the platform value chain based on value chain analysis theory. It then analyzes the business application mode of market entities in REC value chain from the view of value proposition, value realization and user demand; which designing data causality based on RES cloud platform between the roles of market entities, and building dynamic models of economic operation system in energy supply and demand with high proportional RES penetration, and verifying that the disturbing of load data demand complies to anti-Bullwhip effect, and its application value is analyzed.

II. REC DATA FACTORS

Data quality analysis framework for large-scale distributed renewable energy operations shows in Figure 1. According to the characteristics of regional resource endowment and construction of energy transmission channels, renewable energy such as wind farms and photovoltaic power stations were built in reasonable way. Data and files generated from system operation of stations will be uploaded to renewable

energy cloud platform in real time to storage uniformly and global sharing. Renewable energy data quality analysis and control includes four parts: data source analysis, data preprocessing, data quality evaluation, and data quality analysis.

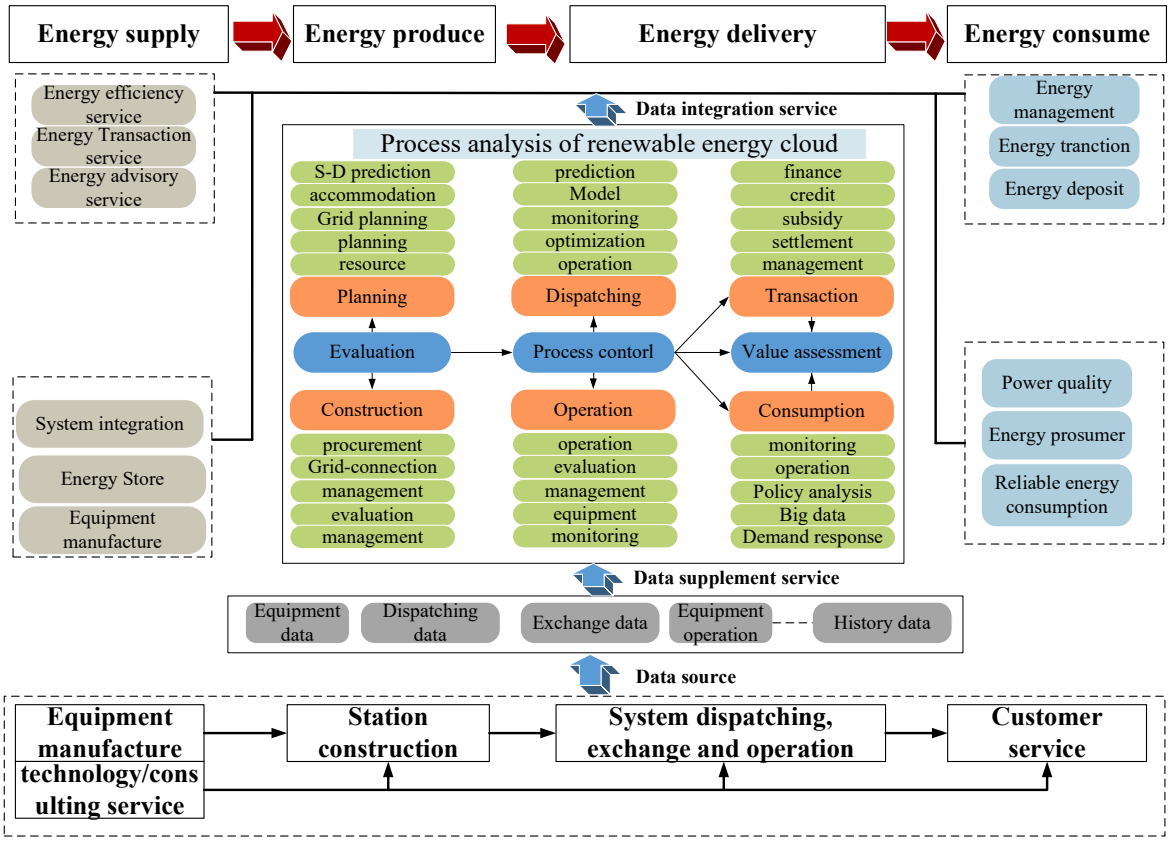

Fig. 1. Supply Chain Perspective Oriented REC Factors Structure

The market entities of EI operation with high proportional RES penetration not only include every type of enterprise in the RES industrial chain, but also the role of electrical prosumers running in the form of distributed micro grid, whose demand for electricity is different. Otherwise, the space and temporal stream shift brought by trading is more frequent. At the side of energy supply, the power supply in the EI operation with high RES penetration includes visible infrastructure and invisible technique consulting services. Infrastructure includes equipment producing enterprises relevant to RES, and upstream raw material supplier, storage supplier and system service integrating supplier, etc. The technique consulting services can provide the specific consulting services like energy trading, energy entrusting, and energy saving. These services need the support of analysis services in data integrating services of REC.

Producing and distribution is the core sector of ensuring reliable EI operation which is charactered by the high proportional RES penetration, and is also the platform which has core effect on energy supply chain. At first, it directs the RES scheduling in early stage, which setting up whole stage modelling analysis and data management in RES stuff design and its construction management, so to realize “digital twin” for the physic stuff. Then, it takes proceeding control to energy production and distribution, which includes the dispatch control of energy and real time operation and maintenance of electric equipment. At last, the user energy using demand is satisfied through energy set menu selection and energy trading scheme choosing, which attains the dynamic balance of electric “producing-consuming”, and realize value feedback in industrial chain of RES.

Look as a whole, the running formation of high proportional RES penetration in EI totally different with traditional “attaching importance to generation, with few cares to supply, without considering consuming”, which using the mode of “deciding supply by demand”, and further emphasizes the demand response and demand side management. Revolving around the user energy demand to schedule the energy generating plan, and keeping high reliability and high resilience in system operation, it can make real time data sharing, and data service achievability will become the key factors needed by policy managing of RES supply chain.

III. Data Value Chain Analysis in REC

Data elements means that, as a producing material, data can not only provide data production or services to economic society, but also deeply coupling with traditional producing factors like labor, technique and capital, to promote social producing effect, and increase economic outcome [20]. The value of data elements lies in reducing or even removing the uncertainty of information, so to largely reduce the chance cost. But data is not a type of natural producing factor, to become the producing factor, it needs below characters: first is the copy right character, with which the relation of handled

data production and service copyright is clear; second is the function characters, which means that it can join the physical producing activity directly and indirectly, to generate value; third is the exchange characters, which means that it can be traded and circulated easily. Using the value chain analysis theory proposed by Mikell. Baud in Harvard Business School, Fig.2 constitutes the value analysis chain of REC based on data elements.

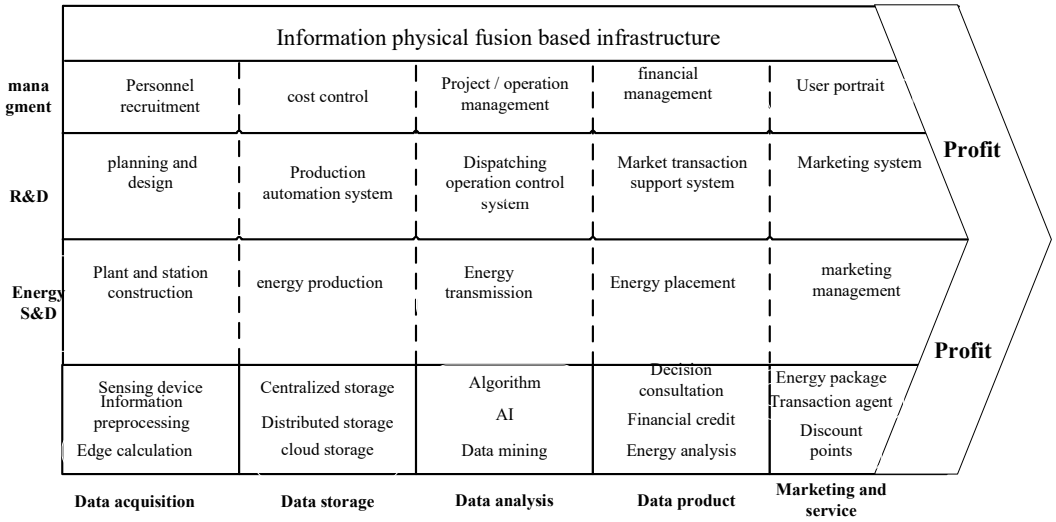

Fig. 2. Data Factor based Renewable Energy Cloud Value Chain

The value chain of REC based on data factors analysis includes three types of activities: basic traffic, foundation traffic and support traffic. Involving around stuff construction, energy producing, energy transmission, energy selling and energy consuming as basic RES supply and demand traffic activities, the basic traffic of the cloud can be divided into the sectors of data gathering, data storage, data handling and analysis, data marketing and service. Combined with the basic platform characters of REC, it can provide the data production like energy analysis, policy consulting, financial investment and government monitoring. The user and up and down stream vendors in the industrial chain, can realize the authority and commercialize of RES data factors based on the trading support system for data production. Support traffic include two activities, which are researching and developing, and organizing and management: where researching and developing activity takes part in the information construction for RES auto producing system, systematic dispatching and running control system, operation and maintenance system and market trading and marketing system, et al. It can not only promote the running efficiencies, but also produce massive traffic data, which is the data source of REC. Organizing and management contains the role of managing activities of staff, enterprises and users. It refers to inner cost control of enterprise, maintenance and finance management, and outer user portrait management. It is the value embodying of data factors in REC.

Taking from online and offline separately, and from the dimensions of core function construction, key traffic, value assertion, customer relationship, and cost structure, Table.1 founds the business mode oriented to different roles of supplier, operation vendors, cloud service platform, customers and energy prosumers in the value chain of REC based on data elements.

TABLE I. DATA FACTOR ANALYSIS BASED RENEWABLE ENERGY CLOUD BUSINESS MODE

Value chain sectors	Analysis domain	online	offline
RES supplier	Core function construction	Device model data construction and maintenance	Equipment running reliable
	Key traffic	device manufacture and detect, meta device modelling	
	Data value assertion	high precision device/equipment model	
	Customer relationship	high precision device/equipment model	Install, debug, maintenance
	Cost structure	Model developing	Raw material procure and human cost
Stuff vendor	Core function construction	Stuff/model data construction and maintenance	Generating, join in grid and reliable maintenance
	Key traffic	system integrating, dispatch and control	

	Data value assertion	Stuff digit map	
	Customer relationship	Model and running state data sharing	stuff maintenance entrusting, dispatch and trade
	Cost structure	System developing	Device procure and maintenance cost
RES service platform	Core function construction	Eco-system construction	Market and user marketing
	Key traffic	platform ability construction and brand extending	
	Data value assertion	Data mining analysis and advanced application	
	Customer relationship	Digital product and service	Marketing, consulting service and trade agent
	Cost structure	platform developing	Marketing cost
RES user/distributed energy prosumer	Core function construction	Energy using credit construction	Energy using plan
	Key traffic	demand side response and management	
	Data value assertion	energy using data and credit data	
	Customer relationship	Evaluate and feedback data	Energy consuming/trading
	Cost structure	Time management	Storage and smart sensor/control devices procure, network construction

As the upstream of RES industrial chain, the RES supplier should supply the running reliability and related digital equipment model to physic stuff as its core ability construction and key traffic, so its value position and assertion in the business model of REC is to model and maintain high precision device and equipment, which can provide precise model parameter data to cascade customers. REC vendor should integrate the equipment system for upstream device suppliers and take offline electricity generating join in grid, and fulfill related operation and maintenance. It takes online model data maintenance of the stuff as the core content of construction ability, with inner assuring the running reliability, outer accepting the instruction of up layer dispatching system. Its value assertion in REC business model is through station and stuff digital map, which can provide stuff level model and real time operation state data to the customers. REC service platform takes the core role of data sharing and value connection in the REC business model. On one side, it should improve itself ability on software platform, and making firm of its hard power, on the other side, in the environment of opening market contention, it should strengthen its construction ability of user marketing and brand spreading, to promote its soft power. Its value assertion in REC business model is to provide digital service product to all kinds of application scenes based on data mining analysis.

As the end user of RES industrial chain, and the final sector of looped REC value chain, the role of passive consumer is changed to active prosumer with the character of "self-generating and self-using, with excess power sells to the grid". Through developing the traffic of demand side response and management, and taking part in the energy using credit construction online, and arranging the energy using plan offline, the uncertainty of supply and demand formation in EI with high proportional RES penetration can be reduced as more as possible. So, its value assertion lies in itself energy using data and credit data.

IV. SYSTEM DYNAMIC MODELING

Information-feedback is the main content of system dynamic modeling [18], so the REC can be modeled as follows:

1)Bounding the modeling system. This paper takes the grid operation with high proportional RES penetration as the modeling object, which builds up the physic system dynamic model of energy supply and consumption. It's the looped value base of REC business model, which referring to four roles of RES, such as supplier, operation vendor, distributor, user and so on. Their generated data in the producing and operation are integrated analyzed by REC platform and then provide data service product to outside object.

2)Relationship analysis. The causality should satisfy below conditions:

$$P_{operation} = P_{demand} \tag{1}$$

$$\sum P_{gen} = \sum P_{consume} + \sum P_{loss} \tag{2}$$

While to keep the real time balance of electrical operation power and demand power (formula 1), at the same time, it keeps the equation of generated energy and consumed energy in the time integrating scale (formula 2). Revolving around four kinds of subsystems, the variables of data stock quantity, data increment quantity, data deactivation quantity, data value changing ratio, data value distribution coefficient and data reserve coefficient, are constituted. And build their causality with the REC platform.

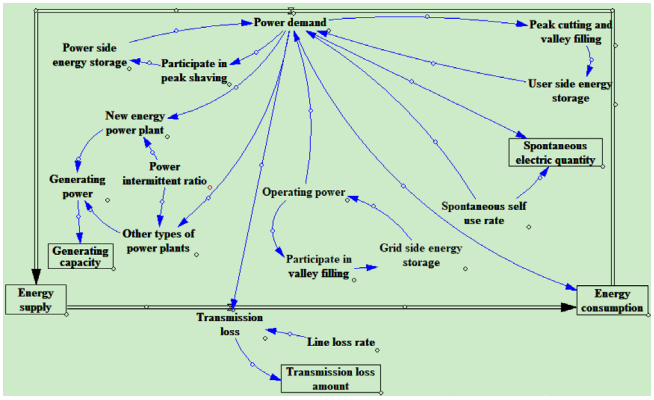

Fig. 3. Dynamic Mode of Energy Supply and Demand System with High Proportion of Renewable Energy Resources

Wherein, RES supplier is responsible for managing and maintaining the data stock quantity of device model, its data update frequency is lower; operation vendor is responsible for managing power production and operation data, its data update frequency is higher; distributor is responsible for managing and maintenance of user data, which can response to user demand change in real time. Though individual's data sharing scheme, these vendors take part in the proceeding of data value transformation and excitation distribution, to realize the value loop.

3) Constitute the dynamic model of energy supply and demand system

Comparing to the lack of power demand resilience in traditional energy supply and demand formation, the formation under high proportional RES penetration accesses the storage equipment at the user side, source side and grid side, which increases the operation resilience of the system. Within it, storage at the user side lies in peak shaving and valley filling, with the expectation of obtaining profit; storage at the source side lies in peak shaving to lower the disturb of power in massive RES stuff grid connection; storage at the grid side lies in valley filling, and providing power supporting for frequency regulating, the related function definition is shown as Table 2.

TABLE II. DEFINITIONS OF IMPORTANT VARIABLE FUNCTIONS

Variable name	definition
Running power $P_{operation}$	Function distribution based on statistic history data
Self-using raito I	$1\text{-}\sum P_{demand}/\sum P_{operation}$
Power demand P_{demand}	$P_{operation}$ * （1-I ）
Peak shaving	IF THEN ELSE($P_{demand} > P_{peak}, 0, 1$)
Valley filling	IF THEN ELSE($P_{operation} < P_{valley}, 0, 1$)
Peak shaving and valley filling	IF THEN ELSE($P_{demand} > P_{peak}$ *or* $P_{demand} < P_{valley}, 0, 1$)

V. CASE ANALYSIS

A. numerical example verification

This paper chooses the load power profile on one day for an area to simulate the system dynamics, shown as Fig.4.

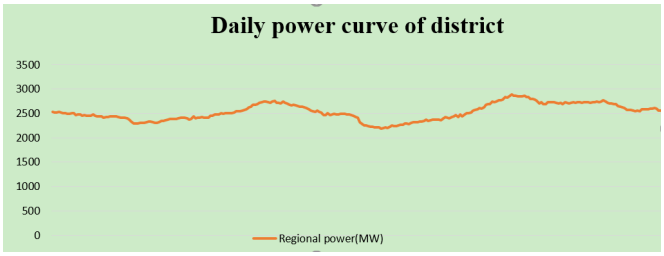

Fig. 4. Daily Power Load Curve of Region

Defining the ratio of power peak and valley difference as:

$$\eta = \frac{\mathrm{MAX}(P_T) - P_t}{\mathrm{MAX}(P_T)}$$

among them， $t \in T = \{0,1,2,\ldots t, t+1 \ldots\}$ (3)

By calculating the ratio of peak and valley difference in this district shown in time dimension based on formula (3), and at the same time, choosing the user load of one 110kv stuff and it related 35kv and 10kv user load, we can get the histogram of the ratio of the peak and valley difference shown in time, shown as Fig. 5.

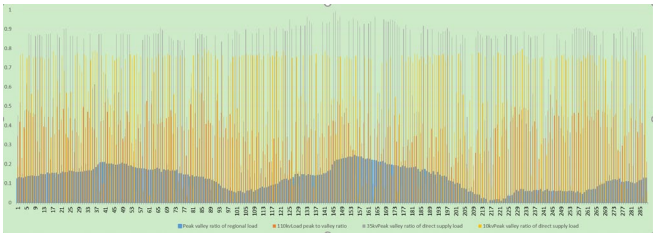

Fig. 5. **Bar Chart of η Values between Different Voltage Classes**

Considering the strengthen of energy using activities at the user side in EI, this paper analyzes the effect of energy using activities to the value of η. In the direct supplying users of 35kv and 10kv, 10% of peak power multiplying 2 hours storage capacity is deployed. In order to ensure the using life and charging and discharging performance, paper [19] take the discharging depth of 60%, and based on regional peak and valley price, one charging and discharging proceeding is executed every day, the obtained η value is shown as in Fig. 6. The comparison of average η value of no configured storage to the profit of daily peak valley difference is shown in table 3.

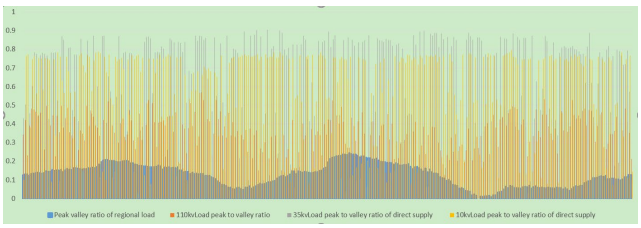

Fig. 6. **Bar Chart of η Values between Different Voltage Classes with Storages Deployed in User Side**

TABLE III. COMPARISON **OF AVERAGE Η VALUE WHETHER USER SIDE DEPLOYS STORAGE EQUIPMENT OR NOT**

User type	No storage	10%storage capacity/peak valley profit(yuan)
35kv direct user	0.64	0.6/167.5

10kv direct user	0.62	0.59/156.6

B. Discussion

In the traditional supply chain logistics systems, there are widely existing Bullwhip effect [20], and that the uncertainty of user demand leads to the amplifying effect of stock quantity in supply chain and of producing quantity in downstream and upstream enterprises. In the model analysis of system dynamics of power demand and supply, the ratio η of load power in peak and valley difference is used to represent the disturb condition of user demand, the ratio of peak valley difference in the user load of low voltage level is far more than that of the up-level transformation and region load, which can be concluded as "anti-Bullwhip effect".

Importing the flexible power resource like storage at the user side can lower the Bullwhip effect, and combined with feedback signal of time varying prices, the uncertainty of user demand can be further lowered.

User side storage participated in anti-Bullwhip effect can obtain the profit based on the opportunity cost of the power disturbing constrain at the demand side. In the supply and demand formation of EI with high proportional RES penetration, in order to realize demand side response in larger space and temporal scale, the EI can't live without the high precision forecast and analysis control of the REC relevant data.

Data can be valued only through aggregation. REC platform has natural advantages in business mode innovation: for one side, in order to deep mining data value, it should have one seat on looped value of data factors in market economy; for the other side, it should set up the data sharing and exciting scheme in every market entity oriented to REC value chain, to improve the user stickiness of the platform.

Wool comes from the sheep. REC value chain lies in the economic operation formation of demand and supply market in EI with high proportional RES penetration. Among them, the profit of data factors in REC platform depends on the value assertion and value distribution in the sectors of value chain in REC. It should realize the credit transmission of owner right, sharing right and using right through data factors' right management, so the new market roles like RES supplier, operation vendor, distributor and platform can ensure their data increasing value revenue.

VI. CONCLUSION

The innovation of business mode for REC should take the data elements as the core. This paper decomposed the REC element sectors from the view of supply chain, and established the value analysis chain of REC platform, and preliminarily discussed the business application mode of every market entity in the REC value chain, and designed the data causality between different market entity roles on REC platform based on data factors, and founded the dynamic model of economic operation system of energy demand and supply. By doing so, the anti-Bullwhip effect is verified in the economic operation system of disturbing load data demand, and sharing data factors information can suppress such effect. Subsequently, further research will be the distribution of suppress value in the new type market entity roles.

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