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Research on the Value-added Ability of PV / Energy Storage / Charging Station Value Chain Based on System Dynamics

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ABSTRACTS. *Value-added ability is the core competitiveness of enterprises on PV / energy storage / charging station value chain (PEVC), and a key to enhance competitive advantage. Based on in-depth analysis of factors affecting the value-added ability of PEVC, this paper builds a system dynamics model of the value-added ability of PEVC, simulates the value-added ability of PEVC, and a path to improve the value-added ability of PEVC through sensitivity analysis of influencing factors is found, which provides a reference for the development of the photovoltaic- energy storage-charging station.*

KEYWORDS: *Photovoltaic; Energy storage; Charging station; Value Chain; Value-added ability; System Dynamics*

1. Introduction

In the 1980s, Michael Porter creatively put up value chain theory, which effectively improved value-added ability of enterprises and helped many enterprises find ways to break the bottleneck of enterprise development [1]. The introduction of photovoltaic power generation and energy storage technology to electric vehicle charging stations formed PECV. To improve core competitiveness of PECV, it is necessary to analyze value-added ability of value chain, that is, focus on value-added link of value chain and analyze driving factors that affect value increment.

At present, analyses of value-added ability of PEVC are relatively less. Research on value-added ability of PECV can draw lessons from current value-added analyses

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of renewable energy industry to carry out in-depth analysis. Literature[2], after making a dynamic and static analysis on the correlation between market structure and profit distribution of each link in value chain of crystalline silicon solar cell industry, found that the more the market structure tends to be fully competitive, the weaker the ability of this link to obtain profit. Zhang Fang et al[3] decomposed value chain of global PV industry. And through case studies, it was found that Chinese enterprises first entered PV module manufacturing through technology acquisition, and then integrate themselves into global clean energy innovation system using vertical integration strategy within the industry. Zhou Fangkai pointed out that there are problems in value chain of China photovoltaic industry, such as an imbalance between supply and demand in different links, loose development in each link and weak development in high value-added links[4]. Zhang Yifei, and An Zenglong studied cost control of each link in value chain of photovoltaic industry[5]. Literature[6], on the basis of discussing structure and operation mechanism of value chain of wind power industry, analyzed dynamic complexity of value-added system of value chain of wind power industry, built a system dynamics model of value-added effect of value chain of wind power industry, studied the overall value-added trend of value chain, explored main factors affecting value increment of wind power industry, and analyzed the sensitivity of its influencing factors.

Although the above literature has studied the problems existing in the value-added process of each link of the photovoltaic and wind power industry from the perspective of value chain, no scholars have analyzed and optimized the value-added ability of PECV. To solve the above problems, this paper, from the perspective of system, makes a qualitative causal analysis of the subsystems that affect the value-added ability of PECV; builds a system dynamic model of the value-added ability of PECV, simulates the value-added ability of PECV, and discusses the relevant suggestions that are helpful to improve the value-added ability of PECV through the transformation simulation of key variables, so as to provide reference theories and methods for the photovoltaic industry -the development of PECV.

2. System dynamic model of value-added ability of PECV

2.1. Determination and assumption of system boundary

To explore the motivation of value-added ability of PEVC, it is necessary to study how to create value and value increment among main bodies of value chain. Therefore, the model should include main bodies that participate in the value increment of value chain and external environment.

The specific modeling framework is shown in Figure 1.

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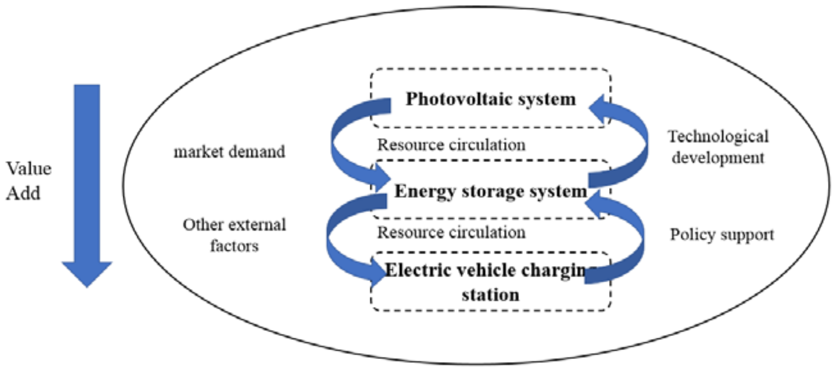

Figure 1. System modeling framework

The boundary of the system should include all important factors related to improvement of economic value, social value and environmental value in the process of value increment of PECV. And, to simplify the model, the following assumptions are made for the system:

(1) All revenues are from electricity sales and charging services, excluding investment, non-operating and other incomes;

(2) The participants are rational people and take profit maximization as decision-making goal;

(3) Changes in power generation technologies other than photovoltaic are not considered.

2.2. Subsystem division of value-added system of PECV

Value increment of PECV involves many participants, technology, management, resources, market, innovation and many other aspects. Among them, resource circulation is the premise of value increment, node operation and user demand are the guarantee of value increment, and technological innovation is the power of value increment. Therefore, after determining the system boundary, value-added system of value chain of PV, energy storage and electric vehicle is divided into a resource circulation subsystem, a node operation subsystem, a user demand subsystem and a technology innovation subsystem in this paper.

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2.3. Causality analysis of value-added system of PECV

2.3.1. Resource circulation subsystem

One of the paths of value increment of PECV is to increase energy output, expand energy trading volume and provide more charging services by investing various resources, so as to obtain corresponding income and increase profits. Therefore, considering the process from resource input, resource output to resource income of PECV, a causality diagram of resource circulation subsystem is built in this paper, as shown in Figure 2.

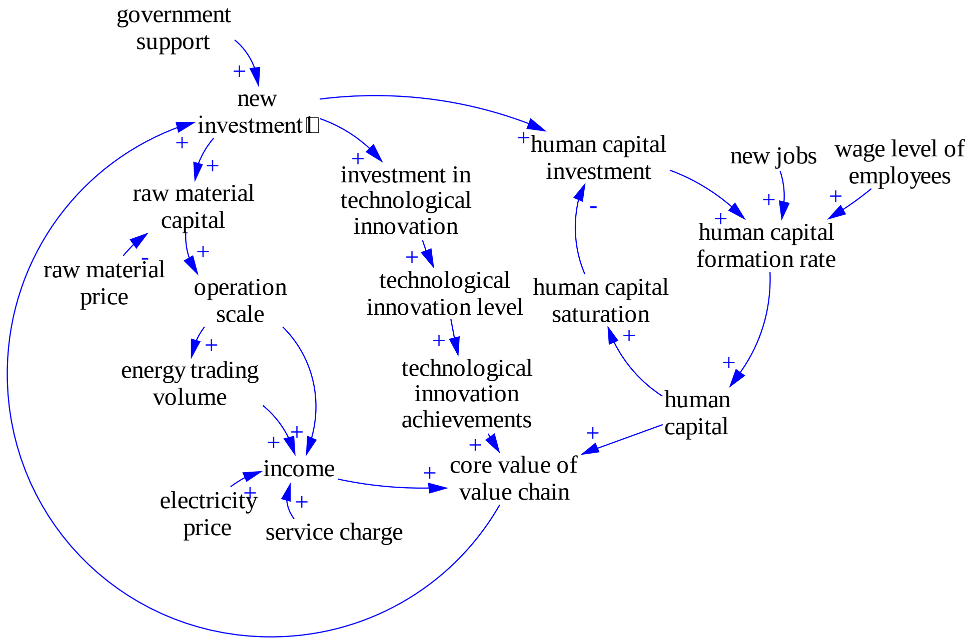

Figure 2. Causality diagram of resource flow subsystem

(1) Resource input. Sufficient resource input is the basis of value increment of value chain. After the enterprise has injected funds, it continuously improves its energy production capacity and service capacity through the input of raw materials, human resources, and technical resources, which will increase the total value chain revenue and protect the value chain. Besides, the strength of government support will also affect resource input.

(2) Resource operation. The system ensures production and operation of value chain via resource input. The input of raw materials can increase energy output, thus expanding the energy transaction; the input of human capital is used for the

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excavation and training of talents, improving formation rate of talent capital; the input of technological innovation can improve research and development ability of value chain, obtain more technological achievements, and the application of the technological achievements in production will also improve the energy productivity and service ability. The operation of various resources can enhance core value of value chain.

(3) Resource income. The revenue of PECV mainly includes two parts, one is revenue from electricity sales, the other is revenue from charging services. The amount of benefits is determined by core competence of value chain. The improvement of core competence can increase resource output, thereby increasing resource revenue. More investment can be added to increase the input of resources, forming a systematic positive feedback cycle.

2.3.2. Node operation subsystem

The operation ability of photovoltaic system, energy storage system and charging station in PECV can improve the coordination of each node in value chain to a certain extent, improve the power generation level, expand operation scale and enhance value-added ability. In consideration of the operation ability of nodes, the causality figure of the node operation subsystem built in this paper is shown in Figure 3.

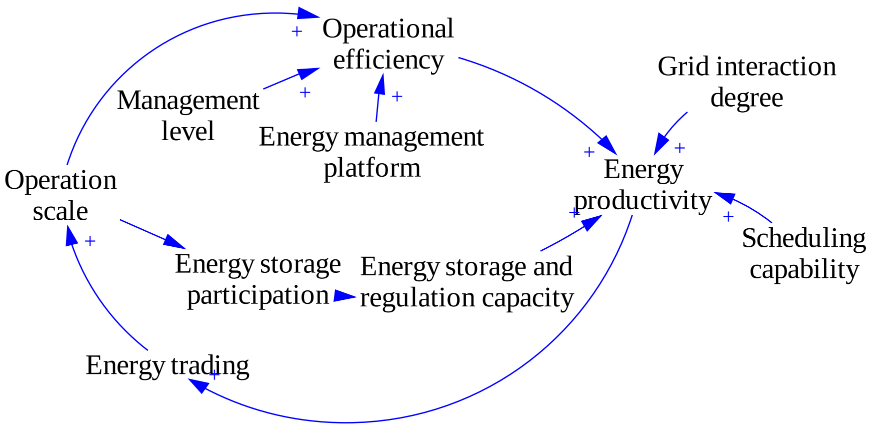

Figure 3. Causality diagram of node operation subsystem

For each node, more resources can increase operation scale of the node. Due to the increase of system capacity and human capital, coordinated utilization of resources can improve the operation efficiency of nodes. The improvement of power

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generation efficiency and service efficiency helps to improve the power supply level and quantity. Also, in order to ensure the supply level, it causes the increase of operation scale, forming a positive feedback loop. In addition, using a reasonable and advanced energy management platform to improve the management level of nodes is also helpful to improve operation efficiency.

As an intermediate node, energy storage plays an important regulatory role and is one of the important factors reflecting value increment. Therefore, the operation of both upstream and downstream nodes affects the configuration of the energy storage system. In the causal analysis of the node operation subsystem, the participation of energy storage is therefore considered separately. The increase of operation scale of energy storage itself or other nodes will affect the configuration of the energy storage system. To coordinate the development, energy storage will enhance its participation, better adjust the relationship between power generation and demand, and improve energy production efficiency.

2.3.3. User demand subsystem

User demand is the basis of value chain operation, and satisfying user demand is the end of value chain creation. Therefore, the user scale of demand end is the key element of value increment of PECV. Considering the development process of the user market, the causal relationship of the user demand subsystem analyzed in this paper is shown in Figure 4.

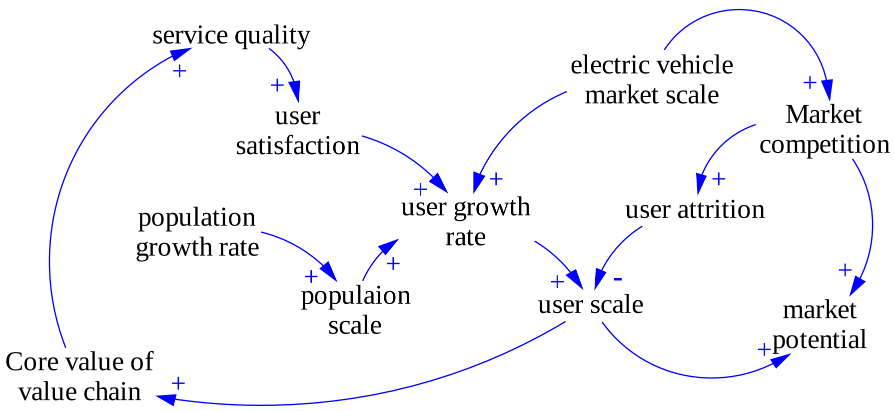

Figure 4.Causal analysis diagram of user demand subsystem

(1) User growth. The key variables in user demand subsystem are user growth rate, user attrition rate and user scale. The user growth rate is affected by population

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scale, electric vehicle market scale, user satisfaction and other aspects. On the one hand, from the perspective of social environment, an increase in population growth rate is likely to improve the user growth rate. When the electric vehicle market scale increases, the number of electric vehicle users increases, which also provides a boost for user growth; on the other hand, operation service level of nodes itself can improve service quality and user satisfaction, thus enhancing user stickiness and improving the user growth rate. The increase of user growth rate indicates the expansion of user scale, so more power demand is proposed, and the information is fed back to value chain nodes. And the operation scale will be increased to meet more demand.

(2) User attrition. The user attrition is mainly related to the degree of market competition. When the user scale increases, meaning that photovoltaic, energy storage and charging station market has good market potential and development prospects, more subjects will participate in the market competition, which increases the market competition. With the increase in market competition, users are facing more choices. Competitors will compete for user resources in various ways, which will result in the user attrition, reduce the user scale and demand for electricity to a certain extent.

2.3.4. Technology innovation subsystem

The operation efficiency of PECV system depends on the development of technology, including power generation technology, energy storage technology, charging technology, information technology, etc. Technology innovation is power of value increment of value chain. Therefore, a technology innovation subsystem is built in this paper. The causal analysis diagram is shown in Figure 5.

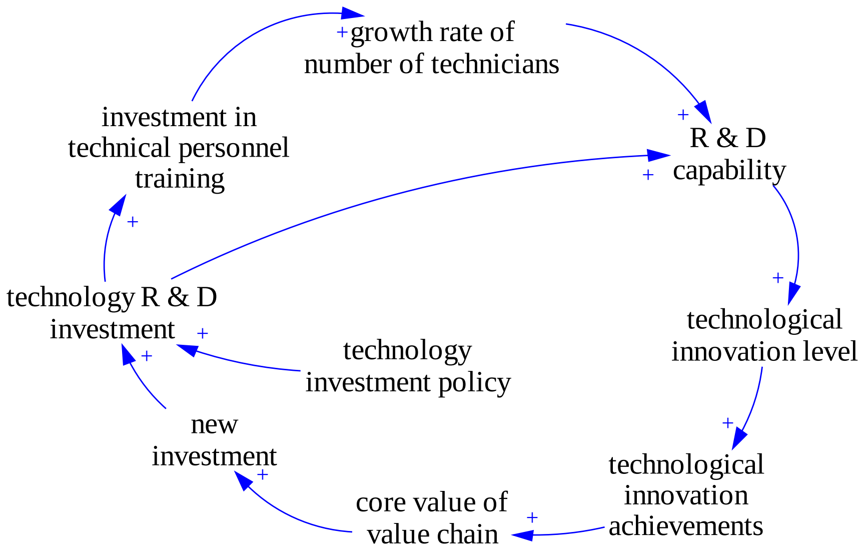

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Figure 5. Causal analysis diagram of technological innovation subsystem

(1) Investment in technological innovation. Part of investment of node related enterprises in value chain is used for technology research and development, which is a guarantee of technology innovation. Part of investment in technological innovation is used for development or introduction of new technologies and purchase of research and development materials, and the other part is used to cultivate high-tech talents and increase number of technical personnel. Both of the two aspects can achieve the purpose of improving technology research and development capabilities, and it is possible to achieve innovation in power generation, energy storage, charging technology, information technology support and other aspects, improving overall technology innovation level of value chain. Also, various technical support policies will promote enterprises to increase investment in technology research and development.

(2) Output of technological innovation. Input in technology innovation will improve the level of it, and then make technology breakthroughs and get results. On the one hand, the improvement of power generation technology and energy storage technology will help to improve power generation efficiency and increase energy output. On the other hand, the improvement of information technology brought by technological innovation, the increase of information sharing, and the improvement of charging efficiency brought by charging technology will significantly improve the service level of value chain system. From causality analysis of resource circulation subsystem, the output of technology innovation will bring the increase of income and input, which will also improve the input in technology research and development, and achieve the effect of positive feedback.

2.4. System dynamic model of value-added ability of PECV

On the basis of the above research, a dynamic model of value-added system of PEC is established by combining the four subsystems according to the relationship between value flow and information flow through core value of value chain, as shown in Figure 6.

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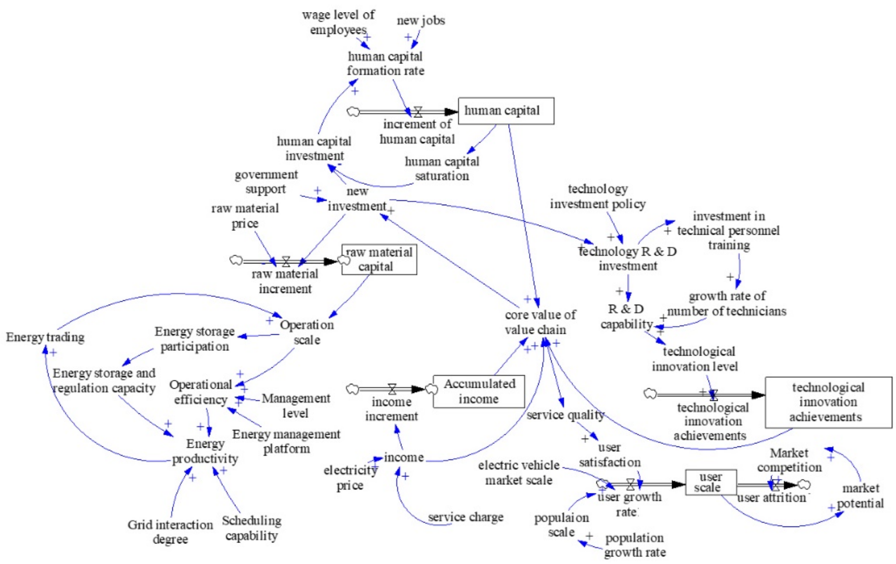

Figure6. Dynamic model of photovoltaic/energy storage/charging station value chain value increment capability system

3. Simulation analysis

3.1. Model validity test

To test validity of the model, actual data is combined in this paper to test the model. Therefore, relevant data of a PEC pilot project from 2016 to 2019 is selected as test data. Main parameters of the system dynamics model are set: system simulation cycle is 4 years, simulation step length is 1 month, initial user scale is 1400 people, initial input of human capital and technology innovation is 100, average electricity price is 0.49 yuan / kWh, and average service cost is 0.71 yuan / kWh.

The main variable formulas in the system dynamics model built in this paper are shown in formulas (1) to (9).

Raw material capital = INTEG (raw material increment, initial raw material) (1)

Human capital = INTEG (delay3 (human capital increment, delay), initial human capital) (2)

Technology innovation achievements = INTEG (delay3 (input increment in technology innovation, delay), initial technology achievements) (3)

User scale = INTEG (user change rate, initial user scale) (4)

Cumulative revenue = INTEG (revenue increment, initial revenue) (5)

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Human capital increment = human capital formation rate × initial human capital (6)

Technology input increment = technology innovation input × SQRT (technology innovation level) (7)

User growth rate = population scale $^{0.2}$ × user satisfaction $^{0.5}$ × electric vehicle market scale $^{0.3}$ (8)

User attrition rate = market competition degree × 0.05 (9)

Mental model test is performed on the system dynamics model of value-added ability of PECV to see whether the system simulation results fit the actual data in numerical value and trend. In this paper, user scale and revenue are two important variables. Set the TIMESTEP as 0.25, 0.5 and 1 respectively, and check the simulation results of these two variables, as shown in Figure 7. It can be seen from the results that the whole system is basically stable without abnormal changes and results.

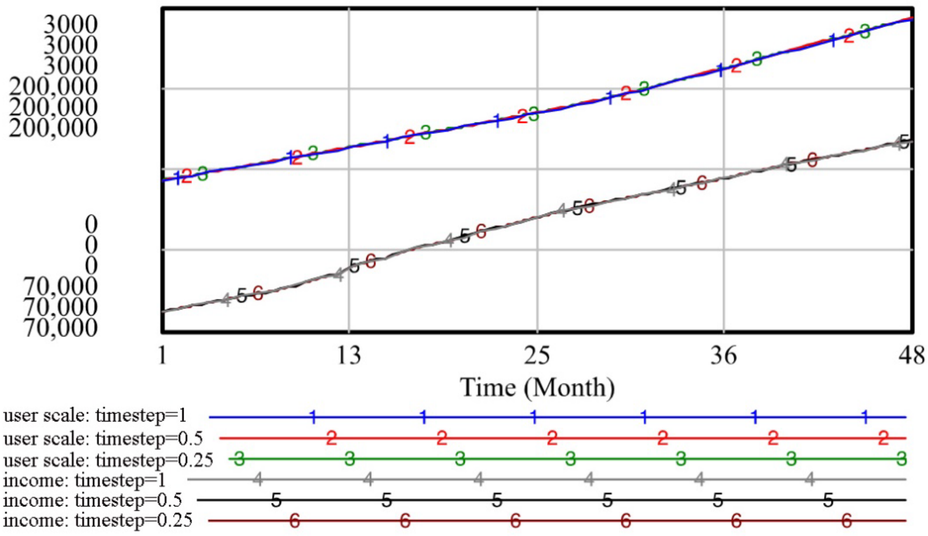

Figure 7. User scale simulation results

In the model test, we can judge whether the simulation results are reasonable by comparing the simulation data with actual data and checking its actual error. Generally, it is considered that the error within 15% indicates that the model is reasonable. Results of 2017-2019 are selected for comparison, as shown in table 1. By comparison, error between the simulation results and the actual results can meet the requirements. In conclusion, the system dynamics model built in this paper can effectively reflect value-added mechanism of PECV, which is consistent with actual system behavior, and the next operation and analysis can be performed.

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Table 1.Mental model test results

Variable	2017			2018			2019		
	Actual value	**Analog value**	**Error**	**Actual value**	**Analog value**	**Error**	**Actual value**	**Analog value**	**Error**
Total income (ten thousand yuan)	113.4	126.5	11.6%	142.5	148.6	4.3%	180.2	167.5	7.1%
User scale	1952	2002	2.5%	2589	2418	6.6%	3120	2918	6.5%

3.2. Simulation analysis of value-added ability of value chain

After the validity of the model is confirmed, the simulation period is extended to 240 months, and the step length is 1 month.

3.2.1. Development trend of value-added ability of value chain

Core value of value chain is defined as sum of accumulated revenue, human capital, technological innovation achievements and user scale in this paper. After the simulation of the model, the results of the above indicators are shown in Figure 8.

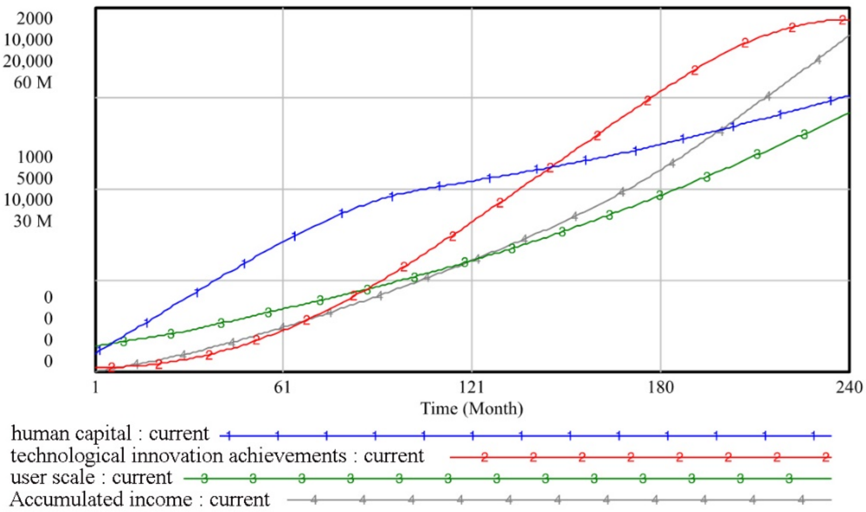

Figure 8.Cumulative revenue, human capital, technological innovation and user scale results

From the above results, it can be seen that the cumulative income of value chain shows an upward trend over time, and it can be found that the income growth rate is

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increasing, which indicates that overall operation of value chain is good, the value-added ability is strong, and has a good market prospect. Moreover, with a gradual expansion of market scale of electric vehicles and increase of user charging demand, the user scale also shows a steady upward trend. Due to a large amount of government subsidies and more input in the early stage, human capital shows a state of rapid growth in the early stage, but the corresponding input has decreased because of gradual saturation of human capital in the later stage, and the growth trend is particularly slow. The results of technology innovation are affected by the periodic trend of technology innovation input. The growth rate in the early stage is relatively fast, while the increase rate in the later stage is reduced, and then gradually flattened.

The simulation results of core value of value chain are shown in Figure 9. It can be seen that the growth trend of core value in the early stage is relatively consistent with the accumulated income and user scale, and the growth rate remains high. In the later stage, the growth trend of core value is correspondingly weakened due to the slower growth of human capital and technology innovation achievements, but still maintaining a certain growth rate. From the change of core value of value chain, we can judge the value-added ability. From the results, we can see that as time goes on, the value-added ability of target value chain gradually increases, the growth rate in the early stage is faster, and the growth rate in the later stage is slowing down, but still keeping the trend of growth.

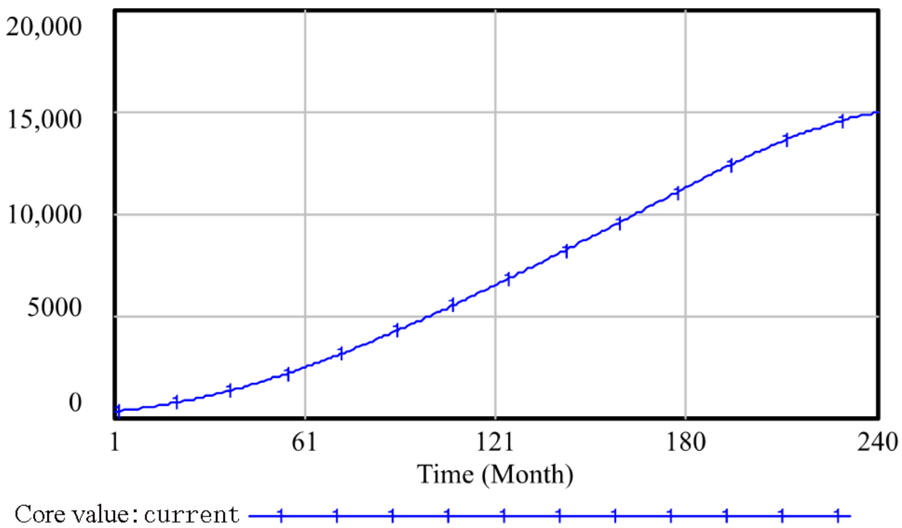

Figure 9.The development trend of value chain core value

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3.2.2. Impact of government support policies on value-added ability

The development of PECV is inseparable from support and guarantee of policies. Different types of support policies have different effects on value-added ability of value chain. The impact of three different forms of government subsidies on the value chain system is explored in this paper: 1) with continuous increase of income, the amount of government subsidies gradually decreases; 2) the amount of government subsidies remains unchanged; 3) with continuous increase of income, the amount of government subsidies gradually increases.

Set government subsidies as the table function related to income: the table function of scenario I is set as WITH LOOKUP ([(0,0)-(1000000,100000)], (0,100000), (200000,91000), (300000,80000), (400000,73000), (500000,67000), (600000,60000), (70000,52000), (800000,38000), (900000,20000), (1000000,0)); The table function of scenario II is set as WITH LOOKUP([(0,0)-(1000000,100000)], (0,50000), (1000000,50000)); The table function of scenario III is set as WITH LOOKUP ([(0,0)-(1000000,100000)], (0,0), (200000,38000), (300000,52000), (400000,60000), (500000,67000), (600000,73000), (700000,80000), (800000,91000), (1000000,100000)). The simulation results of three different scenarios are shown in Figure 10.

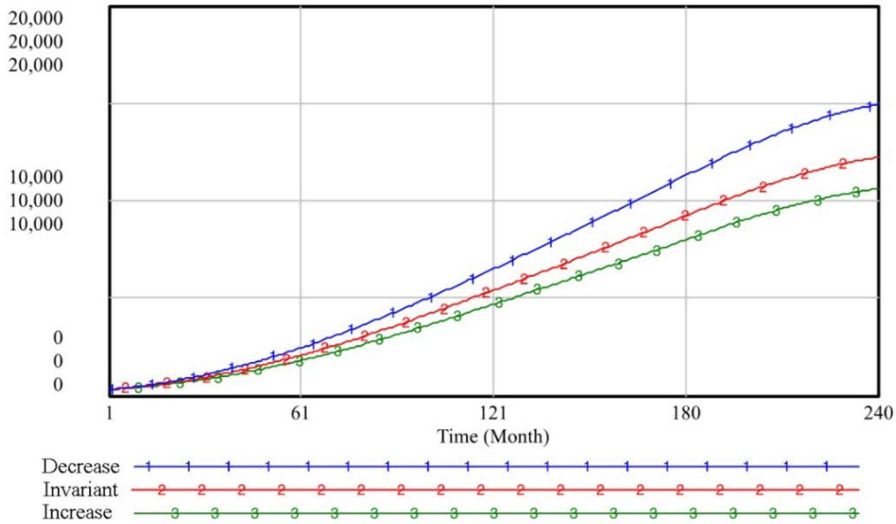

Figure 10.Sensitivity analysis of government support policies

From the above results, we can see that scenario I has the strongest value-added ability, because in the early stage of value chain development, user scale is small, and more government subsidies are needed as an investment to expand the operation scale. In scenario III, government subsidies increase with the increase of income, but

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value-added ability of value chain is the smallest. This is because the value chain has reached a certain scale and development level in the later stage of development, and growth rate of value generated by human capital and technology innovation achievements slows down, resulting in no better effects through increasing government subsidies. From the above results, we can see that in the early stage of value chain development, there is a large demand for policy support, so we can increase the input of subsidies. When the value chain develops to a certain extent, we can reduce or even cancel subsidies, so that we can achieve a good value-added effect.

3.2.3. Impact of technology innovation input on value-added ability

In order to calculate the input of value chain technology innovation, the input coefficient of technology innovation is introduced. Considering the characteristics of enterprises' input to technology innovation, sin function is used in this paper to calculate the coefficient, and the calculation formula is shown in formula (10).

$$\text{input coefficient of technology innovation} = \sin(\text{Time}/\text{ emulation period} \times k\pi) \quad (10)$$

k is a control parameter, which is used to simulate the periodic change of technology innovation input. This paper simulates the system when k = 1, 2 and 3 respectively, and core value change curve of value chain under different scenarios is obtained. The results are shown in Figure 11

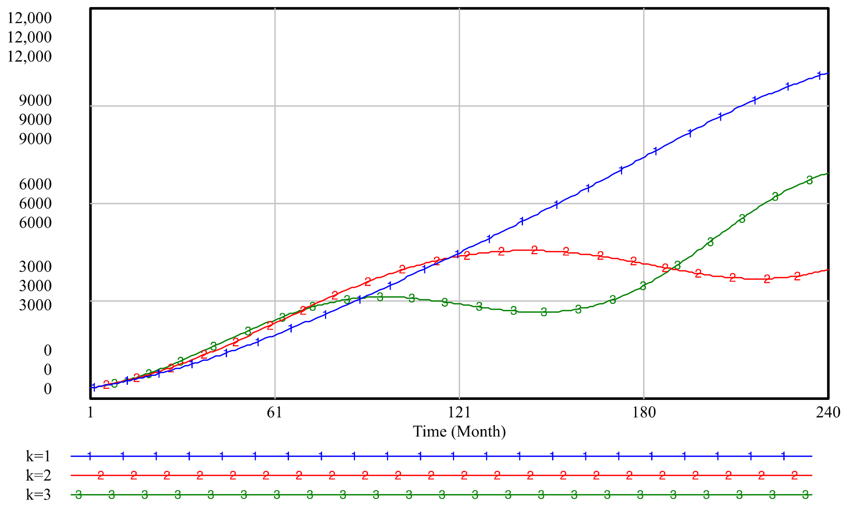

Figure 11.Sensitivity analysis of technology innovation input

In the early stage of value chain development, core value of value chain is the highest when k = 3; in the middle stage, core value is the highest when k = 2; in the

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later stage, the growth of core value is much higher than that of under the other two scenarios when $k = 1$. From the perspective of the overall development trend, when $k = 1$, value chain keeps a continuous growth of core value, and value-added ability is the strongest in the long run.

3.3. Countermeasures and suggestions

In this paper, the influencing factors of value-added ability of PECV are studied in depth through building a system dynamics model of value-added ability of PECV, and a value-added mechanism is defined. To promote the development of PECV and enhance value-added ability, the following suggestions are put forward according to the research results.

3.3.1. Implement support and guarantee policies for industrial development

The development of PECV is currently in the initial stage. From the simulation results, we can see that the market is small at this time, and the development of the industry cannot be separated from the support of policies. Therefore, it is necessary to implement relevant financial policies, financial policies and welfare policies for industrial development to provide financial security and policy support. According to the research results, it is necessary to formulate corresponding support strategies for different stages of industrial development to achieve the best value-added effect. Reasonable policy support can accelerate the development of PECV, enhance PECV's ability to provide clean and efficient electric vehicle charging services and value-added ability of the industry

3.3.2. Enhance core competitiveness

Through the input and flow of various resources, enterprises get different types of resource output to achieve their goals. These resources and capabilities constitute the core competitiveness of enterprises. When resources are scarce and cannot be easily replaced, enterprises can get competitive advantage. Therefore, in the development process of PECV, it is necessary to have some traditional resources first, such as equipment raw materials, marketing resources, network resources, etc., to improve the operation scale and operational efficiency of enterprises. Besides, acquisition and improvement of enterprise innovation ability, management level, human resources, service ability and other resources embody more and more important competitive advantages in the development process. Therefore, we should integrate all kinds of resources and enhance the core competitiveness in the process of value chain development.

3.3.3. Clear market positioning

PECV can make full use of natural resources to provide charging services for

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electric vehicle users, which can bring better environmental and social benefits, but enterprises will still face greater market competition in the early stage of industrial development. With the gradual expansion of electric vehicle scale, although user scale of users increases, the market competition increases, too. This requires enterprises to conduct sufficient market research in the early stage of development, find their own positioning, and look for opportunities in the market competition. As a new way of charging station construction, only by finding its unique operation mode and competitive advantage, and analyzing the market conditions scientifically, can we carry out effective market development in the early stage, expand user scale, and then promote the sustainable development of enterprises.

4. Conclusion

To analyze the promotion mechanism of value-added ability of PECV, this article regards value chain as a system and analyzes the key factors that affect the value-added ability of value chain from the internal and external perspectives. Based on the analysis of influencing factors, the system is divided into a resource circulation subsystem, a node operation subsystem, a user demand subsystem, and a technology innovation subsystem. The causality of each subsystem is analyzed separately, and the system flow chart is obtained, which reveals a promotion mechanism of value-added ability of value chain; through the simulation of the model, the validity of the model is tested, and the development trend of value-added ability of value chain over time is analyzed, as well as the impact of government support policies and technology innovation input on value-added ability. Finally, some countermeasures and suggestions are put forward combined with the simulation results.

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