How Does the Efficiency of Value Realization on a Platform Influence Sustainability Transition? A Case of the Power Industry in China

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In the era of the digital economy, for platform-based actors making a transition from one business field harmful for the sustainable development of society to a new field, their efficiency in value realization (EVR) has become inseparable from the digital platform used. The relationship between EVR on a platform and business transitions is a topic that has not been fully discussed, especially from the perspective of the platform service system. Also, few studies have explored transaction costs and opportunity costs using queuing theory. To fill these gaps and to inform transitions to sustainability, this paper applied a system dynamics method and proposed a framework for analyzing the relationship between EVR and the transition ratio. Findings suggest that improvements in the EVR lead to decreases in response time and may lead to an improved transition ratio. The ratio between EVR and the "entry rate" is important for predicting the transition ratio. However, preference, platform maturity, and the feedback of the transition ratio cause the effect of EVR to dynamically change. Based on this mechanism, the government can take incentive measures to maintain an acceptable transition ratio. For the power industry, the case simulated for this study, the transition can be improved by effectively transmitting a phasing-out policy for platforms and actors, and by guiding power exchange platforms to set reasonable rules, service levels, and growth rates.

Keywords: sustainability transition, efficiency of value realization, value preference, time-varying cost, platform maturity

INTRODUCTION

The sustainability transition (ST), such as the transition from fossil energy power generation to renewable energy power generation, is an important topic for sustainable development. In the digital economy era, a time when platform-driven mechanisms and societies are further emerging, ST should be discussed in terms of an actor's operation on a platform[1] (Mattila and Seppälä, 2018; Egana-delSol and Flanders, 2019; Kloppenburg and Boekelo, 2019; Kolk and Ciulli, 2020).

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[1]The platform, which usually exists in the form of a trading market, is a system that allows participants to engage in value-adding activities, and serves as a digital economics organizer with economic and value goals. These platforms can connect, match, design, coordinate, and oversee the market, accelerating innovation and value creation, and influencing the operation of platform-based actors. Source: Egana-delSol PA and Flanders S. 2019. Platform economy and sustainable energy. In: Leal Filho W, Azul AM, Brandli L, *et al.* (Eds), Affordable and clean energy. Springer International Publishing, Cham, pp.1-9, Mattila J and Seppälä T. 2018. Distributed governance in multi-sided platforms: A conceptual framework from case: Bitcoin. In: Smedlund A, Lindblom A and Mitronen L (Eds), Collaborative value co-creation in the platform economy. Springer, Singapore, pp.183-205.

Platforms can simultaneously influence transition and operational decisions of actors operating on the platform, both in terms of the business field being phased out of and the new niche area. For example, the power exchange center of China has been curbing the trading rate of fired power, by setting priorities that ensure renewable energy consumption[2]. Integrated energy service platforms can automatically make decisions and allocate task orders to specific providers, based on their ranking and comprehensive scores (Wang, 2019). Ranking and scoring, which are directly affected by the platform, influence the velocity of participants' transactions. In these examples, as the platform can accelerate the velocity of transactions, actors can obtain profits from transactions at a higher speed. That is, the input resource can generate a faster increase in value. This leads to changes in an actor's investment in different business fields and can impact the state of the actor's transition. In this process, transaction velocity is closely related to the core concept of the "efficiency of value realization" (EVR[3]).

EVR is a key factor connecting an actor's operations on a platform and an actor's decision to transition. First, EVR, which measures an actor's operational efficiency, is a conjunction between platform and actors. That is, EVR is used to measure the velocity at which the actor's input[4] gains an increase in value at a certain ratio[5] through that platform. EVR is also used to describe the "service rate"[6] of the platform from a service system perspective. Second, EVR influences an actor's decision on transition because this "service rate" influences the actor's response time[7] and time-varying cost (the cost incurred during the response time). This consequently influences actor's profit and investment decisions, which are associated with transition decisions.

In addition, EVR serves as a key factor for ST because the platform changes the actors' transition decisions and behavior mainly in two ways. First, it directly affects the velocity of actors'

value realization by offering service and related rules. Second, its services change the actors' business environment, impacting their utility. Overall, the influence from the platform to the actors' business environment can be largely attributed to the impact on the EVR in each period; however, the influence varies over time. In summary, EVR is a key factor connecting the platform, the actor's operation, and transition. This makes it important to study the influencing mechanism of EVR in the platform operation background in order to accelerate transition.

To analyze the relationship between EVR and transition, and explore a new way of managing ST in the platform economy, we addressed the following question: What is the mechanism shaping the effect of the EVR on the transition ratio[8] in the background of the platform?

To explore this mechanism, we raised a second relevant question. In this relationship, how do two factors - value preference and platform maturity - change the effect of the EVR and affect the transition ratio, shaping the dynamic relationship? This question is raised based on two considerations.

First, when considering sustainable development, the government has a "preference" with respect to different actors' activity and their output. This is usually measured by profit or the index of GDP. This preference is described as a "value preference"[9]. Through ST policies or government outreach, the social value preference is transmitted to the platform. As a result, the platform provides different services for different actors or projects forming different EVRs on the platform. Also, in response to the social value preference, actors form judgements about the importance of output from different business fields (actor's value preference[10]), directly influencing their decision on transition.

Secondly, platform maturity[11] is another important factor, because it is closely related to the effect of platform service. As the ability and influence of a platform grows stronger, the platform service is more powerful in changing EVR, and the effect of EVR on the transition dynamically changes. Thus, value preferences and platform maturity play an important role in the mechanism with respect to EVR and the transition ratio.

By answering these two questions, this study identifies an approach to co-governance between the government and the

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[2]Notice on Issuing the Rules for the Implementation of Middle-term and Long-term Transactions across Regions and Provinces in Beijing Power Exchange Center. No .51[2018].http://www.bj-px.com.cn/html/main/col14/2018-08/30/20180830102119626314055_1.html.

[3]EVR is the amount of objects that gains an increase in value per unit time. "EVR on a platform" is the velocity of the increase in an actor's value on a platform.

[4]The "input" can be capital, product, resources, or affairs to be dealt with.

[5]This ratio is an achievable or target percentage called the "ratio of an increase in value" which is described in notations (**Table 1**). For example, if 50% of the input capital I_1 can increase at an expected ratio r_1 in one year, then the EVR is $0.5 \cdot I_1$. For a transaction platform system, the EVR can be estimated by observing the amount of trade.

[6]The platform service is an "increase in value" detailed as a transaction or management service. The velocity of the increase in value is the quantity of objects being served by the platform system per unit time. Thus, the efficiency of platform-based value realization discussed in this study is the same as the platform's service rate.

[7]Response time: In queuing theory, response time refers to the time between customer arrival and the completion of service, or the total time when a customer stays in the system. In this study, response time is defined as the time of value realization, or the time when the resources that receive added value stay in the system. More specifically, it is the time when the resource passes through a platform system to achieve an increase in value at certain ratio. In a broad sense, it is the time when goals can be achieved through the system.

[8]The actor's decision about investments in different business fields shapes the transition ratio. This ratio is the proportion of a resource that an actor in transition transfers from the original business field to a new business field.

[9]Value preference refers to the evaluation on the importance of profit or output value coming from different value creation activities. The evaluation is made under certain values and criterions. Under the value preference, the wealth originally measured by money and labor time changes according to an assessment of "importance" and becomes the utility value. Under a certain value preference, policies or measures exerted on favored and unsupported fields will differ. It is measured by the coefficient of value preference, shown as notations of α_1, α_2 in **Table 1**.

[10]The value preference discussed in this paper includes the value preference of society, that of platform, and that of the actor. The societal preference is also called social value preference in this paper, while the actor's preference is also called strategic preference.

[11]Platform maturity refers to the capability and influence of platform at different development stages.

platform to accelerate the transition to sustainability. Specifically, by providing a mechanism that reflects the change in the transition ratio, it informs innovative policies with respect to value preference, platform growth, service level, efficiency of value increase, and actor behavior management during a transition.

The rest of this paper is structured as follows. The next section provides the literature review. **Methodology** presents the process of modeling using System Dynamics. **Simulation Result** provides a numerical analysis, using the transition of China's power industry as an illustration. The last section concludes the paper.

LITERATURE REVIEW

Platform Maturity and Preference

Platform maturity and preference are two important factors influencing the platform's service level and the effect of the platform service, respectively. First, platforms have social and environmental values (Martin et al., 2017) and make their own value judgments. Kloppenburg and Boekelo (2019) posited that platforms tend to generate exclusions. Platforms do this by making judgments about the right type of energy production and consumption, raising barriers for new entrants. The values are preset or hidden in the design process, as platforms are established based on an idea, concept, or certain requirements resulting from an analysis by platform operator (Abdelkafi et al., 2019). Platforms affect actors' behavior by offering services, and their value judgments influence their service levels and further change actors' operational efficiency (Xie and Jawad Sajid, 2019).

These studies highlight the presence of preferences and value judgements in the platform system, impacting the platform's behavior and actor's operation. However, the studies do not offer a method or tool for analyzing the influence on platform services and the actor's operation in the context of ST. To fill this gap, we apply the concept of the "value preference" to describe the new decision criteria, including considerations of profit and sustainability. We also offer a tool to explain the decisions related to the platform, society, and the actor in the ST context.

Second, the effect of a platform service is influenced by its maturity. Kim et al. (2018) proposed that a platform experiences three stages in its development: the pre-platform stage, the transitioning stage, and the stabilizing stage. Gawer (2014) noted that the development stage of a platform should include: internal research and development, becoming a supply chain platform, and then becoming an industrial platform. Loux et al. (2020) classified the maturity level of a platform into the nascent stage and mature stage. That study noted that the platform can evolve from a two-sided platform at a nascent stage, bringing together merchants and buyers, to a mature multi-sided platform, bringing together application developers, banks, and advertisers (Loux et al., 2020). Mature and nascent platforms are mainly classified according to age and influence sales differently (Landsman and Stremersch, 2011). Lee (2019) described the maturity level of platform as follows: the start of construction, the perfection of function, the expansion of the application, the exploration in a certain industry, and the establishment of an ecosystem.

Most scholars agree that the platform's maturity refers to its capability level and influence at different development stages. Because the development stage of a platform is often defined based on its capability and influence, the level of development stage is often consistent with its maturity level. In summary, the platform's maturity reflects the level of its capability and influence. When the platform is at a higher stage and of greater maturity, it exerts a stronger effect on the market and stakeholders. At that point, measures taken by the platform generate more influence and as a result, it can significantly increase the actors' operational efficiency.

In conclusion, the preference and maturity of the platform affect its service and the actor's operation. Thus, they are considered to be key factors in the mechanism explored by this study.

Sustainability Transition Theory Related to Phasing Out Activities

Sustainability transition theory mainly discusses how transitions evolve over time and provides policy recommendations to support a progressive transition (Vincent et al., 2016). Widely applied sustainability transition theories include the theory of multi-level analysis and the theory of transition management. Multi-level analysis explains the transition process from three perspectives: niche, institution, and prospect (Geels, 2019; Geels et al., 2017; Köhler et al., 2019; Li and Strachan, 2019). The theory of transition management combines long-term thinking with short-term action (Lachman, 2013; Shum, 2017; Williams et al., 2017).

These theories offer an analytical framework for understanding sustainability transitions. Using a multi-level analysis, Vögele et al. (2018) highlighted possible phase-out pathways for coal-related technologies, highlighting that these processes are influenced by economic, political, technical elements, and social factors. Oei et al. (2020) illustrated the effects of different phase-out pathways for power plants, using an input-output model and regional macroeconomic model. Oei et al. (2019) pointed out that, from a macro perspective, a phase-out path can be jointly managed using a polycentric approach by city, regional, national, and international governments and institutions. Rosenbloom (2018) illustrated how ideas, interests, institutions, and infrastructure interact to create pathways that eliminate coal. Rentier et al. (2019) clarified the impact of different market economies on carbon lock-in and phase-out processes. Rentier et al. (2019) emphasized that strategic interactions, employment protections, government ownership, market price, and profit are important factors affecting a phase-out path. Gloria Baigorrotegui (2019) analyzed destabilizations over short periods, noting that the phasing-out mechanism is formed by three factors: pressure, obstruction, and public overflow to trace the activities. The sustainability transition theories relevant to the phase-out pathway demonstrate the framework, approaches, pathways, influencing factors, and policies. These inform a discussion about transition, considering different sides and factors. However, less attention has been paid to the effect of platform on sustainability transition and related mechanisms.

The Method of System Dynamics Used in Sustainability Transition

Many methodologies have been adopted to analyze the dynamic complex systems in the field of sustainability transition. Examples include extensive sensitivity analysis and Monte Carlo simulations (Banos-Gonzalez et al., 2018), scenario analyses based on the co-simulation method (El-Baz et al., 2019), the fuzzy cognitive mapping-system dynamics approach (Kokkinos et al., 2018; Pereira et al., 2020), differential equation modeling natural experiments (Curseu and Schruijer, 2020), agent-based modeling (Kieckhaefer et al., 2017; Shafiei et al., 2013), and system dynamics modeling (SD modeling) (Bautista et al., 2019, Cavicchi, 2018; Cosenz et al., 2020; Graziano et al., 2019, Papachristos, 2011; Tan et al., 2018).

Of these approaches, SD is a good method for reflecting the systemic interactions among variables (Tan et al., 2018), and is especially useful for analyzing feedback relationships. Ma and Hu (2018) combined SD and coupled game theory to analyze the eco-innovation mechanism and policy in the pulp and paper industry. Bautista et al. (2019) assessed biodiesel production based on a SD model and systems theory. Cavicchi (2018) analyzed the influence of power, institutions, and expectations on the bioenergy transition process by applying qualitative system dynamics and interviewing local actors. Cosenz et al. (2020) conceptualized an approach using dynamic business modeling for sustainability, combining an adapted sustainable business model canvas and system dynamics modeling. Kieckhäfer et al. (2017) studied the system of vehicle, energy, and consumers based on SD and agent modeling. Papachristos (2011) tested the dynamic consistency of the "Multi-Level Perspective" substitution pathway based on the MLP framework and SD modeling.

Two important applications of SD emerge from these studies. First, SD is usually used in mechanism analysis and framework building; one example is the model built by Cosenz et al. (2020). Second, SD is used in scenario simulations and to inform policy recommendations, as in the analysis given by Tan et al. (2018). SD modeling is often integrated with another method; this approach is also shown in this paper. That is, the framework and scenarios analyses in this paper are based both on SD and on the integration of queuing theory.

Studies focusing on platforms and sustainability transitions have consistently explored the ST or platform separately. Only a few papers have linked sustainability with the platform. Specifically, Paundra et al. (2020) studied the environmental impact of ridesharing platforms, based on the interplay of access-based and ownership-based consumption mechanisms. Kloppenburg and Boekelo (2019) and Kolk and Ciulli (2020) discussed the relationship between platform, energy system, and ST. Kolk and Ciulli (2020) also proposed a research agenda for the study of ST by linking society, platform, and actors. However, these theories do not consider the relationship between EVR and transition in the context of the platform. Further, none of these studies have analyzed the perspective of the platform queuing system. Finally, few studies have examined the relationship between ST, platform, society, and actors based on SD modeling and the time-based cost analysis. Based on the

research agenda advanced by Kolk and Ciulli (2020) and theories about platform preference and maturity, this study focused on the dynamic mechanism between EVR on platform and transition ratio, considering the influence from value preference and platform maturity. This study applied the SD method to describe this complex feedback relationship.

METHODOLOGY

This study applied the method of system dynamics, which is a science that combines system science theory with simulations to study feedback structures and system behavior. The method complements the dominant multi-level perspective and the transition management approach, by providing a middle ground between emphasizing agency or structure (Vincent et al., 2016). Because there is feedback in this study's transition model, system dynamics is an effective approach. The system dynamics method includes the following steps. First, the problem is articulated or conceptualized for a dynamic hypothesis. Second, the model is formulated. Third, the model is tested and analyzed (Espinoza et al., 2017; Homer, 2019). In the modeling process, Little's Law in queuing theory is used to analyze the time-varying cost (transaction cost and opportunity cost) which relates to the platform service. The value preference is used to analyze the investment decision in the context of ST. This methodology is shown is **Figure 1**.

Notations

To clarify the model and equations in this study, relevant notations are listed in **Table 1**.

Hypothesis and Model Boundary

The essence of the problem discussed in this paper is the relationship between the input resource, the increase in value of that resource, and the allocation of the resource in the background of the platform's operation. This relationship can be described as a dynamic feedback event: an actor in transition invests resources in different fields. Based on the influence of the platform, the resources placed in different fields lead to increases in value at different EVRs, leading to different profit levels. Given the effects of the profit and value preference, the transition ratio emerges and influences a new round of resource investments.

To make the research about this relationship implementable, five hypotheses (H1–H5) are included in the model. H1: The actors in transition are considered as a whole (A). There are two kinds of business fields for the actor: a new business field (A_1) and the original business field, such as fired power generation (A_2). H2: The social value preference can affect the platform's preference and actor through publicity, education, rules, policy tools, and laws. Also, preference affects utility; in other words, the utility from different business fields is determined by profits and by preference. H3: The influence of quality and competition on the EVR is not considered. In the context of China's power system, the product "power" can be considered homogeneous with respect to problems related to peaks and valleys and can be solved through the regulation and control of social power system.
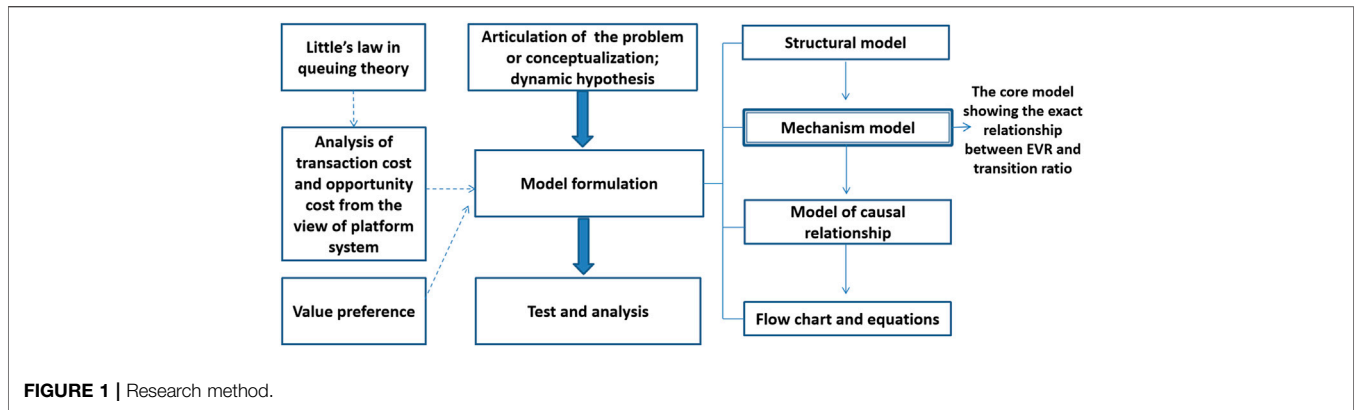
FIGURE 1 | Research method.

This assumption is consistent with the current reality of the power system. H4: The quantity of the supply changes according to demand. H5: The profit from a project in the current period influences the resources to be invested in the next period.

The model boundaries were set as follows: A's new business field (A_1), A's original business field (A_2), and the decision relates to A's investment in a transition. The modeled period covered 20 years (2016–2036). The system of sustainability transition includes three parts: i) the realization of value on the platform in A_1; ii) the realization of value on the platform in A_2; and iii) A's decision-making related to the investment in the transition.

The model boundaries and the overall relationship among the three parts are presented in the general structure in **Figure 2**. The main relationship between the three parts was as follows. The actor's decision-making determines the transition ratio and the resource allocation between A_1 and A_2. Then, by determining the response time, cost and profit, the value realization systems of A_1 and A_2 affect the transition ratio. This interaction relationship is affected by value preference and platform maturity. These feedback relationships are fully explained in the next section.

Dynamic Feedback Mechanism Between EVR and Transition Ratio

The structural model shows the main constituents and general relationship in the transition system. However, the dynamic feedback mechanism between EVR and transition ratio is not precisely related. This is shown as the model illustrating the mechanism involved (**Figure 3**) and is explained as follows.

First, a change in the EVR leads to a change in the transition ratio. The EVR is the consequence of a platform's effect on an actor, however, it is also a driving force advancing the transition. The EVR is influenced by the platform service, platform maturity, and annual input resource. The EVR and entry rate determined the value of the response time (time of value realization). The response time has a direct relationship, with time-driven variations in costs, such as transaction and opportunity costs. Time-driven variations in cost influence profit, which affects resource allocation decisions and the transition ratio in the next period. The value preference impacts this relationship in two main ways. The social value preference affects the value

preference of the platform, which is directly associated with the platform's service level. Also, the social value preference affects the actor's strategic preference, impacting the transition ratio.

Second, the transition ratio generates feedback, which causes this relationship dynamic. Changes in the transition ratio lead to changes in the resources invested into different fields, creating fluctuations in the entry rate. The change in the entry rate results in a change in the EVR. This is because the input resource and subsequent output commodities to be traded during each period are related to the number of objects ultimately traded each period (EVR). In addition, a change in the entry rate also causes changes in the time-driven variations in cost, because the quantity of input resources is closely associated with opportunity and transaction costs.

Design of Causal Relationship and Flow Chart

Causal relationships and the development of the flow chart are necessary steps in the simulation based on system dynamics. First, based on the general structure model and the model illustrating the mechanisms involved, the feedback relationships can be analyzed and a chart outlining the casual relationships can be generated. The model illustrating the mechanism illustrates three classes of feedback. The first class of feedback is "EVR → response time → time-varying cost → profit → transition ratio → input resource → entry rate → EVR." This feedback relationship exists both in A_1 and A_2. It is detailed as "$\mu_1 \to W_1 \to X_1 \to \Pi_1 \to k \to I_1 \to \lambda_1 \to \mu_1$" in A_1, and is shown as "$\mu_2 \to W_2 \to X_2 \to \Pi_2 \to k \to I_2 \to \lambda_2 \to \mu_2$" in A_2. The second class of feedback is "time-varying cost → profit → transition ratio → input resource → entry rate → time-varying cost per unit time → time-varying cost". Feedback from this second class is specified in A_1 and A_2 as "$A_1: X_1 \to \Pi_1 \to k \to I_1 \to \lambda_1 \to C_1 \to X_1$" and "$A_2: X_2 \to \Pi_2 \to k \to I_2 \to \lambda_2 \to C_2 \to X_2$," respectively. The third class of feedback is "input resource → profit → transition ratio → Input resource." This class is specified as "$I_1 \to \Pi_1 \to k \to I_1$" for A_1, and as "$I_2 \to \Pi_2 \to k \to I_2$" for A_2. Based on the feedback relationship between these factors, **Figure 4** provides a chart showing the causal relationships.

Second, based on the casual relationships, more detailed relationships of the factors are described using equations and

TABLE 1 | Notation definitions.

Notation	Explanation
A	Phasing-out actor, such as companies in the fired power industry
A_1	Phasing-out actor's new business field, such as renewable energy sourced power generation
A_2	Phasing-out actor's original business field, such as fired power generation
I	Total resources placed in A_1 and A_2 each period
I_1, I_2	Resources placed in A_1 and A_2, respectively
$I_{1(t)}, I_{1(t+1)}$	Resources placed in A_1 in the current period and the next period, respectively. The variables t and t+1 represent the current period and the next period, respectively
μ_1	Efficiency of value realization in A_1 denoting the velocity at which I_1 achieves an increase in the value on the platform, namely the service rate of the platform
μ_2	Efficiency of value realization in A_2
λ_1, λ_2	The entry rate[a] of A_1 and A_2, respectively
r_1, r_2	Ratio of the increase in value[b], the rate of return on investment without considering the transaction and opportunity cost caused by response time
uc	Unit cost of fired power electricity
M	A large amount of input capital waiting for an increase in value, the value of which should be selected as the largest trade volume to adjust the unit
θ_1, θ_2	Coefficients of factors influencing μ_1 and μ_2, respectively
L_1, L_2	The service level provided for A_1 and A_2 by the platform, respectively
L_{10}, L_{20}	The service level provided for A_1 and A_2 by the platform when the platform preference is neutral, respectively
L_m	Basic service level of platform
$\Delta L_1, \Delta L_2$	Changes in service level as a result of changes in the value preference of the platform
Π	A's total profit
Π_1	A's profit in the new business field
Π_2	A's profit in the original business field
α_1, α_2	Coefficient of social value preference, used to measure the importance of output value from A_1 and A_2 judged by society, respectively. α_1 and α_2 affect the utility of society (e.g., the sum of $\alpha_1 \cdot \Pi_1$ and $\alpha_2 \cdot \Pi_2$ represents the utility of society). The variables α_1 and α_2 are determined using expert-based methods, such as the Delphi method; and can be revealed based on the target ratio of resource allocation or target quota established by the government
α_{1s}, α_{2s}	Phasing-out actor's strategic preference coefficients for A_1 and A_2, respectively, in the context of a sustainability transition. They are affected by social value preference
α_{1p}, α_{2p}	The coefficient of platform's value preference for A_1 and A_2 respectively. They are affected by social value preference
γ_1, γ_2	The coefficients denoting the change of service level L_1 and L_2, respectively, when the coefficient of platform preference deviates from the neutral state for one unit
η_1, η_2	Consistency coefficients of value preference, reflecting the degree of consistency between platform preference and social value preference
P_m	Platform maturity
P_g	The growth rate of platform maturity
W_1	The total response time of all the input resources in A_1
W_2	The total response time of all the input resources in A_2
C_1, C_2	Transaction and opportunity costs per unit time in A_1 and A_2, respectively
P_g	The growth rate of platform maturity
k	A's transition ratio, referring to the proportion of resource that the actor transfers from the original business field to the new business field
ρ_1, ρ_2	Coefficients measuring the influence from marginal capital utility on the decision of I_{a1}
ρ_0	The influence coefficients of I have on I_1
X_1, X_2	Time-varying cost, the cost incurred during response time W_1 and W_2, respectively. This reflects the time-driven variations in cost, referring to the transaction cost (searching cost, information cost, bargaining cost, oversight cost, etc.) and opportunity cost (opportunity cost of holding currency) in the simulation
η_{1s}, η_{2s}	Coefficients measuring the influence from social value preferences α_1 and α_2 on an actor's strategic preferences α_{1s} and α_{2s}, respectively
r	Ratio of time-varying cost per unit time, a coefficient describing relationship between input resource (I_1 or I_2) and the time-varying cost incurred in unit time
q	A target ratio of society, specified as output of photovoltaic power divided by the total output of photovoltaic power and fired power in the simulation
D	Demand of electricity, specified as the total demand of photovoltaic power and fired power in the simulation

[a]*Entry rate: the entry rate of the platform is the quantity of objects accessing the platform system and waiting for an increase in value per unit time. Specifically, "object" refers to a resource, such as capital placed in production. "An increase in value" is the "service" of platform system and is often actualized through transactions. The unit of object entering system was adjusted to make statistics conform to a Poisson distribution.* **Adjusted entry rate = the amount of capital entering the platform system per time unit÷M.**

[b]*The ratio of the increase in value is the return ratio of input resource without considering the response time (response time is explained in the seventh footnote) and time-driven variations in cost such as transaction cost and opportunity cost.* **ratio of the increase in value increase = (revenue − cost irrelevant to response time) ÷ input capital**. *The equation is simplified as* (P − **uc**)÷**uc** *in the simulation. In the equation, "cost unrelated to response time" is the cost that cannot be influenced by the platform, mainly referred to as the production cost in this paper. When discussing the power system, it includes depreciation of fixed assets, operation cost, maintenance cost, financial cost, and tax.*

FIGURE 2 | General structure.
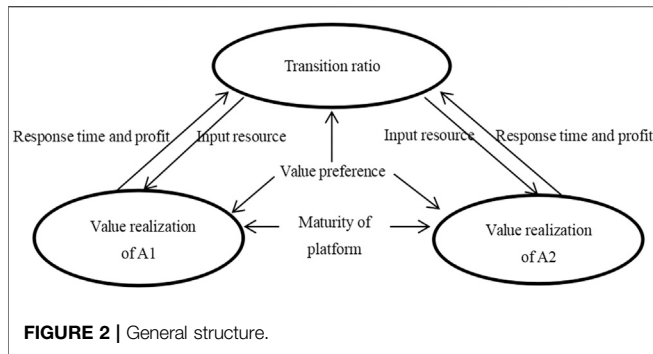
$$\mu_1 = \theta_1 \cdot \lambda_1 \cdot L_1 \cdot P_m \qquad (1)$$

$$\mu_2 = \theta_2 \cdot \lambda_2 \cdot L_2 \cdot P_m \qquad (2)$$

The EVR on the platform is associated with three factors. The first factor is λ_1. This is because if the production plan is developed according to demand, society generally needs the output. As such, the quantity of the supplied products waiting to be traded on the platform each period is related to the volume of products that can be traded through the platform each period. This study considers the case of the power system. As the output of power generation is usually needed and consumed by society, the capacity and quantity of electricity supply each period relates to the

FIGURE 3 | Model illustrating the mechanism between EVR and transition ratio.
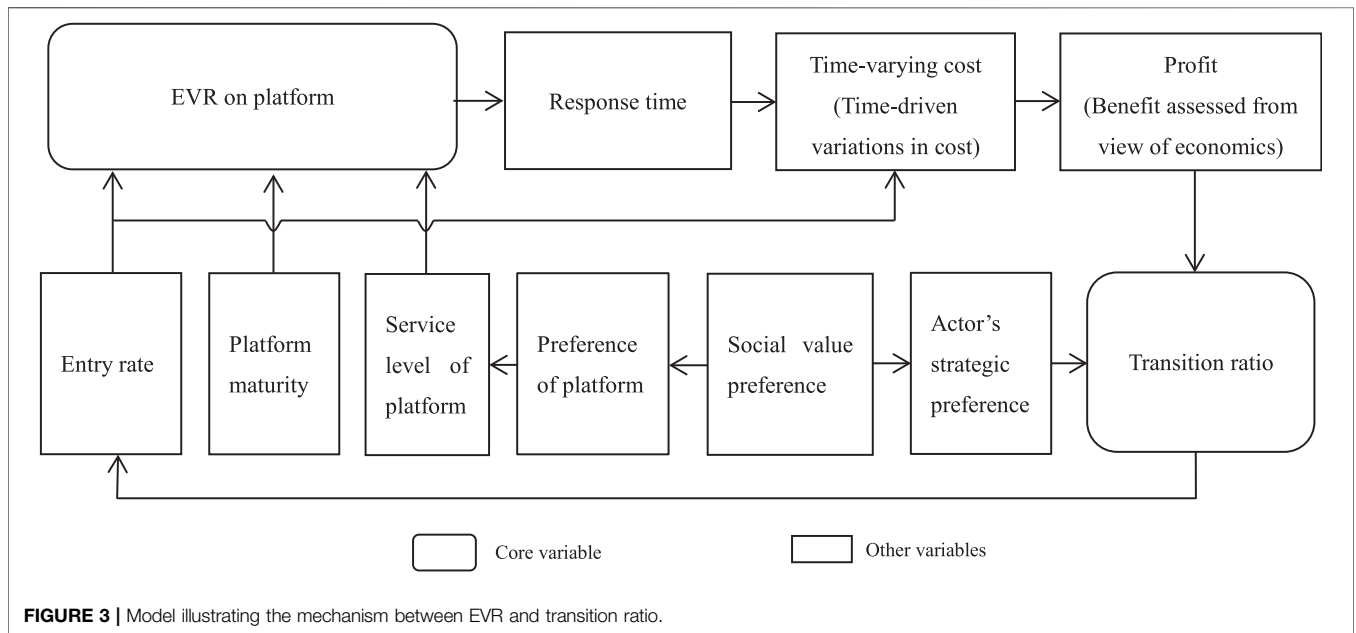
a flow chart. The variables I_1 are established as state variables. The changing rate of I_1 is expressed as $I_{1(t+1)} - I_{1(t)}$. Other variables are established as auxiliary variables. Based on this, a flow chart is drawn to run the simulation (**Figure 5**). In this graph, the transition ratio (k) can influence and be influenced by the value realization systems of A_1 and A_2. The relationships of factors in the flow chart are described using equations explained in **Equations**.

Equations

Based on the structural model, relationship model, flow chart, and the chart of causal relationships, we developed equations related to the value realization and transition ratio.

Equations Relevant to Value Realization

Important variables related to value realization include EVR (μ_1, μ_2), entry rate (λ_2, λ_1), value preference $(\alpha_1, \alpha_2, \alpha_{1p}, \alpha_{2p})$, platform maturity (P_m), time of value realization (W_1, W_2), cost (X_1, X_2), and profit (Π_1, Π_2). Their equations are expressed as follows.

quantity traded each period. Thus, the resource used to produce electricity supplied to the platform waiting for a transaction each period (entry rate) relates to the production resource resulting in the electricity finally traded on the platform each period (EVR). In this case, when λ_2 and λ_1 changes, the platform can create different queuing systems in different years.

The second factor associated with EVR is the service level of the platform. Platform service refers to all the measures taken by a platform that influence the value realization of the actor's input resource, specified as the transaction service in the simulation. The level of service is an assessment or planning level of the platform's influence on different businesses, marked as level 1, level 2,.... The level of service can be estimated using information or recommended statistics (Xie and Jawad Sajid, 2019); rules used to prioritize different businesses; or indexes related to transaction services, payment service, or derivative services (Yu, 2017). A higher level of service reflects a beneficial influence given by the platform. If more objects are traded, there is a greater increase in the resource inputs and increased gains in the value. This leads to a higher EVR.
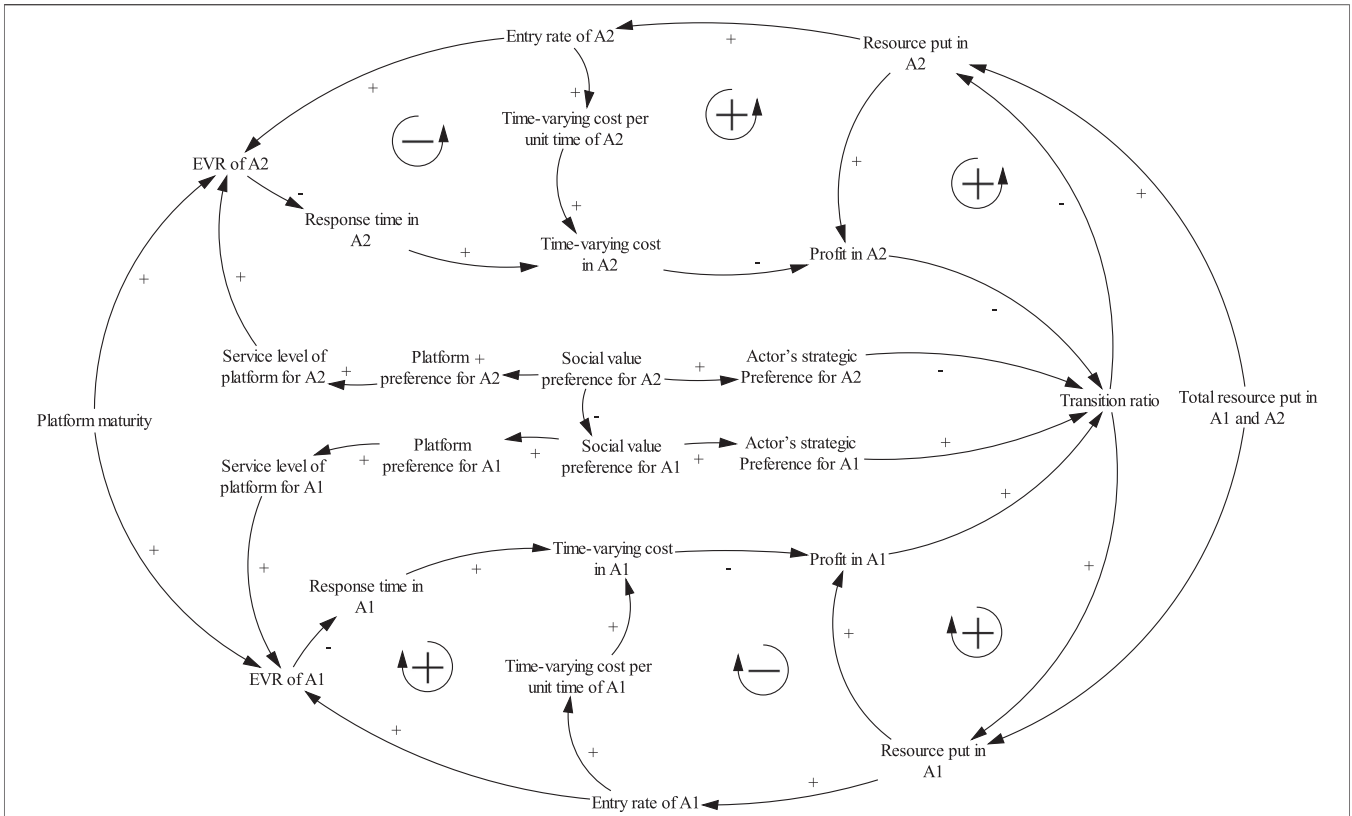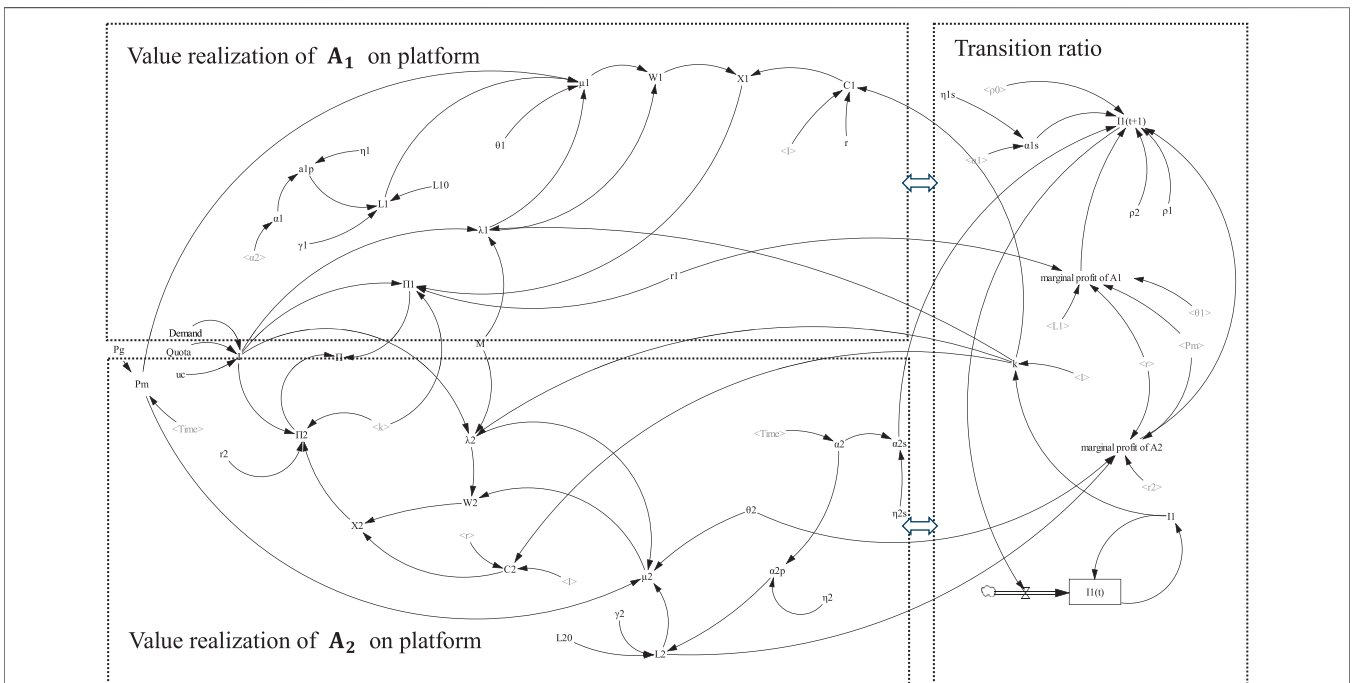
FIGURE 4 | Causal relationship.

FIGURE 5 | Flow chart.

The third factor associated with EVR is P_m, an accelerator for EVR. As described above, a higher P_m corresponds to a higher level of technology and higher platform capability. Platform service is based on the technology, operation, and ability of the platform. Superior technology and higher platform capabilities will enhance the efficiency of platform service, which is directly associated with EVR. More specifically, the same level of service affects the EVR differently when comparing a newborn platform (P_m is low) and a platform with years of development (P_m is high). For example, improvements in EVR differed for the top level of service offered by the famous platform Alibaba in 1997 compared to 2020. Platform service influences EVR by accelerating or decelerating the value realization of objects entering the platform system. A higher platform maturity enhances the effect of the platform service on value realization.

Service level (L_1, L_2), value preference $\alpha_{1p}, \alpha_{1p}, \alpha_1, \alpha_2$, and platform maturity P_m are described in **Eqs. 3–7**.

$$L_1 = \textbf{IF THEN ELSE}\left(L_{10} + \left(\alpha_{1p} - 0.5\right) \cdot \gamma_1 \leq L_m, L_m, L_{10}\right.$$
$$\left. + \left(\alpha_{1p} - 0.5\right) \cdot \theta_1\right) \tag{3}$$

$$L_2 = \textbf{IF THEN ELSE}\left(L_{20} + \left(\alpha_{2p} - 0.5\right) \cdot \gamma_2 \leq L_m, L_m, L_{20}\right.$$
$$\left. + \left(\alpha_{2p} - 0.5\right) \cdot \theta_2\right) \tag{4}$$

$$\alpha_{1p} = \alpha_1 \cdot \eta_1 \tag{5}$$

$$\alpha_{2p} = \alpha_2 \cdot \eta_2 \tag{6}$$

$$P_m = Time \cdot P_g + 1 \tag{7}$$

These equations show that L_1 is determined by a platform's value preference with respect to different objects to be served and the platform's utility. Generally speaking, when the platform attaches more importance and preference to certain behaviors, operations, and their output, the platform provides a higher level of service for the object[12]. For example, the power exchange center of China focuses more attention on renewable energy-sourced power compared to fired power. As such, it prioritizes renewable energy-sourced power transactions to ensure that form of energy is traded and consumed first[13]. In this case, the platform provides a high level of service for renewable energy-sourced power transactions, accelerating the velocity of that transaction. The platform acts as an intermediary, and provides a fair-trade environment. Thus, it must provide a basic service level (L_m) for the actor's operation. In **Eqs. 3, 4**, factors L_{10} and L_{20} represent the service level of the platform when the platform's preference is neutral ($\alpha_{1p} = \alpha_{2p} = 0.5$). The coefficients of value preference usually changed in the range of [0, 1] in the simulation; therefore, the preference was neutral when the values of coefficients α_{1p}, α_{2p} were both 0.5.

The entry rate, response time, and cost are explained based on "Little's Law" in queuing theory, as shown in **Eqs. 8–13**.

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[12]"Object" can be goods, resource, capital, or other items waiting to gain value by the operation on the platform. It is specified as the input resource, measured in production cost in simulation.

[13]Notice on Issuing the Rules for the Implementation of Middle-term and Long-term Transactions across Regions and Provinces in Beijing Power Exchange Center. No. 51 [2018]. http://www.bj-px.com.cn/html/main/col14/2018-08/30/20180830102119626314055_1.html.

$$\lambda_1 = \frac{I_1}{M} \tag{8}$$

$$\lambda_2 = \frac{I_2}{M} \tag{9}$$

According to Little's Law, key factors such as platform service, objects to be served, entry rate, and the service rate were first clarified and the response time was calculated. The platform service can be specifically described as "helping an actor's invested resource gain an increase in value at a certain ratio." For example, the service can be detailed as matching, sales promotion, coordination of operation, quality, or fame certification. The variables I_1 and I_2 represented the resources invested in A_1 and A_2, respectively; these were considered to be the objects served by the platform. This means that I_1 and I_2 experienced increases in value after the outputs of A_1 and A_2 were traded on the platform. Assume that M is a value larger than the maximum value of a single transaction. The expressions $\frac{I_1}{M}$ and $\frac{I_2}{M}$ represent the quantity of objects (measured in unit M) entering the platform, and waiting for service, each period. The quantity of objects measured by M conformed to the Poisson distribution. Based on this, the entry rate is described in **Eqs. 8, 9**. The service rate was also the EVR, as explained in **Introduction**. The total response time of all the input objects being served was calculated using **Eqs. 10, 11**.

$$W_1 = \frac{\lambda_1}{\mu_1 - \lambda_1} \tag{10}$$

$$W_2 = \frac{\lambda_2}{\mu_2 - \lambda_2} \tag{11}$$

For commodities such as electricity, society generally needs the supply. Thus, this study considered an electricity transaction system without congestion. The variable μ_2 was usually more than λ_2. Therefore, the response time per unit of input resource in A_1 and A_2 was calculated as $\frac{1}{\mu_1 - \lambda_1}$ and $\frac{1}{\mu_2 - \lambda_2}$, respectively. Based on this, the response time of all resources placed in A_1 per year was described as $\frac{\lambda_1}{\mu_1 - \lambda_1}$; the response time of all the resources placed in A_2 per year was described as $\frac{\lambda_2}{\mu_2 - \lambda_2}$.

Costs are described in **Eqs. 12–15**.

$$X_1 = W_1 \cdot C_1 \tag{12}$$

$$X_2 = W_2 \cdot C_2 \tag{13}$$

$$C_1 = I_1 \cdot r \tag{14}$$

$$C_2 = I_2 \cdot r \tag{15}$$

More goods to be traded and more resources awaiting an increase in value in one period led to higher transaction and opportunity costs in the period; as such, C_1 and C_2 increased with increases in the input resource I_1 and I_2, respectively.

In addition, two other formulas of X_1 and X_2 were derived from **Eqs. 1, 2, 12–15** as follows.

$$X_1 = k \cdot I \cdot r \cdot \frac{1}{\theta_1 \cdot L_1 \cdot P_m - 1} \tag{16}$$

$$X_2 = (1 - k) \cdot I \cdot r \cdot \frac{1}{\theta_2 \cdot L_2 \cdot P_m - 1} \tag{17}$$

A's profit is divided into two parts: Π_1 and Π_2.

$$\mathbf{\Pi_1 = k \cdot I \cdot r_1 - X_1} \quad (18)$$

$$\mathbf{\Pi_2 = I \cdot (1 - k) \cdot r_2 - X_2} \quad (19)$$

Equations Reflecting the Transition Ratio

The investment in $\mathbf{A_1}$ is described in **Eqs. 20–23**. Based on this, the transition ratio is expressed in **Eq. 23**. The resource placed in $\mathbf{A_2}$ is described in **Eq. 24**.

$$\mathbf{I_{1(t+1)} = \rho_1 \cdot \frac{\partial(\alpha_{1s} \cdot \Pi_1)}{\partial I_1} - \rho_2 \cdot \frac{\partial(\alpha_{2s} \cdot \Pi_2)}{\partial I_2} + \rho_0 \cdot I} \quad (20)$$

Factors on the right side of the equation are assigned a value in period t, that is, the value of the factors at the current time. The factor $\mathbf{I_{1(t+1)}}$ represents the value of $\mathbf{I_1}$ in the next period (period t+1).

An actor's decision to invest in $\mathbf{A_1}$ and the corresponding transition ratio is determined both by profit and sustainable strategic preference. This is because from an economic view, profit plays an important role in resource allocations. However, resource allocations and transition decisions do not always depend on profit, especially with respect to sustainable development. The variables $\mathbf{I_1}$ and k are influenced by the actor's sustainable strategic preference, which refers to the actor's evaluation of the importance of different businesses fields with respect to sustainability. This means that even if two business fields create the same profit for A, they have different effects on A's long-term development and transition, due to government's phasing-out policy and other factors influencing the actor's business environment.

The product of profit and preference "$\mathbf{\alpha_{1s} \cdot \Pi_1}$" and "$\mathbf{\alpha_{2s} \cdot \Pi_2}$" represented the utility for $\mathbf{A_1}$ and $\mathbf{A_2}$, respectively. The expressions $\frac{\partial(\alpha_{1s} \cdot \Pi_1)}{\partial I}$ and $\frac{\partial(\alpha_{2s} \cdot \Pi_2)}{\partial I}$ represented the marginal capital utility of $\mathbf{A_1}$ and $\mathbf{A_2}$, respectively. The values of the coefficients $\mathbf{\rho_1, \rho_2, \rho_0}$ were determined by the importance of relevant factors (marginal capital utility and $\mathbf{I}$) in the decision-making process. Of course, the concrete expression of k could also be determined through optimization and other methods; however, this does not change the key point of the study: the actor makes decisions on the transition ratio based on profit and strategic preference.

$$\mathbf{I_1 = I_{1(t)}} \quad (21)$$

$$\mathbf{I_1 = INTEG\left(I_{1(t+1)} - I_{1(t)}, I_{1(t)}\right)} \quad (22)$$

Setting "$\mathbf{I_{1(t+1)} - I_{1(t)}}$" as a rate variable, the function of $\mathbf{I_1}$ is expressed in **Eq. 22**. Every time the function of $\mathbf{I_1}$ was assigned a new value, a new period began.

$$\mathbf{k = \frac{I_1}{I}} \quad (23)$$

$$\mathbf{I_2 = (1 - k) \cdot I} \quad (24)$$

The transition ratio is a ratio of resource allocation. It describes the portion of resource transferred from an actor's original field to a new field, as shown in **Eq. 23**.

Specific Equations of Value Preference

These equations do not discuss the concrete forms of $\mathbf{\alpha_1, \alpha_2}$. The changing trends in social value preferences were described based on the simulation background's "transition of power industry," shown in **Eqs. 25, 26**.

$$\mathbf{\alpha_2 = Time \cdot (-0.01) + 0.3} \quad (25)$$

$$\mathbf{\alpha_1 = 1 - \alpha_2} \quad (26)$$

Only two business fields are discussed here ($\mathbf{A_1, A_2}$); as such, societal resources were allocated in these two fields. Thus, the relationship between $\mathbf{\alpha_1}$ and $\mathbf{\alpha_2}$ was expressed as $\mathbf{\alpha_1 + \alpha_2 = 1}$. The initial value of $\mathbf{\alpha_2}$ was set at 0.3 and was assigned different values in the following simulation. Due to a gradual depletion of fossil energy, there was a weakening in the degree of social preference for fired power generation. As such, $\mathbf{\alpha_2}$ decreased year by year. Consequently, the degree of social preference to switch from fired power generators to other approaches gradually increased (such as higher levels of renewable energy generation, integrated energy services, or electricity sales). As a result, $\mathbf{\alpha_1}$ increased year by year.

SIMULATION RESULT

Description of the Simulation Environment

According to the feedback mechanism between EVR and the transition ratio that influences the platform and social value preference, as shown in **Methodology**, **Figure 3**, a numerical study was completed, taking the transition of China's power system toward sustainability as the context. This allowed for the visual observation and exploration of the dynamic relationship of the above factors.

In China, it is important to promote the phasing-out of fossil-sourced power generation[14]. The Government has introduced a quota system to ensure that a proportion of electricity is generated for consumption using different energy sources[15]. Rules and policies provide better trading conditions for renewably sourced energy for electricity and ensure the speed of its transaction and consumption[16]. This creates competitive pressure on conventional power suppliers. All of this indicates that the government has different value preference with respect to different sourced power generations. Meanwhile, the platform creates pressure for fossil sourced power generators because of its inherent responsibilities and as a result of government rules. Founded in 2016, the platform was specified as the power trading center of China, and was a not-for-profit platform managed by state-owned power grid corporations[17].

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[14]The Energy Administration, together with the Development and Reform Commission, issued "Suggestions on further promoting supply-side structural reform and further eliminating backward coal-sourced power generator to promote the optimization and upgrading of coal and electricity industry" No. [2019]431 (http://www.nea.gov.cn/2020-05/22/c_139077597.htm).

[15]Notice of the National Energy Administration on the Implementation of Renewable Energy Power Quota System (http://www.nea.gov.cn/2018-11/15/c_1)

[16]Circular of the Energy Bureau of the National Development and Reform Commission (NDRC) on the mechanism of consumption and security for renewable energy sourced electricity. NDRC [2019] No. 807 (http://zfxxgk.ndrc.gov.cn/web/iteminfo.jsp?id=16176).

[17]The platform is responsible for the construction and operation of the electricity market, the implementation of national policies, the conduct of electricity transactions, the promotion of clean energy consumption, and the future development of electricity financial transactions; it is also responsible for making basic rules for electricity transactions in cooperation with relevant government departments; and the establishment of technical, operational and management standards for the electricity market.

According to government rules, the power trading center ensures that the renewable energy sourced power is transacted and used first. It also facilitates the trading of non-fossil sourced energy power by setting bidding and trading rules. For example, the ranking rule was that when the seller's price was the same, renewable energy sourced power was prioritized. Next, the power generated in a manner that benefitted energy conservation and environmental protection was prioritized. In addition, by offering a special platform service for trading the "power" of electricity generation, the trading center promoted the supply of electricity transferred from conventional fossil sourced power generators to renewable energy sourced power generators. These services promoted the production and consumption of non-fossil sourced power, somewhat hindered the use of fossil sourced power generator, and promoted the transformation of fossil-sourced power generators. In summary, both the government and this not-for-profit platform pressured fossil-sourced power generators. These power suppliers' operational efficiency on the platform and the transition decisions were formed in this environment. How would these conventional power suppliers change their transition ratio in this environment, and how transition could be managed in this type of complex relationship was explored in the simulation.

In the simulation, the "phasing-out" actor A was specified as the collective group of fired power plants. The variable I represented A's total resources placed into production based on demand. The total input resource was specified as the cost of electricity production, calculated by "multiplying unit cost (Kilowatt-hour cost) by output." The variable μ_1 was specified as the quantity of resources placed in A_1 per unit time. The entry rate of A_2 was specified as the production cost (the input resource) of the electricity supplied for trading on the platform per unit time. The variable μ_2 was the production cost of the electricity ultimately traded on the platform per unit time. In addition, because power exchange centers serve as the example in this study, the platform services can only affect electricity transactions, not production. Parameters and data sources are included in the attached **Table A1**.

Model Validation

A series of checks were performed to verify the applicability of the SD model: a structural check, extreme value check, reality check, sensitivity check, and unit check. First, the integral causal diagram and flow chart were checked according the mechanism and reality, and a unit check was also performed. The structure was consistent with the model description. Second, for the extreme value check and reality check, irregularities were not found in the system, as shown in **Figures 6**, **7** Third, the sensitivity check found that the transition ratio was not sensitive to "the ratio of time-varying cost per unit time" (r), as shown in **Figure 8A**. However, it is very sensitive to the ratio of the increase in value (r_1, r_2) and the value preference (α_2), as shown in **Figures 8B–D**. Besides, although the growth rate of platform maturity is not a sensitive factor for the transition ratio, the change of growth

rate causes the significant time-varying cost change, as shown in **Figures 8E–G**. All these results were consistent with real-world conditions and platform systems. Detailed tests and analysis of value preference and growth rate are shown in Results and Discussion.

Results and Discussion

After checking the model, the dynamic relationships among factors such as EVR and transition ratio were analyzed (Test 1). Then, the dynamic changes in the transition ratio (k) were analyzed when the EVR changed with the social value preference (Test 2). Finally, changes in the transition ratio were analyzed when the EVR changed with platform maturity (Test 3). The simulation results were as follows.

Test 1 Changes in the EVR, cost, and transition ratio in the current state.

The EVR and entry rate jointly affected the cost, profit, and transition ratio. **Figures 9A–D** shows that μ_1 increased while μ_2 decreased, leading to a decrease in W_1 and increase in W_2. This result generated the force of increasing X_2 and decreasing X_1. However, influenced by a increase in the entry rate λ_1 and a decrease in λ_2, both of which were caused by the feedback of an increasing transition ratio (k), both X_1 and X_2 showed a downward trend. As a result of the synthetic influence from the current transition ratio and time-driven variations in cost, Π_1 went up, while Π_2 went down. Influenced by profit (Π_1, Π_2) and preference, the transition ratio (k) continued to rise.

To reduce the cost in A_1 and to continuously improve the transition ratio, the μ_1 can be improved by changing value preferences, or by raising the platform maturity. This would positively influence the EVR on the transition ratio and would mitigate the negative influence caused by feedback with respect to the transition ratio. This approach was implemented in Test 2 and Test 3. Test 2 showed a better result for changing the costs and improving the transition ratio.

Test 2 Preference varies causing the effect of EVR on transition ratio to change.

The social value preference can be changed using approaches such as implementing phasing-out policies. Changes in the relevant variables were seen when the initial values of α_2 were set at 0.1, 0.3, and 0.5. When the initial value of α_2 was 0.1, the transition ratio rose sharply to 1 in the first year. This would be nearly impossible in reality; as such, we compared the situation when the initial value of α_2 was set at 0.3 and 0.5. A lower α_2 led to a lower μ_2 and a higher μ_1, generating the force of an increasing Π_1 and decreasing Π_2. Subsequently, the synthetic action of value preference and profit increased the transition ratio. However, the transition ratio generated feedback, resulting in more resources placed in A_1 and fewer resources placed in A_2. This trend is shown in **Figures 10H,I**. After that, the synthetic action of entry rate and EVR led to a higher X_1 and a lower X_2. This relationship coincided with **Eqs. 12–15**. Test 2 shows that reducing α_2 and increasing α_1 led to a higher μ_1, lower μ_2, higher Π_1, lower Π_2, and a higher transition ratio. However, it may also lead to a higher X_1 and lower X_2 as a result of the feedback effect.

Test 3 With different platform maturity, the state of transition varies.

The transition state was tested when P_g was set at values of 0.01, 0.05, and 0.1. The results show that when P_g was higher, the EVR of both A_1 and A_2 was higher and both the time-varying cost of A_1 and A_2 were lower. With the change in cost, the profit and transition ratio changed. A special outcome was that the transition ratio decreased slightly as P_g increased (see **Table 2**). This can be explained as follows. As P_m rose, X_2 decreased significantly more than X_1 because the input resource of A_1 kept increasing. This led to a sharp rise in C_1 and decrease in C_2. As the time-varying cost (X_1, X_2) changed in this way, the marginal profit of A_2 rose more than A_1. This led to a decrease in the transition ratio. However, the change in the transition ratio was not evident as P_g changed in this test, because time-varying cost only made up a small proportion of the full benefit. When ratio of the time-varying cost per unit time (r) rose and time-varying costs consequently occupied a higher proportion of the profit, the transition ratio significantly decreased as P_g increased. This is shown in **Figure 11H**. Although improvements in platform maturity improved the benefit of A_1, this improvement did not ultimately improve the transition ratio when the time-varying cost of A_2 was reduced more than A_1.

Further Discussion and Policy Implications
Further Discussion

The results of each test were discussed in Results and Discussion; however, there remain issues related to multiple tests or equations that deserve further discussion. In addition, the analysis highlights a number of policy implications.

First, according to Test 2 and Test 3, improvements in the EVR for A_1 did not always lead to a decrease of X_1 in the feedback effect of the transition ratio. When the platform grew at a low rate of 0.01, or if the preference for α_2 was at a relatively high level of 0.5, there was an increasing trend in X_1 (the slope of $X_1 > 0$), as shown in **Figures 10F, 11C**. This means that when P_g was low or α_2 was high enough, the positive power from μ_1 to X_1 could be weaker than the negative power of the feedback about the rising transition ratio on X_1, leading to an increase in X_1. This result indicates that platform development should not be too slow, or it may prevent an improved transition ratio and result in a decreasing trend of X_1. Also, the government should show a relevant low preference for A_2 and higher preference for A_1 using measures such as phasing-out policies, to affect the preference of the platform and to promote μ_1.

Second, **Eqs. 20, 23** indicate that marginal profit $\frac{\partial \Pi_1}{\partial I_1}$ and $\frac{\partial \Pi_2}{\partial I_2}$ can be respectively specified as

$$\frac{\partial \Pi_1}{\partial I_1} = r_1 - \frac{r}{\frac{\mu_1}{\lambda_1} - 1} \tag{27}$$

and

$$\frac{\partial \Pi_2}{\partial I_2} = r_2 - \frac{r}{\frac{\mu_2}{\lambda_2} - 1} \tag{28}$$

These expressions are directly related to the transition ratio. From the view of a queuing system, $\frac{\mu_1}{\lambda_1}$ and $\frac{\mu_2}{\lambda_2}$ in **Eqs. 27, 28**, respectively, represent the reciprocal values of the traffic intensity in systems A_1 and A_2, respectively. The increase of $\frac{\mu_1}{\lambda_1}$ or decrease of $\frac{\mu_2}{\lambda_2}$ may enhance the transition ratio. This implies that even if λ_1 is low and λ_2 is high at the beginning of the transition, a satisfactory transition ratio could be achieved by adjusting $\frac{\mu_1}{\lambda_1}$ and $\frac{\mu_2}{\lambda_2}$. This leads to the conclusion that EVR and the ratio between EVR and entry rate should be observed, predicted, and influenced to help manage the transition.

Third, the simulation specified actor A as the collective representation of phasing-out actors. However, the framework that analyzed the preference, an actor's resource allocation, and the platform system could also be used to analyze a special actor's transition. Ultimately, the transition ratio is, in essence, a resource allocation ratio, and the platform is a system which can record the entry rate and service rate. As such, the feedback mechanism of the transition ratio can be used to explain other problems related to resource allocations, if the entry rate of the input resource and service rate of the operation system can be recorded or estimated.
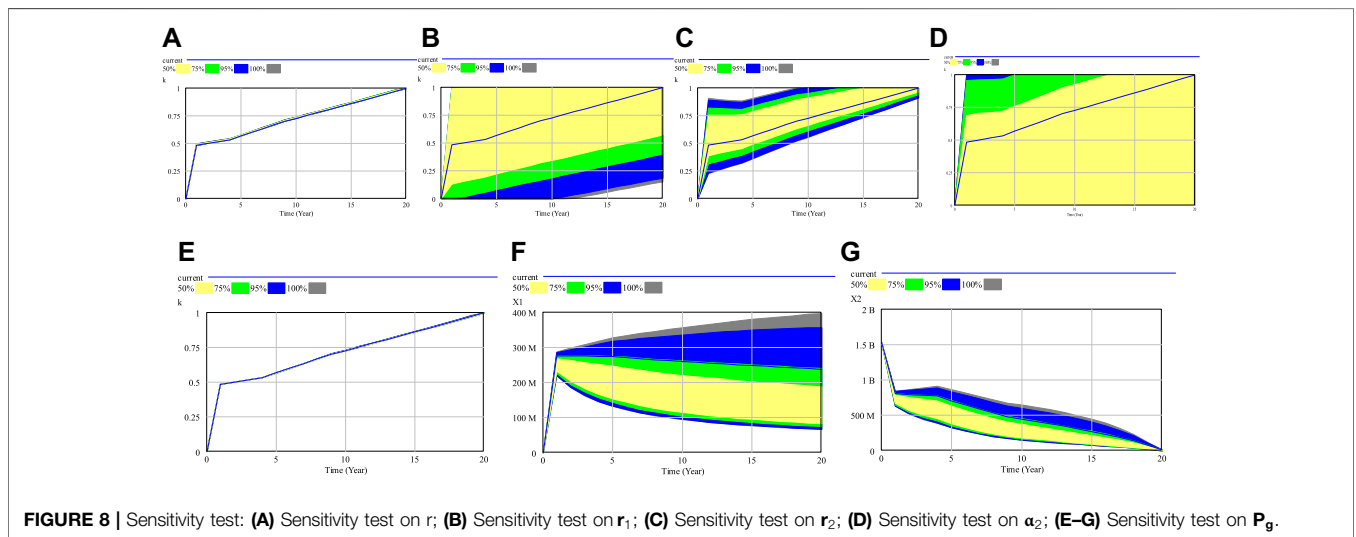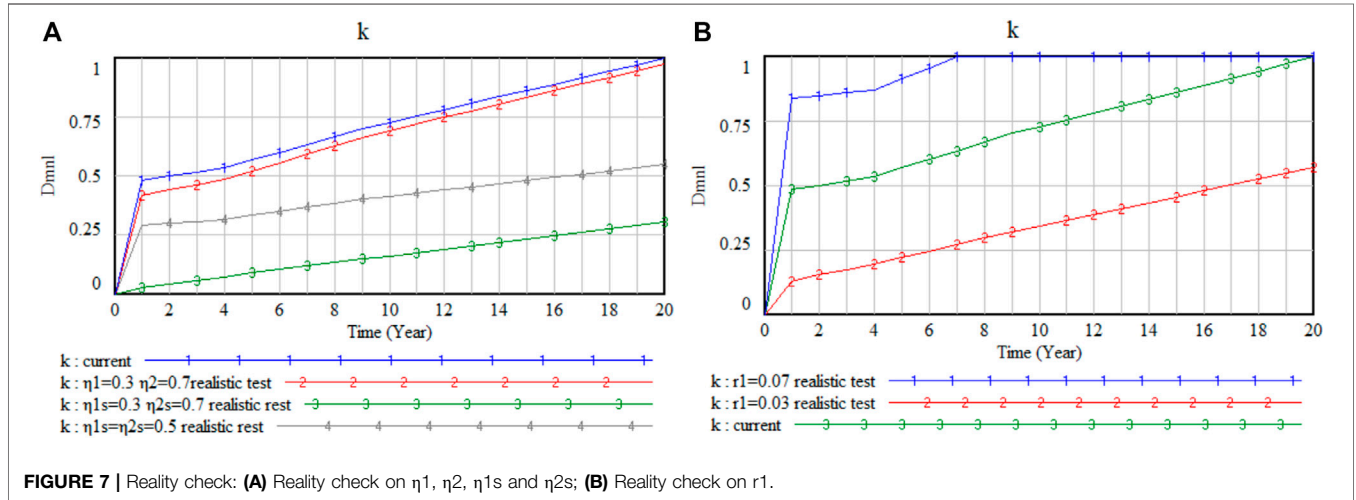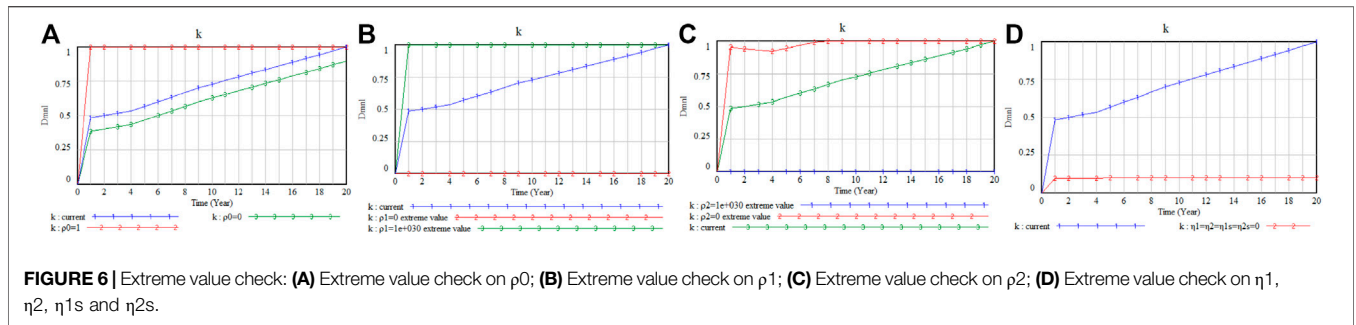
Policy Implications

Based on these results and discussions, this section proposes policies for better managing ST. First, the government should analyze changes in time-varying cost, profit, and transition ratios by observing and estimating the EVR and the entry rate, with the help of platform information systems. Based on this, incentive measures can be used to adjust the value preference. The efficiency of value realization and platform growth can be simulated, compared, and selected to maintain changes in the transition ratio within an acceptable range. The result can be predicted by analyzing the change in the transition ratio given the mechanisms described in this study.

Second, the government can help form appropriate social value preferences taking measures such as phasing-out policies, financial policies, consumption policies, and outreach. Also, the government should effectively transmit preferences to platforms and actors and encourage them to conform to expected preferences to accelerate transition.

In addition, platforms should be guided to set reasonable rules and service levels, consistent with expectations about social value preferences and with a coherent transition strategy. For example, platforms may offer new queuing or ranking rules which do not benefit the low qualified actors who are phasing-out. Meanwhile, they could offer services that help phasing-out actors to enter and operate in A_1. Also, platforms should be incentivized to maintain a not-overly-slow growth rate to significantly reduce the cost in A_1 when the EVR in A_1 improves, allowing for effective EVR measures. However, purely improving platform growth may not be effective for a transition if the time-varying cost of A_2 improves to a larger extent compared to A_1 as a result of improving platform maturity. Through all these efforts, a path to sustainability transition can be established through co-governance between the government and the platform. This can lead to the harmonious development of society and actors in a digital platform economy.
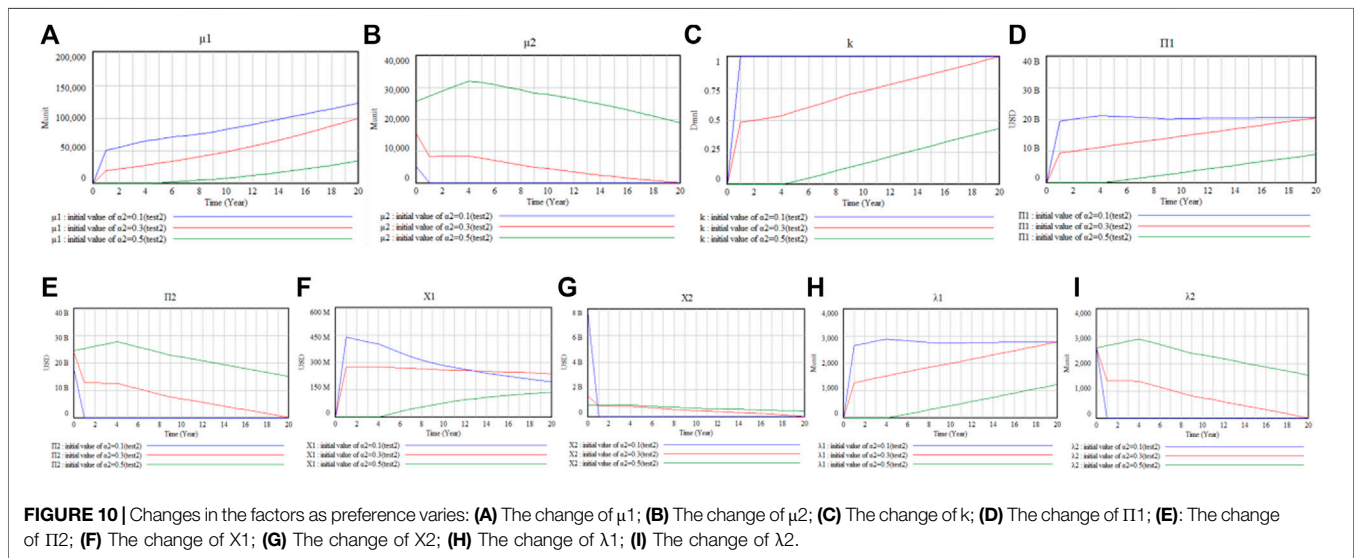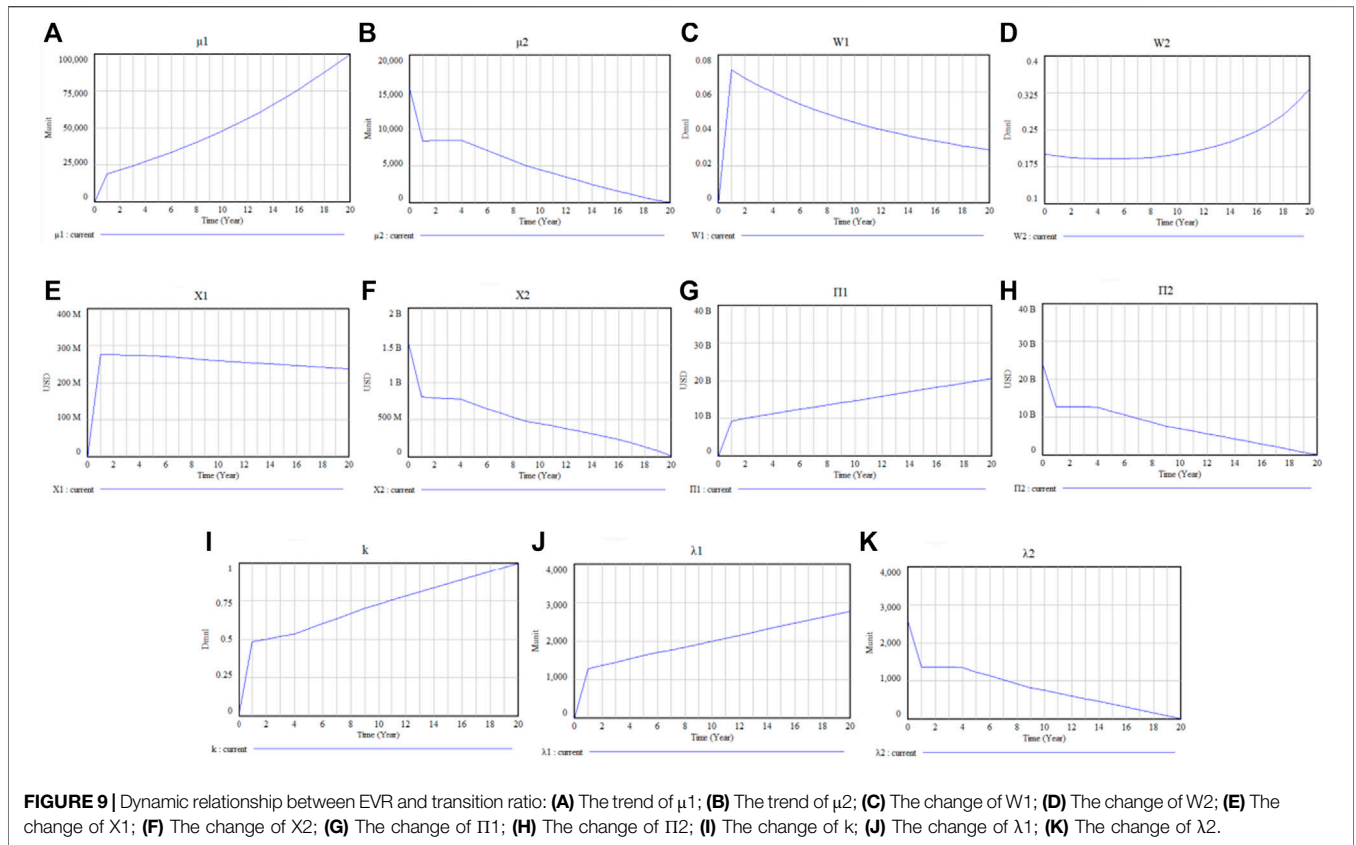
FIGURE 6 | Extreme value check: **(A)** Extreme value check on ρ0; **(B)** Extreme value check on ρ1; **(C)** Extreme value check on ρ2; **(D)** Extreme value check on η1, η2, η1s and η2s.

FIGURE 7 | Reality check: **(A)** Reality check on η1, η2, η1s and η2s; **(B)** Reality check on r1.

FIGURE 8 | Sensitivity test: **(A)** Sensitivity test on r; **(B)** Sensitivity test on r_1; **(C)** Sensitivity test on r_2; **(D)** Sensitivity test on α_2; **(E–G)** Sensitivity test on P_g.

CONCLUSION

This study explored the mechanisms associated with EVR, time-varying costs, actors' resource allocation, and the transition ratio. Co-governance measures were also explored.

First, sustainability transitions were found to be influenced by EVR and entry rate, especially the ratio reflecting the "reciprocal of traffic intensity." By improving EVR in A_1 and reducing EVR in A_2, the response time and time-driven variations in costs changed, leading to an improved transition ratio. However, the ultimate change in the transition ratio also depended on the entry rate, which changed dynamically as a result of feedback about the transition ratio.

FIGURE 9 | Dynamic relationship between EVR and transition ratio: **(A)** The trend of μ1; **(B)** The trend of μ2; **(C)** The change of W1; **(D)** The change of W2; **(E)** The change of X1; **(F)** The change of X2; **(G)** The change of Π1; **(H)** The change of Π2; **(I)** The change of k; **(J)** The change of λ1; **(K)** The change of λ2.

FIGURE 10 | Changes in the factors as preference varies: **(A)** The change of μ1; **(B)** The change of μ2; **(C)** The change of k; **(D)** The change of Π1; **(E)**: The change of Π2; **(F)** The change of X1; **(G)** The change of X2; **(H)** The change of λ1; **(I)** The change of λ2.

Second, the value preference transmitted from the government to the platform and actor played an important role in determining the effect of EVR on the transition. When the social value preference for A_2 decreased, the EVR of A_1 rose, and the A_2 declined. This improved the transition ratio.

Third, both the EVR of A_1 and A_2 improved when there was a higher growth in platform maturity. This led to an increase of profit for both A_1 and A_2. Nevertheless, this simultaneous increase in the EVRs in different fields may not improve the transition ratio and could even lead it to decline. The ultimate change in the transition ratio is decided both by the extent of the improved profits in

TABLE 2 | The value of transition ratio with different values of P_g ($r = 0.02$).

Time (Year)	0	1	2	3	4	5	6	7
k ($P_g = 0.01$)	0	0.4828	0.4999	0.5164	0.5326	0.5682	0.601	0.6344
k ($P_g = 0.05$)	0	0.4828	0.4996	0.5159	0.5319	0.5673	0.5997	0.6330
K ($P_g = 0.1$)	0	0.4828	0.4993	0.5155	0.5312	0.5665	0.5989	0.6320
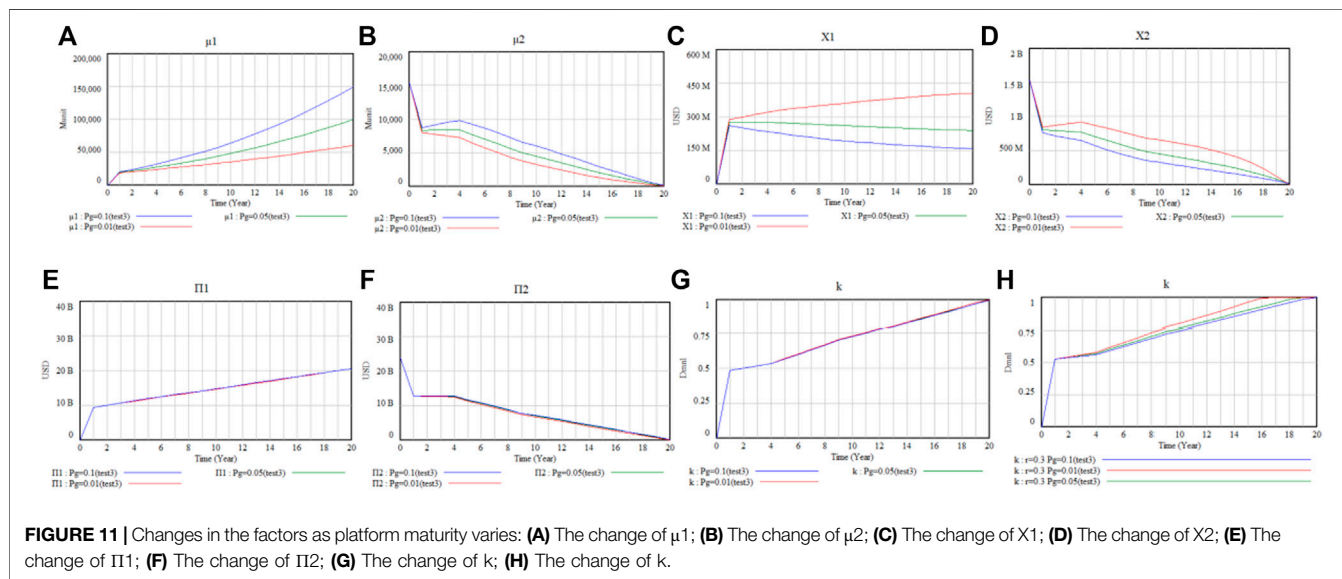
FIGURE 11 | Changes in the factors as platform maturity varies: **(A)** The change of μ1; **(B)** The change of μ2; **(C)** The change of X1; **(D)** The change of X2; **(E)** The change of Π1; **(F)** The change of Π2; **(G)** The change of k; **(H)** The change of k.

different fields as a result of platform maturity improvements, and the ratio between time-varying cost and profit.

The main contributions of this paper are as follows. First, the study illustrated the analysis path from the EVR on a platform to the transition ratio during the dynamic change of multiple factors. This allowed for a model to be established that illustrated an actor's operation and investment decisions, amidst the background of a digital platform economy and sustainability transitions. Second, the EVR and time-driven variations in costs, such as transaction and opportunity costs, were analyzed from the new perspective of the platform service system. Little's Law was used to analyze those costs. This extended the application of queuing theory to investments, transaction costs, and transitions to sustainability. It also linked the method of SD with another field, involving stochastic methods. For research on the platform-driven economy, the problem of judging the efficiency and value of digital service may be solved from a new perspective (the value increase of object) and by a new tool (EVR and response time). Third, the transmission of value preference was integrated into the framework of analysis with respect to ST. By introducing the "value preference" to the field of ST, profit was converted into utility, impacting transition decisions. The coefficient of value preference was introduced to describe evaluations about the utility of output, wealth creation, and the increase in the value of a resource. This ST mechanism, which considers value preferences, may reflect the first attempt in this new field to manage value preferences and the relevant resource allocations through co-governance with digital platforms. Such an exploration of the mechanisms involved in value preference and in public affairs such as ST may contribute to reducing the negative effects of a purely profit-driven market mechanism.

Some limitations remain in this study's model. For example, the model did not consider competition when analyzing the EVR. The transition of the power system in China was used as an example for the simulation. As such, the problems of power peaks and valleys were assumed to be addressed using the social power system, and the power products were considered to be nearly homogeneous. However, when products are heterogeneous, the EVR is affected by operations and competition. In other words, if competition is considered, a relatively low cost may lead to a higher EVR. This study, in contrast, assumed a stable competitive environment. In the future, the function of EVR could be expanded, and correlative factors such as production and operation could be included to address other transition problems in a different context. In addition, the study simulation only considered the situation where the social value preference could be effectively transferred to the platform and the actor. When the consistency coefficient of value preference varies, relevant variables also change.

Future research should include a multi-platform analysis. In addition, the relationship between the EVR and transition ratio could be studied in a more specific way, by considering

production and operational conditions on specific platforms, or by discussing specific policies and actors. This could help explore more concrete policies for sustainability transitions.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

JX: Conceptualization, software, writing TL: Conceptualization, supervision, funding acquisition PT and YL: Supervision and editing XL: Software QL and MS: Editing.

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APPENDIX

TABLE A1 | Value of the parameters in numerical study.

Parameter	Value	Data sources
uc	Initial year 2016: **uc** = 0.04 (USD/KWH). The changing rate of **uc** is calculated based on Pan and Chi (2017)	Comparison and prediction of the LCOE of coal-fired power generation projects and large-scale pv projects in China (Pan and Chi, 2017)
D	1.23 e+013KWH	Calculated using power industry statistics from 2009 to 2018 provided by China's Electricity council http://www.cec.org.cn/guihuayutongji/tongjxinxi/niandushuju/
q	The value is 0.24 in the starting year. The rate of change is 0.01	According to the "Notice of the National Energy Administration on the implementation of renewable Energy power quota system" and statistical statements and measurements from the power industry in China from 2016 to 2018 http://www.nea.gov.cn/2018-11/15/c_1
l	Unit cost (**uc**) multiplied by the quantity of output	In the simulation, the resources placed into power production is measured by cost, so the value of **l** is calculated by multiplying the unit cost with the quantity of output
r_{a1}	0.05	Simulated data
r_{a2}	0.0661	The calculation is based on the financial index of industrial enterprises from 2016 to 2018 (Central People's government of the PRC) http://www.gov.cn/xinwen/2017-01/26/content_5163619.htm http://www.gov.cn/xinwen/2018-01/26/content_5260850.htm http://www.gov.cn/xinwen/2019-01/28/content_5361707.htm
r	0.02	Simulated data
α_2	$\alpha_2 = \text{Time} \cdot (-0.01) + 0.3$	Simulated data. For the fired power plants that are considered "phasing-out actors," $\alpha_2 \leq 0.5$. According to this scope, tests were conducted when the value of α_2 is as follows $\alpha_2 = \text{Time} \cdot (-0.01) + 0.3$, $\alpha_2 = \text{Time} \cdot (-0.01) + 0.1$, $\alpha_2 = \text{Time} \cdot (-0.01) + 0.5$
η_1 η_2	1	Since the power exchange center of China is currently a public not-for-profit platform, it is believed that the value preference of this platform is highly consistent with social value preference
α_{1s} α_{2s}	$\alpha_{1s} = \alpha_1 \cdot \eta_{1s}$ $\alpha_{2s} = \alpha_2 \cdot \eta_{2s}$ The variables η_{1s} and η_{1s} are the consistency coefficients between the social value preference and the actor's strategic preference. $\eta_{1s} = \eta_{2s} = 1$	Simulated data. The simulation assumed that the social value preference can be effectively transmitted to the actors through outreach and policies from the government of China
P_g	$P_g = 0.05$ In simulation, the level of platform maturity in the starting year is marked as the standard value 1. It increases at rate P_g	Simulated data. Three levels, $P_g = 0.01, 0.05, 0.1$, were simulated
θ_1 θ_2	10	Simulated data
M	1.49622e+008	Data are based on trading volume information collected from the trading announcement of Beijing power Exchange center from January 2017 to October 2019 https://pmos.sgcc.com.cn/pmos/index/infoList.jsp?itemid = 213000&title = %E4%BA%A4%E6%98%93%E5%85%AC%E5%91%8A&curpage = 1
ρ_1 ρ_2	1e+013	Simulated data
γ_1 γ_2	2	Simulated data
L_{10} L_{20}	1	Simulated data
L_m	0.1	Simulated data