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Optimization Model and Multidimensional Evaluation of Benefits for Power Grid Investment Decision Making Based on Statistical Analysis

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Abstract With the rapid development of the economy and the increasing improvement of people's living standards, the social demand for electricity is increasing, and the construction of a strong and reliable power grid seems to be crucial. Grid investment construction is directly related to the development of the economy, the improvement of people's living standards and the safe and economic operation of the grid. In this paper, according to the construction principle of index system, the index system for analyzing the investment efficiency of power grid enterprises is established, the research theory of system dynamics is introduced, and the simulation model of power grid investment efficiency is constructed. The parameters of the model are set, and the economic benefits generated by the investment in power grid of Province A are simulated from the economic benefits of the power grid, social benefits and environmental benefits, and the investment benefits are analyzed by using the super-efficient DEA model. After the simulation analysis of the investment benefits of power grid in province A, it can be proved that the simulation model of power grid investment benefits based on system dynamics established in this paper is scientific and effective. H grid company is selected as the object of empirical research, H grid company investment comprehensive efficiency is low, mainly because the technical efficiency constraints on the improvement of comprehensive efficiency.

Index Terms grid investment efficiency, system dynamics, super efficiency DEA model, investment efficiency evaluation

I. Introduction

The investment decision of grid planning is the core of realizing the grid project from planning to operation, and it is also the key to the lean management of grid enterprise investment [1]. In recent years, under the continuous improvement of the economic level of China's power grid, power grid enterprises have shown high investment enthusiasm, which undoubtedly increases the investment efficiency of the enterprises and makes the investment scale of power grid enterprises show an increasing trend [2]-[4]. For this reason, China has put forward higher requirements for the accuracy of the evaluation results of grid investment efficiency. On the one hand, power grid enterprises have successively formulated work programs and management methods, established the mechanism of “spending money to ask for results”, and carried out practical exploration of power grid investment decision-making [5], [6]. On the other hand, the innovation of grid planning and investment decision-making methods to improve the scientific level of investment decision-making has become a key issue to be resolved [7], [8].

Investment efficiency is a characterization of the actual or expected results achieved in terms of economy, security, and society of a specific grid project or grid investment activities within a certain time and space range [9]. Efficiency and effectiveness reflect the input-output relationship of grid investment activities and the management level of grid investment activities for a specific grid project or within a certain time and space, respectively [10], [11]. For grid planning and investment, the economics of grid projects, the advantages and disadvantages of the regional investment environment and the management level of enterprises are the key elements in determining grid planning and investment, and the decision-making process should take into account the benefits, efficiency and effectiveness [12], [13]. In the context of the application of decision-making models, in order to improve the investment efficiency evaluation ability of power grid enterprises, and promote the healthy and sustainable development of power grid enterprises, how to scientifically analyze and design the power grid investment efficiency evaluation model is a problem that technicians must think about and solve [14]-[16].

At present, there have been many studies related to grid planning and investment decision-making methods. Literature [17] explored the application of multi-objective optimization model in the analysis of grid investment benefits, by proposing the assumptions and constraints of grid operation and establishing the optimization model, combined with the NSGA-II algorithm to solve the problem, to obtain the optimal investment proposals under different power project scenarios. Literature [18] establishes a deep neural network-based planning method for power grid investment decision-making, which analyzes the investment behavior, production and consumption as well as capacity prediction of the power system, so as to plan the layout of the power industry and the investment scheme in line with the current production capacity, and to promote the sustainable development of the power grid system. Literature [19] shows that the investment decisions of electric power enterprises are influenced by a combination of economic and behavioral factors, for this reason, an investment decision evaluation method based on the Agent model is designed to provide decision makers with accurate price forecasts and explain the potential impacts hidden under the implicit assumptions by improving the transparency of the algorithm. Literature [20] investigated the uncertainty representation regarding power system planning and adjusted the power system investment planning by analyzing the optimization schemes for the combination of transmission lines, battery energy storage systems and pumped storage systems under the conditions of increasing long-term uncertainty granularity. Literature [21] proposes a grid-distributed energy system joint decision-making model based on blockchain alliance, which fully takes into account the characteristics exhibited by the development of distributed energy resources, and at the same time promotes the relevant investment decisions with the goal of maximizing the interests of participating entities, so as to achieve an effective improvement in the decision-making of the grid-distributed energy system. Literature [22] uses the gray prediction model to analyze the investment demand of grid enterprises, while combining the enterprise investment capacity to build a grid investment coordination optimization model under the constraints, and empirical studies have shown that the model generates a grid investment program with high effectiveness and precision, and realizes the maximization of grid investment benefits. Overall, grid planning and investment decision-making is a complex decision-making process, and it is necessary to continuously refine the evaluation method of investment benefits to generate a demand investment decision optimization model that is more in line with the precise investment of the grid.

Based on the principle of evaluation index construction, the study establishes the index system of grid investment effect evaluation. On the basis of the traditional DEA model, an improvement is proposed to obtain the super-efficient DEA model. The key evaluation indexes are selected from the three aspects of economic, social and environmental benefits of the power grid, and the system dynamics model established in this paper is used as an example of power grid investment and construction in Province A. The H Power Grid Company is selected as a case study object, and on the basis of in-depth analysis of the investment efficiency problem, the super-efficiency DEA model is used to conduct in-depth analysis from the comprehensive efficiency, scale efficiency and pure technical efficiency respectively. Pure technical efficiency is analyzed in depth.

II. SD-based system dynamics simulation model for grid investment efficiency

II. A. Construction of Grid Investment Efficiency Indicator System

II. A. 1) Principles for the selection of indicators

The selection of DEA model indicators is not a simple listing of the characteristics of the assessment object, the selection of indicators to ensure that the assessment is practical and feasible, and the assessment conclusions obtained are scientific and reasonable, so the selection of input indicators for the model should follow the following principles have certain principles:

(1) The principle of combining clarity of purpose and unity of purpose

The purpose of the selected evaluation indicators should be clear. And the selected indicators can clearly reflect the content to be evaluated, not to select some indicators that are not related to the evaluated object and evaluation content.

(2) Principle of combining comprehensiveness and emphasis

The evaluation of the investment and construction efficiency of power grid enterprises should be evaluated from the economic and social benefits, so when selecting indicators, we should fully consider all aspects and cover the content of the evaluation as much as possible, and once there is an omission of indicators, the evaluation results will be biased.

(3) Principle of combining dynamism and stability

Grid enterprise investment and development is a long-term process, therefore, the establishment of the indicator system should not only fully take into account the dynamic characteristics of the grid system, but also maintain the relative stability of the indicators in a certain period of time.

(4) Principle of operability

Indicator selection should take into account the degree of difficulty of the indicator data and its quantification, i.e., the indicators should be operable · . It is necessary to ensure that the various connotations of sustainable development are comprehensively reflected, but also conducive to popularization.

(5) Scientific principle

The setting of indicators for evaluating the investment efficiency of power grid enterprises should be carried out under a scientific and correct guiding ideology. The design of the indicators should have a clear purpose, both in practice to be effective, but also in theory with a scientific basis.

(6) Principle of relevance

Any indicators for the evaluation of investment efficiency of power grid enterprises must reflect the intrinsic connection with the objectives. However, in order to ensure the objectivity, accuracy and effectiveness of the evaluation results, when selecting indicators, we should avoid as much as possible the correlation between the indicators, especially the high correlation.

II. A. 2) Establishment of an indicator system

By reviewing a large amount of historical literature, referring to the views of some experts as well as a large amount of information and data, this paper constructs a system of investment efficiency indicators for power grid enterprises as shown in Table 1, based on the basic principles of indicator establishment.

Table 1: The efficiency indicator of network enterprise investment

Primary indicator	Secondary indicator	Tertiary index
Input index	Management input	Investment in fixed assets
	Cost investment	Unit power grid asset investment
	Structural input	Proportion of fixed assets
		Network investment accounts for the proportion of network infrastructure investment
	Physical input	The proportion of the production of the line road
		The proportion of new production capacity
Output index	Business performance	Operational benefit
		Future capacity
		Network investment benefit
		Cost control capability
	Asset benefit	Asset size
		Asset flow velocity
		Capital efficiency
	Quality of network development	Grid condition
		Power supply quality

II. B. Grid Investment Benefit Measurement Model

II. B. 1) Data envelopment analysis

DEA is a new field of research at the intersection of operations research, management science and mathematical economics, which was developed by Charnes and Cooper et al. in 1978 on the basis of the concept of “relative efficiency evaluation” as a system analysis method, especially suitable for dealing with complex systems with multiple inputs and outputs [23].

Model C^2R is one of the most widely used DEA models. The mathematical model with Archimedean infinitesimals and relaxation variables is:

$$\begin{aligned}
&\min \theta-\varepsilon\left[\sum_{r=1}^{t} S_r^{+}+\sum_{i=1}^{m} S_i^{-}\right] \\
&s.t. \sum_{j=1}^{n} \lambda_j x_{ij}+S_i^{-}-\theta x_{ij0}=0 \\
&\sum_{j=1}^{n} \lambda_j y_{rj}-S_r^{+}=y_{rj_0} \\
&\lambda \geq 0, j=1,2,\cdots,n \\
&S_i^{+} \geq 0, S_r^{+} \geq 0
\end{aligned} \tag{1}$$

where: n is the number of decision unit DMUs; θ is the degree of effective utilization of inputs relative to outputs, which is the relative efficiency value of the decision unit $(0 \le \theta \le 1)$, reflecting the efficiency of the comprehensive allocation of resources in DMUs; x_{ij} is the amount of inputs of the j th decision unit for the i th type of input; y_{rj} is the output quantity of the j th decision unit for the r th type of output; λ_j denotes the coefficients of the linear combination of a number of decision units; S_i^- and S_r^+ are both slack variables denoting the amount of redundancy of the inputs and the shortfall of the outputs, respectively; and ε is the non Archimedean infinitesimal, $\varepsilon = 10^{-6}$ can be taken in practical application.

In Eq. (1), when $\theta = 1$ and $S_i^- = 0, S_r^+ = 0$, it means that this DMU is DEA valid; otherwise, it is weakly valid ($\theta = 1$ and $S_i^- > 0$ or $S_r^+ > 0$) or non-DEA valid ($\theta < 1$).

In order to study the formation factors of technological inefficiency, related scholars expand the use of the C^2R model and the concept of ratio, add constraints $\sum_{j=1}^{n} \lambda_j = 1$ to Eq. (1), and get the BC^2 model. From this model, technical efficiency can be obtained, which in turn leads to scale efficiency as well as returns to scale (combined efficiency = technical efficiency × scale efficiency).

When analyzing DMUs that are not DEA effective, it is necessary to derive information such as the direction of input and output improvement and the attainment of targets, in order to provide suggestions for the actual business activities of the enterprise to improve the efficiency of production and management.The method used in the DEA model is projection analysis, i.e., $\hat{x}_{i0} = x_{i0}\theta_0 - S_i^-, \hat{y}_{i0} = y_{r0}\theta_0 + S_r^+$, $\hat{x}_{i0}$ and $\hat{y}_{i0}$ are the adjusted inputs and outputs of the non-DEA efficient unit to reach DEA efficient, which is the final result after optimization.

II. B. 2) Improvement of the DEA Model - Super-Efficient DEA Modeling

The super-efficient DEA model is improved in the traditional CCR model, because the solution of the dyadic problem can intuitively reflect the investment efficiency of each project, so this paper analyzes the dyadic problem with the help of the CCR model, whose dyadic model is shown in model (2):

$$
\begin{aligned}
&\min \theta \\
&\sum_{j=1}^{n} \lambda_j x_{ij} - \theta x_{ik} \le 0 \\
&-\sum_{j=1}^{n} \lambda_i y_{rj} + y_{rk} \le 0 \\
&\lambda \ge 0 \\
&i = 1,2,\dots,m; r = 1,2,\dots,q; j = 1,2,\dots,n
\end{aligned}
\tag{2}
$$

where the optimal solution of the model's objective function is θ^*, and $1-\theta^*$ denotes the maximum extent to which inputs can be scaled down at the current level of technology without lowering output. The smaller θ^* is, the greater the extent to which inputs can be scaled down and the lower its efficiency value. On the contrary, when θ^*, it means that the evaluated decision unit DMU is on the frontier, and there is no room for the reduction of all inputs under the condition of no reduction of outputs, and it is in a technically efficient state, while $\theta^* \le 1$, the project is in a technically inefficient state, and there is room for improvement.

The only difference between the improved super-efficiency model centered on the input-oriented CCR radial model and the standard efficiency model is the addition of the restriction $j \ne k$, i.e., the evaluated decision-making unit DMUs in the reference set are excluded, so that the efficiency evaluation value of the effective DEA may be greater than 1. Based on this idea, the super-efficiency DEA linear programming model is shown in (3):

$$
\begin{aligned}
&\min \theta \\
&\sum_{\substack{i=1 \\ i \ne k}}^{n} \lambda_i x_{ij} - \theta x_{ik} \le 0 \\
&-\sum_{\substack{j=1 \\ i \ne k}}^{n} \lambda_i y_{rj} + y_{rk} \le 0 \\
&\lambda \ge 0 \\
&i = 1,2,\dots,m; r = 1,2,\dots,q; j = 1,2,\dots,n
\end{aligned}
\tag{3}
$$

The meaning of the parameters in the super-efficient DEA model is the same as that of the CCR model, through which the efficiency value between the DMUs of each decision-making unit can be obtained, and because the efficiency value of the model can be greater than 1, the super-efficient DEA has a lower requirement for the decision-making center than the ordinary DEA model, which improves the flexibility of the practical application of the DEA model, and is extremely important in the measurement of the relative efficiency between the DEAs, all of which are effective projects. It is of great significance to measure the relative efficiency value between the DEA projects that are all effective.

II. C.System dynamics simulation model construction for power grid investment planning

II. C. 1) Definition of system dynamics

System dynamics (SD) is a cross-cutting and comprehensive discipline based on system theory, integrating feedback control theory and information theory, ten computer simulation and modeling technology as a means [24]. System dynamics based on a given goal, multiple interdependent factors organically combined into an overall decision-making system, can W solve highly nonlinear, high-order, multivariate, multiple feedback and other complex and variable large system problems, not only in the macro to grasp the trend of the development of things, but also to analyze the interactions between the microscopic elements within the system.

II. C. 2) Causality map for grid investment planning

Through in-depth analysis of the grid investment in the field of all relevant factors affecting the selected system elements mainly include: load, demand-side resources, planned investment in transmission capacity, transmission capacity, permitted revenues, transmission and distribution tariffs, the market for the indicator, reliability indicators, these factors through the dynamic correlation constitutes a number of cause and effect feedback loop, and thus constitutes a self-organizing, adaptive, feedback characteristics of the dynamic System. The causal feedback relationships between the system elements are shown in Figure 1.

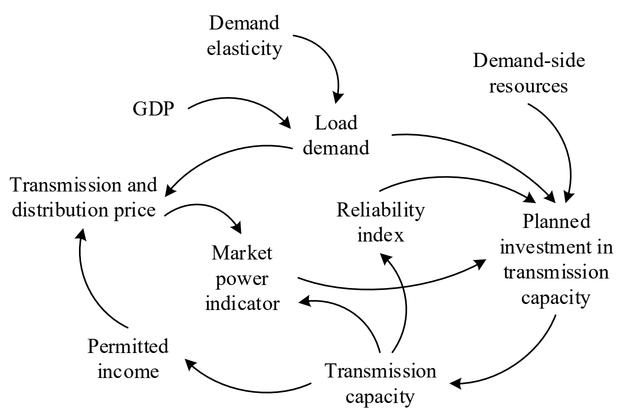

Figure 1: Network investment planning causality feedback relationship

In the grid investment planning causal feedback relationship diagram, there are two feedback loops, namely, the grid reliability feedback loop and the market force control incentive feedback loop.

(1) Grid reliability feedback loop: load demand/demand-side resources→planned investment transmission capacity→transmission capacity→reliability index→planned investment transmission capacity.

(2) Market power control incentive feedback loop: load demand/(transmission capacity→permitted revenue)→ transmission and distribution tariff→market power indicator→planned investment in transmission capacity→ transmission capacity.

II. C. 3) Stack diagram of the grid investment planning system

The system dynamics stack flow diagram model for grid investment planning is shown in Figure 2. Considering the inclusion of load demand, electricity price and other time-varying factors in the stack flow diagram model, this chapter will assume that the time horizon of the system dynamics model is 10 years, while in order to ensure that changes in electricity price can have a more significant impact on the adjustment of the balance of power supply and demand for more than one year, the model needs to ensure that the temporal resolution is small, where it is assumed that the system dynamics model has a time step of 0.26.

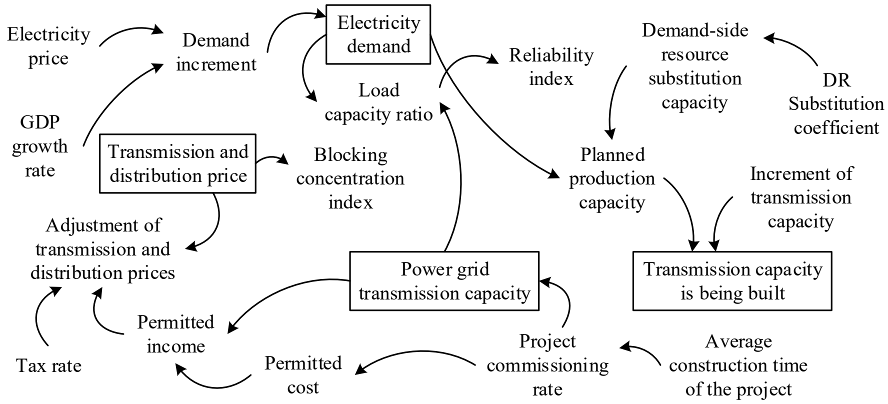

Figure 2: Network investment planning system flow chart

(1) Electricity Demand Growth Segment

Electricity demand is influenced by two aspects. On the one hand, driven by the market consciousness, power users take the initiative to adjust their own load plan according to the signal of the market price of electricity, which is partly expressed in the form of the price elasticity coefficient of electric power demand; on the other hand, affected by the macroeconomic development, the growth of electric power demand and the growth of the GDP show a certain correlation, which is partly expressed in the form of the coefficient of elasticity of electric power.

$$D(t) = INTEG(\Delta D(t)) \tag{4}$$

$$\Delta D(t) = D(t) \times v_{GDP} \times \varepsilon_1 \times P_1^{\wedge\varepsilon_2} \tag{5}$$

where $D(t)$ is the demand for electricity; $\Delta D(t)$ is the incremental demand for electricity; and $INTEG()$ is the equation of state, which represents an integral relationship; v_{GDP} is the GDP growth rate; $\varepsilon_1, \varepsilon_2$ are the coefficient of elasticity of electricity and the coefficient of price elasticity of electricity demand, respectively; P_i is the sales tariff.

(2) Investment Planning Session

Grid enterprises formulate capacity investment with two main considerations. First, according to the existing capacity to meet the load demand, to determine the future expansion plan to meet the requirements of the grid capacity adequacy: Second, the government departments in accordance with the vertical market power in the electricity market, the reasonable returns on the grid enterprise to formulate the appropriate control and incentive policies, reflected in the adjustment of transmission and distribution prices, and then the grid enterprise through the trade-off between the price of electricity and the marginal cost of capacity expansion, and then determine its corresponding investment Willingness.

$$S_{inc}(t) = D(t) \times \varphi_{rel} + S(t) \times \varphi_{obs} \tag{6}$$

$$\varphi_{rel} = IFTHENELSE(\lambda > \lambda_{EXP}, 0, \lambda_{EXP} - \lambda) \tag{7}$$

$$\varphi_{obs} = IFTHENELSE((1 - P_2 / C_{mar,cap}) < 0, 0, 1 - P_2 / C_{mar,cap}) \tag{8}$$

where $S_{inc}(t), S(t)$ are the planned investment capacity and grid transmission capacity, respectively; $\varphi_{rel}, \varphi_{abs}$ are the reliability metrics and the blocking concentration metrics, respectively; λ, λ_{EXP} are the capacity ratio and the Expected Capacity Ratio; P_2 is the transmission and distribution tariff; and $C_{mar,cap}$ is the marginal capacity cost.

(3) Demand-side resource substitution links

Under the current situation of increasing penetration, demand-side resources play the role of substituting supply-side capacity in the power system. Properly playing the role of demand-side resources in the power system can delay or replace part of the supply-side expansion program.

$$S_{DR}(t) = D(t) \times \beta \tag{9}$$

$$S_{DR}^{rep}(t) = S_{DR}(t) \times \beta_1 \tag{10}$$

$$T_{DR}^{del} = LOOKUP_{DR}(S_{DR}) \tag{11}$$

$$\Delta S(t) = DELAY(S_{inc} - S_{DR}^{rep}, T_{DR}^{del}) \tag{12}$$

where $S_{DR}(t), S_{DR}^{rep}(t), \Delta S(t)$ are the demand-side resources, demand-side resource substitution capacity, and new transmission capacity, respectively; β, β_i are the demand-side resource penetration and DR resource substitution factor, respectively; T_{DR}^{del} is the demand side resource delay investment time; $LOOKUP_{DR}()$ is the demand side resource delay coefficient table function; and $DELAY()$ is the delay function.

(4) Transmission capacity construction link

In this paper, the construction cycle of transmission capacity investment projects is considered, and the delay function from plan formation to project commissioning is set.

$$S_{con}(t) = INTEG(V_{com} - \Delta S(t)) \tag{13}$$

$$V_{com} = DELAY(S_{con}(t), T_{com}) \tag{14}$$

$$S(t) = INTEG(V_{com}) \tag{15}$$

where $S_{con}(t), S(t)$ are transmission capacity under construction and grid transmission capacity, respectively; V_{com} is the project commissioning rate; and T_{com} is the average project construction cycle.

(5) Government regulation of incentive links

The government sets regulatory and incentive policies for the vertical market power situation of transmission companies in the market, reflected in the adjustment of transmission and distribution tariffs. Adjusting the transmission and distribution tariffs based on the benefits and costs of the grid's new asset projects can make the transmission and distribution tariffs effectively reflect the reasonable benefits of the grid, and make the transmission and distribution tariffs play an accurate incentive role for grid investment.

$$P_2(t) = INTEG(\Delta P_2(t)) \tag{16}$$

$$\Delta P_2(t) = R_{per} / (\Delta D(t) \times h) - P_2(t-1) \tag{17}$$

$$R_{per}(t) = (I_{per} - C_{per}) \times (1 + \omega) \tag{18}$$

$$I_{per} = (S(t) \times C_{ave,cap}) \times \left(1 - \gamma \times \frac{r(r+1)^t}{(r+1)^t - 1}\right)(1 + \phi) \tag{19}$$

$$C_{per} = V_{com} \times C_{ave,cap} \times (\gamma + \xi) \tag{20}$$

where $\Delta P_2(t)$ is the transmission and distribution tariff adjustment; R_{per} is the permitted revenue; h is the maximum load utilization hours, I_{per} is the permitted revenue; and C_{per} is the permitted cost; $\omega, \gamma, r, \phi, \xi$ are the tax rate, depreciation rate, market rate of return, average cost of capital and O&M rate, respectively.

III. Grid investment efficiency model simulation and investment effectiveness analysis

III. A. Model parameterization

Due to the complexity and dynamics of the feedback relationship contained in the system dynamics, the parameters are correspondingly more, so the parameter estimation is somewhat difficult. Therefore, one of the differences between system dynamics and other prediction models is that it has relatively low requirements for the accuracy of the relevant parameters, which can meet the modeling needs, but this does not mean that the parameters in the system dynamics model can be set arbitrarily. In order to improve the accuracy and validity of the model as much as possible, so as to reflect the development and construction trend of the power grid more accurately, the setting of the relevant parameters in the model built in this paper is based on the actual situation of the development and construction of the power grid in province A.

Table 2 shows the initial values of model variables. First of all, for the initial value of the variables in the system, according to the actual development of province A and its power grid, by the end of 2017, the total GDP of province A was 2,894.15 billion yuan, the population was 81,352,200, the electricity consumption of the whole society was 312.915 billion kilowatt hours, the total electricity sales of the power grid was 253.158 billion kilowatt hours, the load was 50.83 million kilowatts, and the investment of the power grid was 19.537 billion yuan and 1.264 billion yuan respectively[25]-[27].

Table 2: Model variable initialization

Variable name	Initial value	Unit
GDP	28941.5	Hundred dollars
population	8135.22	Boa
The whole club will use electricity	3129.15	100 million kilowatt-hours
sales	2531.58	100 million kilowatt-hours
load	5083	Ten kilowatts
Grid infrastructure investment	195.37	Hundred dollars
Technical investment	12.64	Hundred dollars
Marketing investment	0.81	Hundred dollars
Information investment	0.84	Hundred dollars
New material conductor	0	kilometer

III. B. Simulation and modeling analysis of power grid investment benefits

III. B. 1) Simulation and modeling analysis of economic benefits

In this paper, the economic benefits of grid investment are mainly characterized by unit grid asset power supply load, unit grid asset power sales and maximum load utilization hours, and the following are the simulation results of the relevant indexes with the actual development of power grid in Province A as an example.

(1) Power supply load per unit of grid assets

Figure 3 and Table 3 show the simulation results of power supply load per unit of grid assets in Province A from 2010 to 2027. As can be seen from Figure 3 and Table 3, affected by the change in the growth rate of power supply load, the power supply load of unit grid assets fluctuates between 5 and 61,000 kW/billion yuan before 2018, benefiting from the rapid growth of the power supply load of the grid in Province A in 2013 and 2016, and the power supply load of unit grid assets reaches 60,870,000 kW/billion yuan in 2013, with an increase of 45.79% compared with the previous year by 45.79%, and the power supply load per unit of grid assets reached 63,764.2 thousand kW/billion yuan in 2016, an increase of 25.15% compared with the previous year, indicating that the power supply load per unit of grid assets in this period fluctuates but the overall level is good, thus reflecting the good economic benefits of the grid; after 2016, the power supply load per unit of grid assets of the province is on a downward trend, indicating that its economic benefits of grid investment are gradually decreasing. The reason for the year-on-year decline in the power supply load per unit of grid assets in Province A may be that the growth rate of power supply load in the province has decreased, causing it to be lower than the growth rate of the province's total grid assets.

For the region with high expected power load growth and weak internal network structure, it is necessary to reasonably increase the power grid investment in the region to give full play to the benefits of power grid investment; for the region with low expected power load growth and strong internal network structure, the power grid investment in the region should be reasonably reduced.

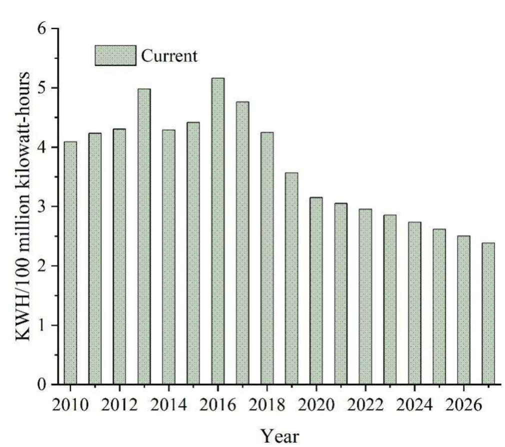

Figure 3: The simulation results of power load of unit grid assets

Table 3: The simulation results of power load of unit grid assets

Time (year)	Power grid load(100 million kilowatt-hours)	Growth rate	Time (year)	Power grid load(100 million kilowatt-hours	Growth rate
2010	5.02836	——	2020	4.19533	-0.001%
2011	5.24412	4.29%	2021	4.07852	-2.78%
2012	4.17539	--20.38%	2022	3.09721	-24.06%
2013	6.0872	45.79%	2023	3.02783	-2.24%
2014	5.29853	-13.00%	2024	3.00983	-0.59%
2015	5.09251	-3.89%	2025	2.79453	-7.15%
2016	6.37642	25.15%	2026	2.48587	-11.06%
2017	5.57728	-14.29%	2027	2.39612	-3.61%
2018	5.36439	-3.82%			
2019	4.75572	-11.35%			

(2) Maximum load utilization hours

Figure 4 shows the simulation results of maximum load utilization hours in Province A from 2010 to 2027. As can be seen from the figure and table, the annual maximum load utilization hours of power grid in province A basically remain between 4600 hours and 5000 hours, with a relatively smooth development trend, indicating that the average utilization degree of power grid in this province is relatively stable. Since the maximum load utilization hours is a characterization index reflecting the relationship between the maximum load and electricity, the regional electricity consumption structure is one of the important influencing factors of this index, and the electricity consumption structure is mainly influenced by the industrial structure.

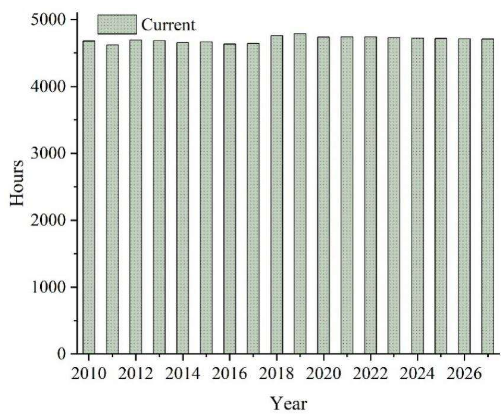

Figure 4: Maximum load utilization hour simulation results imulation result

According to the above analysis of the key assessment indicators of grid economic efficiency, it can be seen that the maximum load utilization hour is an important characteristic indicator reflecting the relationship between the maximum load and the power sales, which can reflect the average degree of utilization of the grid, and its value is equal to the ratio of the annual power sales of the region to the maximum load of the year.

III. B. 2) Simulation and modeling analysis of social benefits

In this paper, the social benefits of grid investment are mainly characterized by electricity growth GDP and per capita electricity consumption, and the following are the simulation results of electricity growth GDP indexes using the actual development of power grid in Province A as an example.

Figure 5 and Table 4 show the simulation results of electricity growth GDP in Province A from 2010 to 2027. From the simulation results of Fig. 5 and Table 4, it can be seen that the electricity growth GDP of Province A fluctuates constantly before 2020, and shows a rising trend year by year after 2020, and the growth rate basically stays in the range of 6%-9%, which indicates that the GDP of this province is more sensitive to the change of the electricity consumption of the whole society in this province, and when the consumption of the whole society for the electricity is improved, the GDP of Province A will be affected to a certain degree, i.e., the supply and consumption of the electric power resources is important for a region's development. The supply and consumption of electricity resources have a driving effect on the economic development of a region.

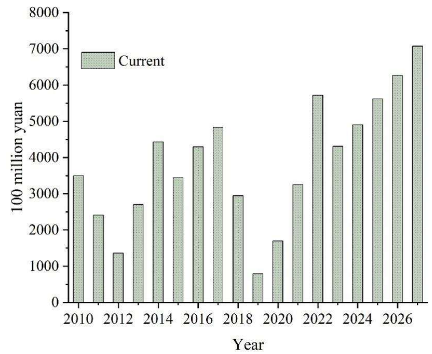

Figure 5: GDP simulation results

Table 4: GDP simulation results

Time (year)	Power growth (100 million yuan)	Growth rate	Time (year)	Power growth (Hundred dollars)	Growth rate
2010	3831.56	——	2020	4508.58	-29.31%
2011	1515.83	-152.77%	2021	4785.79	7.83%
2012	3224.52	53.00%	2022	5183.93	7.68%
2013	4722.63	31.72%	2023	5508.34	-8.16%
2014	3516.17	-34.31%	2024	5783.37	4.76%
2015	4578.71	23.21%	2025	6193.42	6.62%
2016	5137.36	10.87%	2026	6457.02	4.08%
2017	695.471	-638.69%	2027	6832.74	5.50%
2018	1859.57	62.60%			
2019	5957.7	68.79%			

III. B. 3) Simulation and modeling analysis of environmental benefits

According to the analysis of the key assessment indicators of grid environmental benefits mentioned above, it can be seen that the environmental benefits of grid investment in this paper are characterized by CO2 emission reduction, and Table 5 shows the simulation results of CO2 emission reduction based on the actual development of the power grid in Province A as an example. It can be seen that based on the actual development of power grid in province A and the background of relevant national policies, the province's carbon dioxide emission reduction as a whole shows an increasing trend year by year, which is related to China's efforts to build a smart grid and province A in recent years, vigorously eliminating low-end production capacity, strictly controlling the total amount of coal consumption of the relevant policies, as well as the power grid of province A to take the initiative to adapt to the large-scale development of the province's clean energy for the province's access to the consumption of renewable energy power generation. The initiative to create a solid grid foundation to guarantee the full consumption of renewable energy power generation, thereby increasing the amount of renewable energy power generation, is inextricably linked. Among them, the province's carbon dioxide emission reduction in 2018 was 70,384.2 tons; by 2023, the province is expected to achieve a carbon dioxide emission reduction of 88,342.8 tons; by 2027, the province is expected to achieve a carbon dioxide emission reduction of 109,382 tons.

Table 5: Emulation results of carbon dioxide reduction

Time (year)	Carbon dioxide emissions(ton)	Time (year)	Carbon dioxide emissions(ton)
2010	45536.8	2020	75393.7
2011	46085.6	2021	79453.4
2012	47854.5	2022	83672
2013	54863.4	2023	88342.8
2014	62758.5	2024	93286.3
2015	68755.6	2025	98312.5
2016	67817.4	2026	105732
2017	68953.4	2027	109382
2018	70384.2		
2019	72184.3		

III. C. Benefit Evaluation Based on Super-Efficient DEA Modeling

According to the constructed evaluation index system, this chapter empirically analyzes the investment efficiency of H Grid Company using the super-efficiency DEA model.

III. C. 1) Integrated efficiency analysis

Comprehensive efficiency is the effect that can reflect the resource allocation, utilization efficiency and other comprehensive capabilities of each decision-making unit, and it is the ratio of the input cost of the smallest element when the output of the investment project is optimal to the actual input cost of the power grid company in the case of unchanged scale. Therefore, the comprehensive efficiency value can reflect the utilization of input resources in the investment and construction process of each provincial grid company, that is, the higher the comprehensive efficiency, the higher the degree of utilization of input resources of the grid company, and when the value of comprehensive efficiency is greater than 1, the provincial grid company is DEA effective.

The integrated efficiency value of grid company H for 2019-2023 is shown in Table 6. According to the table data, it can be seen that in the period of 2019-2023, the integrated efficiency value of H Grid Company is inefficient, and the integrated efficiency shows a gradual downward trend, even if the integrated efficiency is improved in 2021 and 2023, and the integrated efficiency of 2023 is decreased by 0.19 compared to 2019, but analyzed from the input variables, H Grid Company invests in transmission lines of 35 kV and above circuit length increased by 9.74% compared to 2019, and investment in transformer capacity of 35 kV and above increased by 41.21% compared to 2019, theoretically, the integrated efficiency of investment should show a trend of gradual improvement, but the integrated efficiency of investment decreases instead in the case of increased inputs.

Table 6: H grid company 2019-2023 comprehensive efficiency value

Year	Integrated efficiency
2019	0.67
2020	0.48
2021	0.55
2022	0.46
2023	0.48
Mean	0.53

III. C. 2) Technical efficiency analysis

Technical efficiency is the productivity of the input resources of the decision-making unit at a fixed scale. That is, the proportion of the minimum input resources in the state of maximum output at a given scale for the grid company under the condition of continuous change of scale. The value of technical efficiency can represent the extent to which the comprehensive efficiency of the grid company is affected by pure technical efficiency. Technical efficiency and scale efficiency are crucial to the comprehensive efficiency of the grid company, but the improvement of scale efficiency mainly depends on the management style and system of the grid company, which is a chronic process and can not be changed quickly, so the improvement of the comprehensive efficiency can try to make efforts to break through from the pure technical efficiency.

The technical efficiency value of H power grid company in 2019-2023 is shown in Table 7. From the data in the table, it is found that the pure technical efficiency of H Grid Company maintains the same changes as the comprehensive efficiency, both showing a gradual downward trend, due to the fact that the comprehensive efficiency = pure technical efficiency × scale efficiency, so the reason for the ineffectiveness of the comprehensive efficiency is that the pure technical efficiency is low, that is, the technical level of the H Grid Company at this stage can't keep up with the current level of the company's development, or it is lagging behind the current level of economic development.

Table 7: H grid company 2023-year technical efficiency value

Year	Integrated efficiency
2019	0.65
2020	0.51
2021	0.53
2022	0.50
2023	0.51
Mean	0.54

III. C. 3) Scale efficiency analysis

Scale efficiency is the difference between the target scale and the current scale, i.e., the company's state of ensuring the optimal output resources, the comprehensive efficiency of the inputs at the production boundary compared to the inputs at the optimal scale, provided that the management techniques and related systems remain unchanged. This efficiency value is the result obtained by dividing the integrated efficiency by the pure technical efficiency, i.e., using the scale efficiency value it can be concluded whether the state of the company's maximum output resources is at the optimal scale.

The scale efficiency value for Power Grid Company H for 2019-2023 is shown in Table 8. From the data in the table, it can be seen that the scale efficiency of Power Grid Company H has remained unchanged at 1 for five years, which indicates that Power Grid Company H has never reduced its investment in the construction of scale and has a high scale efficiency. However, the pure technical efficiency of Power Grid Company H is always lower than the scale efficiency between 2019 and 2023. In this case, the scale efficiency remains basically unchanged, and the pure technical efficiency shows a basically decreasing trend. Meanwhile, the gap between scale efficiency and pure technical efficiency reaches its maximum in 2023, while the lowest efficiency value is found in 2023, which means that the comprehensive inefficiency is mainly determined by pure technical efficiency, indicating that the level of technological innovation in Power Grid Company H is not high, which in turn leads to inefficient investment.

Table 8: H grid company 2023 scale efficiency

Year	Scale efficiency
2019	1.00
2020	1.00
2021	1.00
2022	1.00
2023	1.00
Mean	1.00

IV. Conclusion

This paper constructs the input-output evaluation index system for investment efficiency analysis of power grid enterprises, then proposes a quantitative model of power grid investment efficiency based on system dynamics, sets the relevant parameters in the model, simulates and analyzes the economic, social and environmental benefits generated by the investment of power grid in Province A, and measures the investment efficiency of power grid companies in 2019-2023 using the super-efficiency DEA model. After the simulation and simulation analysis of the investment efficiency of the power grid in province A as an example, it is proved that the established simulation model of power grid investment efficiency based on system dynamics is effective, while the DEA value of the comprehensive efficiency value of the power grid company H is inefficient in every year from 2019-2023, and there is a situation in which there is an overdevelopment of the scale of the company that leads to a waste of the input resources of the power grid and there is a slack variable in the input resources.

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