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Research on the Impact Mechanism of Farmers' Digital Literacy on Enhancing Service Satisfaction of Power Grid Companies: An Implementation Path Based on the Interpretability of Machine Learning Models

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ABSTRACT

This study focuses on the "service supply - user demand" tension issue in the service satisfaction of power grid companies during the process of Chinese-style modernization. China has achieved remarkable results in the construction of power grid infrastructure, but there are regional differences in user satisfaction, especially in rural areas. Under the background of digitalization of power grids, although digital technology brings benefits, the differences in digital infrastructure and usage levels in rural areas have led to a digital divide, shifting from an "access gap" to a "capability gap". Digital literacy has become the key to enhancing service satisfaction. In view of the existing research deficiencies, this paper constructs an index system for measuring and evaluating the digital literacy of farmers, and uses the XGBoost and SHAP models to quantitatively analyze the influence mechanism and implementation path of digital literacy on the service satisfaction of power grid companies. The research results can provide a scientific basis for power grid companies to precisely optimize services, helping them identify key influencing factors, optimize the allocation of service resources, enhance service satisfaction, and promote the high-quality development of power grid services.

1. Introduction

In the process of Chinese-style modernization, the service satisfaction of power grid companies is confronted with practical tensions in the dual dimensions of "service supply - user demand". From the perspective of the vertical development trajectory, China has achieved remarkable accomplishments in the construction of power grid infrastructure, and the stability of power supply has been significantly enhanced[1-3]. However, from the perspective of the horizontal user demand pattern, there are significant differences in the satisfaction of different regions and groups with power grid services, especially in rural areas, where the satisfaction of rural users with power grid services is much lower than that of urban users[4]. This binary tension of "supply-demand" reflects three deep-seated contradictions: insufficient institutional maintenance of rural power grid facilities, structural lag of traditional power service models, and systematic obstacles to the integration of digital technology in power grid services[5-6]. Especially against the macro backdrop of a 35.6% digital penetration rate in the power grid, how to build a sustainable power grid service optimization mechanism has become a key bottleneck that power grid companies must break through to enhance service satisfaction.

Although digital technology has brought many benefits to power grid services, there are regional differences in the progress of digital infrastructure construction in rural power grids and the usage level of digital power grid services by farmers[7], which has led to the benefits not being fully realized. Instead, to a certain extent, it has given rise to the phenomenon of the digital divide. With the continuous improvement of digital power grid infrastructure, the once

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significant "access gap" has gradually been alleviated. Currently, the digital divide issue is more prominently manifested as a "capacity gap"[8-10]. In the era of vigorous digitalization of power grids, digital literacy has become a key driving force for farmers to effectively utilize power grid services and enhance service satisfaction. From a practical perspective, digital literacy is a new driving force for enhancing the satisfaction of power grid services. The "Key Points of Digital Rural Development Work in 2023" clearly states the implementation of the "Digital Literacy Enhancement Project". By establishing a three-level cultivation system of "county-level digital schools - township training bases - village-level service stations"[11], the improvement of farmers' digital literacy and skills has promoted the phased progress of digital services in the power grid. Therefore, enhancing the digital literacy of farmers is an effective way to narrow the digital divide and an important means to optimize the quality of power grid services and consolidate the achievements of power grid services.

In the process of digital technology accelerating its integration into power grid services, the role of data elements is becoming increasingly crucial[12]. From the perspective of the power grid service supply side, the digital upgrade of power grid infrastructure, such as the installation of smart meters and the real-time collection and analysis of power grid operation data, provides data support for precise services[13]. On the user demand side, the application of digital technology has also generated a large amount of data, such as the usage frequency and preferences of users for digital power grid services[14]. These data provide a basis for power grid companies to optimize their services. However, the lagging progress of digital infrastructure construction in rural power grids and the insufficient digital literacy of farmers have led to differences in the generation and utilization of these data. On the one hand, the coverage rate of smart meters in rural areas is low and the data collection is incomplete, which affects the precise prediction of rural power demand by power grid companies. On the other hand, the insufficient digital literacy of farmers leads to a lack of usage data for digital power grid services, making it difficult for power grid companies to optimize services based on farmers' demands[15-16]. Therefore, enhancing the digital literacy of farmers can not only narrow the digital divide but also promote the effective generation and utilization of data elements, thereby optimizing the quality of power grid services and improving service satisfaction.

At present, there are no relevant studies focusing on the impact of farmers' digital literacy on improving the service satisfaction of power grid companies. In view of the problems existing in the depth of quantitative analysis, the scientificity of the evaluation system and the diversity of research methods in the current studies, based on theoretical analysis and research hypotheses, this paper constructs a measurement and evaluation index system for farmers' digital literacy. Based on the artificial intelligence model and the theory of model interpretability, it quantitatively expounds the influence mechanism of digital literacy on the service satisfaction of power grid companies. The realization path by which farmers' digital literacy affects the service satisfaction of power grid companies was explored and analyzed.

2.Materials and methods

2.1.Theoretical analysis and research hypotheses

The improvement of farmers' digital literacy has a multi-dimensional empowering effect on the service satisfaction of power grid companies. Through the dual path of enhancing farmers' awareness and willingness to participate in power grid services and optimizing the allocation of power grid service resources, an innovative practical mechanism has been constructed for improving the service satisfaction of power grid companies.

From a theoretical perspective, based on the theories of farmers' behavior, human capital, and information economy, digital literacy, on the one hand, serves as a key ability for farmers to process and utilize information related to power grid services. It can reduce information asymmetry, enhance farmers' cognition and decision-making level regarding power grid services, and achieve the rational allocation of power grid service resources by optimizing their own decisions. Enhance the possibility of seizing new technology and service opportunities, and improve their integration into the digital society and service satisfaction. On the other hand, as a special human digital capital, it can enhance farmers' ability and skills to utilize power grid services, alleviate the differences in service satisfaction caused by a lack of capabilities, and ultimately achieve balanced development of power grid services. Fig 1 shows the theoretical framework of the impact of digital literacy on the service satisfaction of power grid companies.

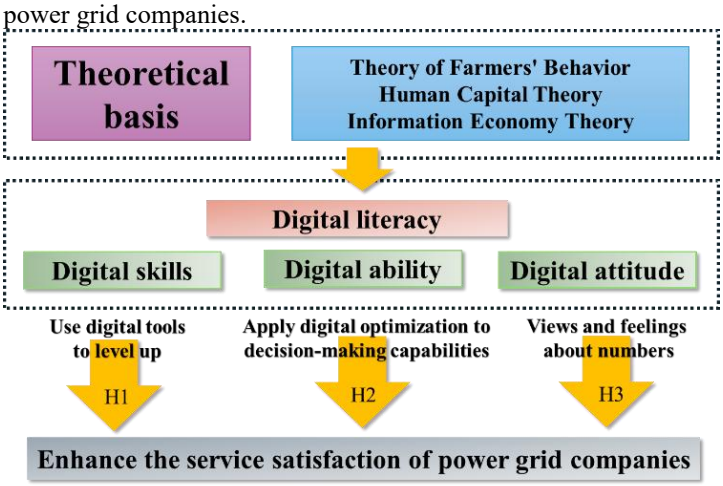


Fig 1. Theoretical framework of digital literacy's impact on service satisfaction in power grid companies.

The concept of Chinese digital literacy is defined by the "Action Plan for Enhancing the Digital Literacy and Skills of All Citizens (2021)" as the skills, abilities and attitudes of individuals to adapt to the demands of the information age and comprehensively apply digital technologies to solve problems. To facilitate empirical analysis, this paper, based on this outline and in combination with international mainstream digital literacy frameworks (such as the EU DigComp framework), deconstructs digital literacy into three core dimensions that have a logical progressive relationship and complementary functions: digital skills, digital capabilities, and digital attitudes. Although the three are interrelated, they have clear distinctions in terms of cognitive levels, behavioral manifestations, and value orientations: (1) Digital skills focus

on an individual's basic operational mastery of digital tools and platforms, manifested as the procedural knowledge and technical proficiency required to complete specific tasks, belonging to the level of "whether to use or not"; (2) Digital competence emphasizes the ability to integrate, apply and innovatively use digital resources in real situations to solve complex problems, which belongs to the level of "whether it can be used well". It not only involves technical operations, but also high-level cognitive and behavioral strategies such as information discrimination, social interaction, and rights protection, reflecting the level of active participation, effective communication, and self-empowerment of farmers in the digital environment. (3) Digital attitude focuses on an individual's value judgment, emotional tendency and ethical awareness regarding digital technology and its social impact, and belongs to the level of "whether willing to use it and whether to trust its use". Subjective psychological factors such as privacy protection awareness, the degree of trust in digital services, and the willingness to support the promotion of technology are key soft variables that drive the formation of continuous usage behavior and satisfaction.

Based on the above definition, this paper further elaborates on the mechanism analysis of how each dimension affects the service satisfaction of power grid companies:

Firstly, digital skills, as the fundamental threshold for farmers to access and use the digital services of the power grid, directly determine whether they can smoothly connect to online service channels (such as payment, repair reporting, information inquiry, etc.). The improvement of skill levels helps to reduce the barriers to the use of technology, alleviate the exclusion effect caused by geographical, temporal or information asymmetry in traditional offline service models, thereby expanding the coverage of services, enhancing the efficiency of resource allocation, and ultimately increasing farmers' accessibility, awareness and overall satisfaction with power grid services. Based on this, the research hypothesis is proposed:

H1: Promoting the improvement of digital skills has a significant positive impact on the service satisfaction of power grid companies.

Secondly, digital capabilities are reflected in the comprehensive qualities of farmers in proactively obtaining, evaluating, integrating and feeding back service information within the digital ecosystem. Farmers with higher digital capabilities can more effectively utilize online platforms to participate in service evaluations, express their demands, safeguard their rights and interests, and optimize their electricity usage decisions through data-driven approaches. This deep participation not only enhances the quality of service interaction but also prompts power grid companies to continuously improve service processes based on user feedback, forming a virtuous cycle of "user empowerment - service optimization - satisfaction improvement". Therefore, it is proposed that:

H2: Promoting the improvement of digital capabilities has a significant positive impact on the service satisfaction of power grid companies.

Then, digital attitude, as a psychological driving force influencing the adoption and continuous use of technology, profoundly shapes farmers' sense of trust, security and identification with the digital services of the power grid. Positive digital attitudes (such as confidence in privacy protection, recognition of the digital value of services, and support for technology promotion) can reduce farmers' perception of risks in online services, enhance their willingness to use them and emotional attachment. At the same time, a good sense of ethics and social responsibility also helps to build a more inclusive and fair service environment and narrow the service experience gap between urban and rural areas caused by cognitive differences. This forms a sustainable and warm path for improving service satisfaction. Based on this, it is proposed that:

H3: Promoting the improvement of digital attitudes has a significant positive impact on the service satisfaction of power grid companies.

2.2.Construction of data sources and index evaluation systems

The research data were obtained through the design of a questionnaire Survey, with the questionnaire design referring to the "Chinese General Social Survey" (CGSS) project. This survey constitutes the most representative national database of individual farmers' Internet usage at present, providing reliable case support for exploring the impact of farmers' digital literacy on the service satisfaction of power grid companies. The questionnaire design is shown in Table 1. This questionnaire focuses on farmers' digital literacy and their satisfaction with power grid services, covering dimensions such as basic information, digital skills, information acquisition and verification, online service usage, privacy concerns, and service quality evaluation. The design is comprehensive and targeted, capable of systematically reflecting the digital literacy level of farmers and their perception and evaluation of power grid services, providing reliable data support for research and facilitating precise analysis of the impact of farmers' digital literacy on the service satisfaction of power grid companies.

Table 1. Sample survey questionnaire

Number	Question content	Options
Q1	Your gender	Male/Female
Q2	Your age	Aged 18-30 /31-50 /51-70 / over 70
Q3	Your educational attainment	Primary school and below/junior high school/senior high school/technical secondary school/college and above
Q4	Your family's annual income (in ten thousand yuan)	Less than 50,000 yuan / 50,000-100,000 yuan / 100,000-200,000 yuan/over 200,000 yuan
Q5	Can you use your mobile phone or computer to access the Internet to inquire about power service information?	Always can/sometimes can/seldom can/cannot
Q6	Can you pay your electricity bill online via your mobile phone or computer?	Always can/sometimes can/seldom can/cannot
Q7	Can you use the mobile APP or website of the power grid company to	Always can/sometimes can/seldom can/cannot

Number	Question content	Options
	check the power outage information?	
Q8	Can you obtain power failure repair information through the Internet?	Always can/sometimes can/seldom can/cannot
Q9	When you come across online messages related to power services, do you verify them first before believing them?	Always verify/sometimes verify/rarely verify/never verify
Q10	Have you ever shared information about power services through social media such as wechat and Weibo?	Always/sometimes/rarely/never
Q11	Do you often express your opinions or suggestions about power services on the Internet?	Always/sometimes/rarely/never
Q12	Have you ever used the online services of the power grid company (such as online repair reporting and online consultation)?	Always/sometimes/rarely/never
Q13	Have you ever used the mobile payment functions of the power grid company (such as Alipay or wechat Pay) to pay your electricity bill?	Always/sometimes/rarely/never
Q14	Have you ever participated in a satisfaction survey of power services through online channels?	Always/sometimes/rarely/never
Q15	Are you worried that your personal privacy might be leaked online, especially when using websites or apps related to power services?	Very worried/a little worried/not very worried/not worried at all
Q16	Do you think the online services provided by power grid companies are convenient and fast?	Very convenient/relatively convenient/Average/not very convenient/very inconvenient
Q17	Do you think that power grid companies have improved service quality through digital means?	Strongly agree/relatively agree/Generally/not quite agree/strongly disagree
Q18	Would you be willing to recommend the online services of the power grid company to your friends or family?	Very willing/relatively willing/Average/not very willing/very unwilling
Q19	Do you think power grid companies should further enhance the promotion and application of digital services?	Strongly agree/relatively agree/Generally/not quite agree/strongly disagree
Q20	How satisfied are you with the services of the power grid company?	Satisfied/Dissatisfied

By consulting the literature included in important domestic and foreign databases such as Web of Science, China National Knowledge Infrastructure (CNKI), and Google, and sorting out the research on related topics of digital literacy of rural residents at home and abroad, it provides a theoretical basis for the design of the index system of digital literacy of rural residents in China. Based on this, while taking into account the availability of data, a digital literacy evaluation system was constructed. The evaluation system for the satisfaction index of farmers' digital literacy with the services of power grid companies is shown in Table 2.

Table 2. The evaluation system of farmers' digital literacy on the service satisfaction index of power grid companies

First-level indicator	Secondary indicators	Corresponding questions in the questionnaire	Quantitative method
Basic Information (BI)	Gender (SE)	Q1	Category indicators, converted through integer encoding, {' male ':1,' female ':2}
	Age (AG)	Q2	Category, by integer encoding conversion, {' 18 to 30 years old: 1, '31 to 50 years old: 2,' 51-70:3, '70 years of age or older: 4}
	Educational Attainment (ED)	Q3	Category index, through integer encoding conversion, {' primary school and the following: 1, 'middle school' : 2, 'high school: 3,' technical secondary school: 4, 'college graduate or above, 5}
	Annual income (IN)	Q4	Category, by integer encoding conversion, {' 50000 yuan the following: 1, '5-100000 yuan, 2,' 10-150000 yuan, 3, 'more than 150000 yuan, 4}
Digital Skills (DS)	Basic Operational Skills (DS1)	Q5、Q6、Q7	Assign the options to 4, 3, 2, and 1 respectively, and calculate the average value
	Information Acquisition Ability (DS2)	Q8、Q9	Assign the options to 4, 3, 2, and 1 respectively, and calculate the average value
Digital Capability (DC)	Social Operation Competence (DC1)	Q10、Q11	Assign the options to 4, 3, 2, and 1 respectively, and calculate the average value
	Network Application Capability (DC2)	Q12、Q13	Assign the options to 4, 3, 2, and 1 respectively, and calculate the average value
	Rights Protection Ability (DC3)	Q14	Assign the options to 4, 3, 2, and 1 respectively
Digital Attitude (DA)	Privacy and Security Awareness (DA1)	Q15	Assign the options to 4, 3, 2, and 1 respectively
	Service Satisfaction (DA2)	Q16、Q17、Q18	Assign the options to 4, 3, 2, and 1 respectively, and calculate the average value
	Promotion Intention (DA3)	Q19	Assign the options to 4, 3, 2, and 1 respectively

From the perspective of technology empowerment, the improvement of farmers' digital literacy is an important driving force for the growth of service satisfaction of power grid companies. Digital skills are the key foundation for farmers to integrate into the digital society and improve their quality of life with the help of digital tools, and they are also the prerequisite for farmers to interact better with power grid companies. Digital skills are mainly measured by basic operational abilities and information acquisition capabilities. Mastering basic operational skills such as equipment networking and software installation is the first step for farmers to integrate into digital life and also the foundation for smoothly using the online service platform of the power grid company. Efficiently obtaining information through the Internet is an essential basic quality for farmers in the digital age. It can help them promptly understand the service policies, power outage notifications, and electrical safety knowledge of power grid companies, thereby better cooperating with the service work of power grid companies.

The construction of digital capabilities places more emphasis on systematicness and innovation. It is a core element for farmers to achieve sustainable development in the digital environment and also a key link to enhance the service satisfaction of power grid companies. Digital capabilities can be measured from dimensions such as social operation capabilities, network application capabilities, and rights protection capabilities. For instance, farmers can promptly feedback electricity usage issues through social operation capabilities, conveniently handle electricity usage business through network application capabilities, and safeguard their own electricity usage rights through rights protection capabilities. All these contribute to enhancing their satisfaction with the services provided by power grid companies.

Digital attitude, as a flexible indicator for measuring the digital literacy of rural residents, is of great significance to the healthy and sustainable development of the digital society and directly affects farmers' evaluation of the services provided by power grid companies. Digital attitudes are mainly measured from aspects such as privacy and security awareness, social impact cognition, and participation in online behavior. Farmers have a good awareness of privacy and security and can use the online services of the power grid company with confidence. Having a correct understanding of the social impact of power grid companies' services will provide greater support for their digital service initiatives. Actively participate in online activities, be able to promptly feedback opinions and suggestions, and promote the continuous improvement of services provided by power grid companies. Therefore, the improvement of farmers' digital literacy not only helps them enjoy digital life better, but also significantly enhances the satisfaction of power grid companies with their services

2.3.Model construction

Based on the digital literacy index system, this section, by constructing a machine learning model and conducting interpretability analysis, deeply explores the influence mechanism of digital literacy (including digital skills, digital capabilities, and digital attitudes) on farmers' satisfaction with the services of power grid companies, studies the influence mechanism of different digital literacy capabilities on farmers' satisfaction with the services of power grid companies, and assesses the importance of digital literacy characteristics. The proposed explainable machine learning model can not only determine the satisfaction of farmers with the services of power grid companies based on their digital literacy, thereby quantifying the service quality and marketing effect of power grid companies, but also precisely quantify the causal relationships among various variables, mine hidden patterns in the data, and provide a scientific basis for power grid companies to optimize services.

2.3.1.Machine learning model based on XGBoost

As an efficient gradient boosting algorithm, XGBoost optimizes the objective function by gradually adding new decision trees, thereby enhancing the prediction accuracy of the model for farmers' satisfaction. The core objective of each iteration is to minimize the weighted squared loss function:

$$L^{(t)}=\sum_{i=1}^{n}\left[g_i f_t(x_i)+\frac{1}{2}\mathrm{h}_i f_t^2(x_i)\right]+\Omega(f_t) \tag{1}$$

In the formula: g_i and h_i represent the first-order derivative (gradient) and second-order derivative (Hessian value) of the i th sample, respectively. $f_t(x_i)$ denotes the model's predicted value for sample x_i at the t Tth iteration, while $\Omega(f_t)$ is the regularization term used to prevent model overfitting. This process enables the model to progressively learn and optimize predictions of farmer satisfaction, accurately identifying key factors influencing satisfaction.

When constructing each decision tree, XGBoost selects the optimal split point by calculating the split gain to minimize the loss function. The split gain is calculated using the following formula:

$$\mathrm{Gain}=\frac{1}{2}\left(\frac{\left(\sum_{i\in I_L} g_i\right)^2}{\sum_{i\in I_L}\mathrm{h}_i+\lambda}+\frac{\left(\sum_{i\in I_R} g_i\right)^2}{\sum_{i\in I_R}\mathrm{h}_i+\lambda}-\frac{\left(\sum_{i\in I} g_i\right)^2}{\sum_{i\in I}\mathrm{h}_i+\lambda}\right)-\gamma \tag{2}$$

In the formula: I_L and I_R represent the sample sets of the left and right subtrees after splitting, respectively. I denotes the sample set before splitting. λ and γ are regularization parameters. The model performs splitting based on farmers' digital literacy characteristics (such as digital skill levels, digital competency performance, and digital attitude tendencies), prioritizing features with greater influence on satisfaction. This enables more precise segmentation of high-satisfaction and low-satisfaction farmer groups.

2.3.2.Explainability model based on SHAP

SHAP (SHapley Additive exPlanations) is a model interpretation tool based on Shapley values, used to quantify the contribution of each feature to model prediction outcomes. In research examining how farmers' digital literacy enhances satisfaction with power grid company services, SHAP can help understand the impact of features such as digital skills, digital capabilities, and digital attitudes on farmers' service satisfaction.

The Shapley value is a concept in cooperative game theory used to fairly distribute cooperative gains. In machine learning, Shapley values are used to measure each feature's contribution to model predictions. For a feature j, its Shapley value ϕ_j is defined as:

$$\phi_j=\sum_{S\subseteq F\setminus\{j\}}\frac{|S|!(|F|-|S|-1)!}{|F|!}[f(S\cup\{j\})-f(S)] \tag{3}$$

In the formula: ϕ_j represents the Shapley value of feature j, indicating the average contribution of feature j to the model prediction.

In practical applications, directly calculating Shapley values is computationally intensive. Therefore, SHAP provides approximate computation methods. For XGBoost models, SHAP employs the Tree SHAP algorithm to efficiently compute Shapley values for each feature. The core idea of the Tree SHAP algorithm is to leverage the structure of decision trees, recursively calculating the contribution of each feature.

3.Results and discussion

Based on machine learning models, this paper constructs an index system for farmers' digital literacy to deeply analyze

the influence mechanism of digital skills, digital capabilities and digital attitudes on the service satisfaction of power grid companies, providing theoretical basis and practical guidance for power grid companies to optimize their service strategies.

3.1.Analysis of model discrimination accuracy

Compare the performance of three models, XGBoost, Logistic Regression, and Support Vector Machine (SVM), in terms of the accuracy of satisfaction discrimination to evaluate the impact of farmers' digital literacy on the service satisfaction of power grid companies. Fig 2 shows the comparison of evaluation indicators of different models. Through the evaluation of key performance indicators, including Accuracy, area under the ROC curve (AUC), F1 score, Precision, Recall and Specificity, the XGBoost model demonstrated its superiority in all indicators.

The XGBoost model demonstrates a significant advantage in handling the complex relationship between farmers' digital literacy and the service satisfaction of power grid companies. This is mainly due to its ability to effectively capture nonlinear relationships and interaction effects in the data by constructing multiple weak predictive models (usually decision trees) and combining them into a strong predictor. In addition, the built-in regularization term of XGBoost helps prevent overfitting of the model and enhances its generalization ability, which is crucial for ensuring the model's predictive performance on new data. The flexibility of XGBoost is reflected in allowing users to adjust multiple parameters, such as the learning rate and the maximum depth of the tree, to adapt to different data characteristics and business requirements. Meanwhile, XGBoost has certain robustness against outliers and noise data, which helps to enhance the stability and reliability of the model in practical applications.

In contrast, the logistic regression and SVM models performed slightly worse on this research subject. Due to its linear assumption, the logistic regression model may not be flexible enough when dealing with data with complex feature interactions, which limits its ability to capture the complex relationship between farmers' digital literacy and service satisfaction. Although SVM performs well in some cases, its sensitivity to parameter selection and the computational cost on large-scale datasets affect its performance.

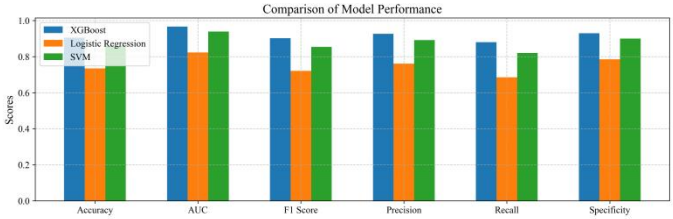


Fig 2. Comparison of evaluation indicators of different models

Fig 3 shows the comparison of PR curves and ROC curves of different models. The PR curve reflects the trade-off between the precision and recall rates of the model at different thresholds, while the ROC curve shows the relationship between the true positive rate (recall rate) and the false positive rate of the model at different thresholds. The area under it (AUC) is an indicator to measure the model's ability to distinguish positive and negative samples. The closer the AUC value is to 1, the stronger the model's discrimination ability. The significance of the PR curve and the ROC curve lies in their ability to help understand the performance of the model in practical applications. In the prediction of power grid service satisfaction, more attention is usually paid to the identification of positive categories (i.e., farmers with high satisfaction), as this information is crucial for power grid companies to improve services and enhance farmers' satisfaction. The performance of XGBoost on the PR curve outperforms the other two models, indicating that it can maintain a high recall rate as well as a high accuracy rate. This means that XGBoost can identify more truly satisfied farmers while reducing the misjudgment of dissatisfied farmers as satisfied ones. In addition, the area under the ROC curve (AUC) of XGBoost is 0.97, which is much higher than the 0.82 of logistic regression and 0.94 of SVM, indicating that XGBoost has a stronger ability to distinguish whether farmers are satisfied with grid services.

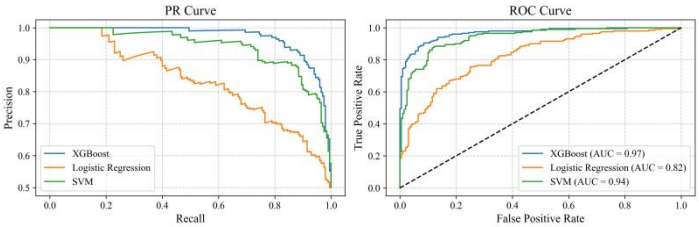


Fig 3. Comparison of PR curves and ROC curves of different models

3.2.Model interpretability analysis

By constructing the XGBoost model and the SHAP model, the influence mechanism of farmers' digital literacy on the service satisfaction of power grid companies was deeply explored. Fig 4 shows the interpretability analysis results of the model based on SHAP, demonstrating the average impact of each feature on the model output and the relationship between feature values and SHAP values. It can be seen that educational attainment (ED), information acquisition ability (DS2), social operation ability (DC1), and basic operation ability (DS1) have the most significant impact on service satisfaction. Farmers with a higher level of education are better able to understand the digital services of power grid companies and make more effective use of digital tools and platforms, thereby enhancing their satisfaction with the services. The ability to obtain information is an important component of farmers' digital literacy, directly affecting their understanding of power grid service information. A higher ability to obtain information helps farmers promptly learn about service policies, power outage notifications, etc., thereby enhancing their satisfaction. Social operation capabilities reflect farmers' interactive abilities in the digital environment, which may help them more effectively feedback electricity usage issues and participate in the improvement process of power grid services, thereby enhancing satisfaction. Basic operational skills are the foundation for farmers to use the online service platform of the power grid company, directly affecting farmers' acceptance and usage experience of digital services.

Farmers with a higher level of education generally have a positive impact on the service satisfaction of power grid companies. Farmers with a higher ability to obtain

information also tend to have a higher positive impact on service satisfaction, indicating that the ability to obtain information is a key factor in improving satisfaction. Farmers with higher social operation capabilities also have a more significant impact on service satisfaction. This might be because they can interact more effectively with power grid companies and participate in service improvements. Farmers with higher basic operational skills have an equally significant impact on service satisfaction, which indicates that basic operational skills are the foundation for farmers to enjoy digital services. By enhancing the digital literacy of farmers, the service gap between urban and rural power grids can be effectively narrowed, the quality of power grid services can be optimized, and a sustainable improvement in service satisfaction can be achieved. The above conclusion is consistent with the hypothesis of this paper, that is, promoting the improvement of digital skills, digital capabilities and digital attitudes has a significant positive impact on the service satisfaction of power grid companies, thereby verifying the key role of digital literacy in enhancing the service satisfaction of power grids.

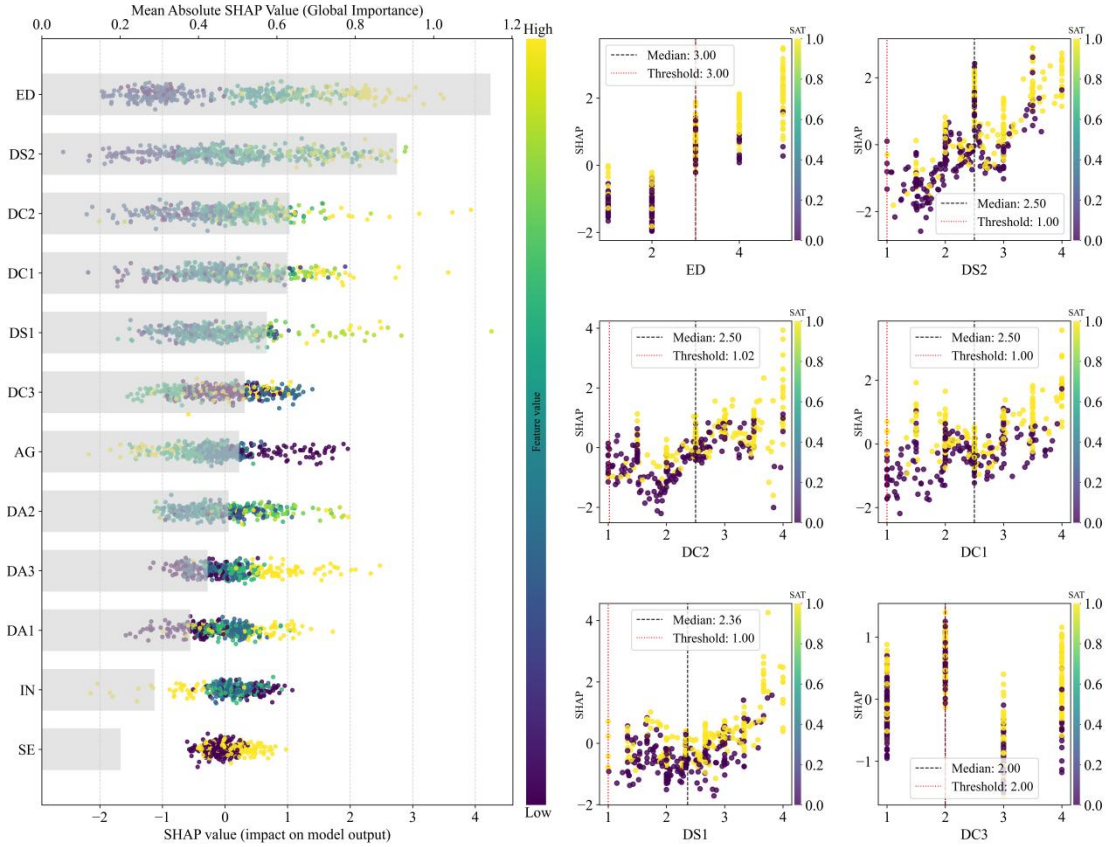


Fig 4. Model interpretability analysis based on SHAP

4.Research value

In the practice of the Qian Haijun Community Convenience Service Station, a model of The Times in Cixi, Ningbo, through the application of "three-network co-construction" (three-dimensional co-construction of organization, channel and team) and digital tools, the power grid company has achieved remarkable results. By means of "Zhejiang Power One-Click Service", "Grid Cloud Phone" and the wechat ecosystem "Cloud Service" platform (including AI intelligent customer service and work order management), power grid companies have significantly lowered the service threshold, enabling users to provide full-process feedback on their demands without complex operations. This precisely aligns with the current situation of digital literacy in rural areas and addresses the issue of insufficient online touchpoints. The community manager team has been standardized and covered in rural communities. Research data shows that 90% of community residents confirm that the power department takes the initiative to contact them, and 42% maintain an average of five high-frequency interactions per month. Through job responsibilities and a three-year training program (including ten high-frequency courses such as electricity prices and charges), a standardized service team has been established. These practical achievements have provided a rich experience foundation for the service optimization of power grid companies. However, in the process of further optimizing services, some challenges are still faced. How to accurately identify the differences in digital literacy among farmers and how these differences affect farmers' satisfaction with the services of power grid companies is an urgent problem to be solved.

The impact of farmers' digital literacy on the service satisfaction of power grid companies was studied by using XGBoost and SHAP modeling, providing a scientific basis for power grid companies to precisely optimize services. By building machine learning models and conducting interpretability analysis, power grid companies can clearly identify the specific influencing factors of farmers' digital literacy improvement on service satisfaction, and thus invest

resources in a targeted manner to optimize the allocation of service resources. The proposed model can identify which factors among digital skills, digital capabilities and digital attitudes have the greatest impact on satisfaction, helping power grid companies accurately position the direction of service optimization. In addition, the model can also help power grid companies identify potential service shortcomings and further optimize fault response mechanisms, etc.

After understanding the relationship between farmers' digital literacy and service satisfaction, power grid companies can carry out precise marketing activities to enhance farmers' trust and loyalty to the power grid companies. From the perspective of customer relationship management, power grid companies can proactively care for farmers with lower digital literacy and possibly lower satisfaction levels based on the model prediction results. This not only helps power grid companies improve service quality and customer satisfaction, but also enhances their social image and demonstrates their active fulfillment of social responsibilities as public service enterprises.

For farmers, the research, through quantitative analysis, reveals the direct impact of enhancing digital literacy on the service satisfaction of power grid companies, helping farmers recognize the importance of improving their own digital literacy. The improvement of digital literacy enables farmers to better understand and utilize the digital services of power grid companies, such as checking their electricity consumption through mobile applications, thereby arranging electricity usage more reasonably and avoiding unnecessary electricity bills. In addition, after farmers' digital literacy improves, they can communicate more effectively with power grid companies and reduce the electricity usage troubles caused by information asymmetry.

From a more macroscopic perspective, the improvement of farmers' digital literacy helps narrow the digital divide between urban and rural areas and promotes the digital transformation of rural regions. With the improvement of farmers' digital literacy, they can not only better integrate into the digital society, but also make better use of digital tools in other fields (such as digital finance, digital agriculture, etc.) to expand sales channels and promote the sustainable development of rural economy and society. The proposed explainable machine learning model can not only judge the satisfaction of farmers with the services of power grid companies based on their digital literacy, thereby quantifying the service quality and marketing effect of power grid companies, but also accurately quantify the causal relationship among various variables, mine hidden patterns in the data, and provide a scientific basis for power grid companies to optimize services.

5.Research limitations and prospects

This paper constructs a digital literacy evaluation index system and quantitatively reveals the influence mechanism of farmers' digital literacy on the service satisfaction of power grid companies by combining XGBoost and SHAP methods. However, there are still several limitations. Firstly, the research mainly relies on cross-sectional questionnaire data. The geographical coverage and group representativeness of the samples are limited, which may affect the external validity of the conclusion. Secondly, the measurement of digital literacy is mostly based on subjective self-assessment, making it difficult to completely avoid cognitive biases. Moreover, although the model has good predictive capabilities, the SHAP interpretation essentially reflects feature contributions rather than causal relationships, failing to fully control potential confounding variables and lacking the strength of causal inference. Furthermore, the current analysis has not yet delved deeply into the interaction effects and mediating paths among various dimensions of digital literacy, and the guidance for the actual service optimization of power grid enterprises remains rather abstract.

Future research can be expanded in multiple aspects: First, introduce multi-period panel data or combine objective behavior logs (such as usage records of power apps) to enhance the dynamics and accuracy of digital literacy measurement; Second, integrate causal inference methods (such as dual machine learning) or structural equation models to enhance mechanism identification and theoretical explanation; Third, explore the moderating role of situational factors such as digital infrastructure and policy support, and verify the actual impact of digital literacy improvement on service satisfaction through field intervention experiments. Ultimately, efforts should be made to promote the transformation of research results into intelligent diagnostic tools and precise service strategies, providing scientific support for the digital service upgrade of power grid companies in the context of rural revitalization.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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