



Modeling the Sustainability and Resilience of Regional Electricity Distribution Systems in the Face of Imbalance and Fault Crises: The Role of Strategic Agility in Load Management and Physical Asset Management

Mahmoud Fereydouni^{1*} 

¹ Department of Electrical Engineering, Technical and Vocational University (TVU), Tehran, Iran

* Corresponding author email address: mfereydouni@tvu.ac.ir

Received: 2025-11-13

Revised: 2026-05-11

Accepted: 2026-05-18

Initial Publish: 2026-10-11

Final Publish: 2027-07-01

Abstract

This study aimed to model the sustainability and resilience of regional electricity distribution systems under imbalance and fault crises by examining the direct and indirect effects of strategic agility through load management capability and physical asset management capability. This applied, quantitative, cross-sectional study used a descriptive-correlational design with a structural equation modeling approach. The statistical population consisted of managers, engineers, supervisors, and technical, planning, maintenance, asset-management, and system-operation specialists working in electricity distribution and related regional power organizations in Tehran, Iran. A total of 384 participants were selected using stratified purposive sampling. Data were collected using a structured researcher-developed questionnaire measuring imbalance and fault crisis exposure, strategic agility, load management capability, physical asset management capability, system sustainability, and system resilience. The measurement and structural models were analyzed using partial least squares structural equation modeling with SmartPLS, and indirect effects were assessed using 5,000 bootstrap resamples. Imbalance and fault crisis exposure had significant negative effects on system sustainability ($\beta = -0.214$, $t = 4.756$, $p < 0.001$) and resilience ($\beta = -0.267$, $t = 6.209$, $p < 0.001$). Strategic agility significantly predicted load management capability ($\beta = 0.628$, $t = 17.444$, $p < 0.001$) and physical asset management capability ($\beta = 0.592$, $t = 15.179$, $p < 0.001$) and directly improved sustainability ($\beta = 0.178$, $p < 0.001$) and resilience ($\beta = 0.196$, $p < 0.001$). Load management significantly predicted sustainability ($\beta = 0.337$, $p < 0.001$) and resilience ($\beta = 0.358$, $p < 0.001$), while physical asset management also significantly predicted sustainability ($\beta = 0.293$, $p < 0.001$) and resilience ($\beta = 0.276$, $p < 0.001$). Significant indirect effects confirmed partial mediation. The model explained 61.3% of the variance in sustainability and 66.8% of the variance in resilience. Sustainability and resilience in regional electricity distribution systems depend on the simultaneous management of crisis exposure and the development of strategic agility, effective load management, and systematic physical asset management. Strategic agility contributes to system performance both directly and by strengthening operational capabilities that enable electricity distribution organizations to respond more effectively to imbalance and fault conditions.

Keywords: Strategic agility; electricity distribution systems; system resilience; sustainability; load management; physical asset management; imbalance crisis; fault management.

How to cite this article:

Fereydouni, M. (2027). Modeling the Sustainability and Resilience of Regional Electricity Distribution Systems in the Face of Imbalance and Fault Crises: The Role of Strategic Agility in Load Management and Physical Asset Management. Management Strategies and Engineering Sciences, 9(7), 1-16.

1. Introduction

Electricity distribution systems constitute a critical layer of modern energy infrastructure because they form the final operational interface between bulk power supply and end users and therefore directly determine the continuity,

quality, reliability, and accessibility of electricity services. The performance of distribution networks has become increasingly important as electricity systems face growing demand, aging infrastructure, operational complexity, distributed generation, electrification of transport and buildings, and greater dependence of economic and social



activities on uninterrupted power supply. In this environment, conventional approaches focused primarily on routine reliability and efficiency are no longer sufficient. Distribution companies must simultaneously ensure long-term sustainability and develop resilience against abrupt disturbances, technical faults, demand-supply imbalances, extreme events, and organizational disruptions. Sustainability in electricity distribution refers not merely to environmental performance, but also to the ability of the system to preserve technically reliable, economically efficient, resource-conscious, and socially acceptable service over time. Resilience, in contrast, emphasizes the capacity to anticipate, absorb, withstand, respond to, recover from, and adapt to disruptive events. These two concepts are complementary because a sustainable system that cannot tolerate shocks remains operationally vulnerable, while a resilient system that depends on inefficient resource utilization or unsustainable infrastructure may not remain viable over the longer term. The changing operating environment of electricity distribution companies has intensified the need to reconsider the determinants of system performance. Previous studies in the electricity distribution sector have shown that organizational and environmental conditions can substantially shape performance outcomes. Bahrini et al. emphasized the influence of the external environment on performance management in electricity distribution companies, demonstrating that organizational performance cannot be understood independently of environmental turbulence and contextual pressures [1]. This observation is particularly important under contemporary conditions in which distribution organizations are exposed to volatile consumption patterns, resource scarcity, regulatory changes, climate-related disturbances, and rapidly evolving technologies. Similarly, Fallahi et al. demonstrated the importance of systematic performance assessment among electricity distribution companies and highlighted differences in operational efficiency across organizations [2]. Their findings underscore that electricity distribution performance is multidimensional and that efficient resource utilization is a central requirement for maintaining acceptable service. Evidence from Iranian electricity distribution companies has likewise shown that efficiency and scale are not uniform across organizations, suggesting that managerial and operational capabilities influence the ability of electricity distributors to transform available resources into effective service outcomes [3].

One of the most pressing challenges confronting contemporary electricity systems is the imbalance between

available power supply and electricity demand. Such imbalance can emerge from rapid demand growth, peak-load concentration, insufficient generation or transmission capacity, weather-dependent renewable generation, operational restrictions, and unexpected equipment outages. At the distribution level, these pressures may manifest as overloaded feeders, voltage instability, transformer stress, load shedding, service interruptions, and accelerated asset deterioration. Accordingly, effective management of consumption patterns has become increasingly important. Zhang et al. showed that electricity consumption behavior is dynamic and that identifying meaningful consumption patterns can support more sophisticated understanding and management of demand [4]. From a distribution-system perspective, the ability to identify dynamic load behavior can contribute to forecasting, segmentation of consumers, demand response, peak reduction, and adaptive operational decision-making. Load management therefore represents more than a short-term balancing mechanism; it constitutes a strategic capability through which distribution operators can reduce stress on physical infrastructure and improve overall system adaptability.

Demand-side flexibility has also become an increasingly important resource for balancing modern electricity systems. Abdelmotteleb et al. examined customer engagement in the provision of flexibility products at the electricity distribution level and demonstrated the importance of consumer participation in creating operational flexibility [5]. Their work suggests that electricity distribution companies can no longer rely solely on infrastructure expansion to address demand pressures. Instead, flexibility can be achieved through coordinated participation of customers, dynamic consumption management, and mechanisms that enable loads to respond to system conditions. This perspective is particularly relevant when distribution networks face persistent imbalance crises, because demand-side flexibility can reduce peak pressure, defer infrastructure investment, limit the severity of emergency load curtailment, and provide operators with additional options during system disturbances. Consequently, the effectiveness of load management may constitute a major pathway through which electricity distribution systems enhance both sustainability and resilience.

At the same time, the physical condition of distribution infrastructure remains a fundamental determinant of system reliability. Electricity distribution networks consist of extensive portfolios of transformers, feeders, substations, protection devices, cables, switches, control equipment, and

other assets whose failure can cause localized or cascading service disruption. The management of these assets must therefore move beyond corrective maintenance toward systematic life-cycle planning, condition monitoring, preventive and predictive maintenance, risk-based prioritization, and strategic replacement. Valizadeh and Hosseini proposed a project-based approach to the development of organizational risk management in electricity distribution companies, illustrating the relevance of structured risk management for complex utility environments [6]. Such approaches are particularly important because physical asset failures are not isolated technical events; they interact with organizational preparedness, resource availability, emergency response, and operational flexibility. Effective physical asset management can reduce failure probability, shorten restoration time, optimize maintenance expenditure, and improve the capacity of a distribution system to continue functioning under adverse conditions.

The importance of physical infrastructure management becomes even more evident when electricity networks are exposed to extreme weather and sudden disturbances. Karami and Separi investigated durability and resiliency improvement in the Mazandaran Electricity Distribution Company against storm-related disruptions and highlighted the necessity of strengthening distribution infrastructure against severe external events [7]. Their work illustrates that resilience is closely tied to the physical robustness and recoverability of electricity assets. However, resilience cannot be achieved exclusively through structural reinforcement. Networks must also possess the organizational capacity to mobilize resources, reconfigure operations, prioritize critical functions, and restore services rapidly. Therefore, physical resilience and organizational resilience should be considered as interconnected dimensions rather than separate objectives. This is especially relevant in regional electricity distribution systems where asset deterioration, fault propagation, resource limitations, and supply-demand imbalance can occur simultaneously.

Human and organizational factors are equally important in determining the capacity of electricity distribution companies to cope with operational crises. Samavi identified strategic factors associated with efficient human resource management in Iranian electricity distribution companies, emphasizing the role of organizational capabilities in sector performance [8]. In addition, Rezaei Dizgah et al. demonstrated that organizational culture can affect safety performance among employees of electricity distribution

organizations [9]. These findings indicate that technical systems are inseparable from the organizational environments in which they operate. Emergency decisions, maintenance quality, risk perception, communication, coordination, safety behavior, and resource allocation are all influenced by managerial and cultural characteristics. When electricity distribution organizations face rapidly changing operational conditions, technical competence alone may not be sufficient if decision-making structures are rigid or if organizational units cannot coordinate quickly. Therefore, the capacity to adapt strategically becomes a central determinant of effective crisis response.

The notion of strategic agility provides a useful theoretical framework for understanding this adaptive capacity. Strategic agility refers to the ability of an organization to detect important changes in its environment, make timely strategic decisions, mobilize or reconfigure resources, and implement coordinated responses with minimal delay. In volatile and technologically intensive environments, strategic agility enables organizations to respond more rapidly than traditional hierarchical planning systems. Recent research has increasingly emphasized strategic agility as an important mechanism linking managerial capabilities, digital readiness, and organizational resilience. Tenggonu et al. showed that dynamic managerial capabilities can enhance strategic agility and digital readiness, highlighting the importance of managerial sensing, decision-making, and resource orchestration under changing conditions [10]. Similarly, Shao emphasized the role of digital transformation in strengthening organizational agility and competitive capabilities, indicating that technological transformation can support faster information processing, coordination, and strategic response [11]. These insights are directly relevant to electricity distribution organizations, which increasingly depend on digital monitoring, advanced metering, predictive analytics, automated control, and integrated asset information systems.

Strategic agility may be particularly important in electricity distribution because operational crises often require rapid decisions across multiple functional domains. During periods of supply-demand imbalance, managers may need to coordinate load prioritization, demand response, feeder reconfiguration, emergency maintenance, public communication, and resource redistribution within a limited time. Similarly, major faults may require immediate assessment of asset condition, dispatch of technical teams, switching decisions, restoration sequencing, and protection of critical consumers. Organizations with greater strategic

agility should theoretically be better able to integrate these activities because they possess stronger strategic sensitivity, decision speed, resource fluidity, and cross-functional coordination. Shayanmehr et al. specifically linked human resource management strategies with organizational resilience through strategic agility, suggesting that agility can operate as an important mechanism through which organizational capabilities are transformed into resilience outcomes [12]. This supports the proposition that strategic agility may not only exert a direct effect on resilience but may also influence resilience indirectly by strengthening specific operational capabilities.

Emerging work on artificial intelligence and digital management further reinforces the relationship between agility and resilience. Kaya and Yalçın proposed an AI-driven meta-theoretical perspective on resilience and strategic agility, emphasizing the increasingly interconnected nature of technological capability, adaptive decision-making, and organizational resilience [13]. In a related domain, Karami described how AI-driven human resource analytics can contribute to workforce resilience and agility by improving evidence-based decision-making and adaptive workforce management [14]. Although these studies are not specific to electricity distribution, their implications are important for utilities because the contemporary power sector increasingly generates large volumes of operational, asset, customer, and workforce data. The ability to translate such data into rapid strategic decisions can strengthen the management of both loads and physical assets. Digitalized decision support can help identify emerging demand pressures, detect asset deterioration, allocate maintenance resources, prioritize response teams, and evaluate alternative operational scenarios before disruptions escalate.

The sustainability dimension of electricity distribution also extends beyond immediate technical performance. Electricity companies increasingly face expectations related to environmental responsibility, responsible resource use, workforce development, and ethical organizational practices. Yahya Pour et al. developed a green human resource management excellence model for electricity distribution companies in northern Iran, demonstrating the relevance of environmentally oriented organizational practices to utility management [15]. Although green human resource management focuses primarily on organizational and workforce practices, it reflects a broader transition toward sustainability-oriented management within electricity distribution companies. This transition implies

that sustainable utility performance requires coordination among technical, organizational, environmental, and human dimensions. The effective management of physical assets can reduce unnecessary replacement and resource waste, while improved load management can reduce network losses and peak-load stress. Strategic agility may further support sustainability by enabling organizations to realign resources and operational priorities as environmental, technological, and demand conditions change.

Institutional learning and knowledge exchange also influence the adaptive capacity of electricity distribution organizations. Moghaddas Nodeh examined challenges associated with university-industry collaboration in the Tehran Province Electricity Distribution Company and highlighted barriers that can constrain effective interaction between academic knowledge and industrial needs [16]. This issue is relevant to resilience and sustainability because contemporary electricity distribution challenges often require interdisciplinary knowledge involving power engineering, data analytics, asset management, organizational strategy, and crisis management. Weak university-industry collaboration can restrict the transfer of advanced methods and technologies into operational settings. Conversely, stronger knowledge integration can support innovation in forecasting, fault diagnosis, predictive maintenance, smart-grid operation, demand management, and resilience planning. Thus, the adaptive capability of electricity distribution companies is affected not only by internal resources but also by their capacity to acquire and integrate external knowledge.

The combined evidence suggests that the sustainability and resilience of electricity distribution systems should not be modeled as the outcome of isolated technical variables. Rather, they emerge from interactions among external pressures, strategic organizational capabilities, load-management practices, and physical asset-management processes. Exposure to imbalance and fault crises can directly weaken system performance by increasing operational stress and disruption risk. However, organizations may mitigate these effects when they possess the strategic agility required to detect threats quickly and mobilize appropriate responses. Strategic agility can strengthen load management by improving the speed and coordination of demand-related decisions, and it can strengthen physical asset management by enabling rapid prioritization of maintenance, replacement, and emergency resources. These operational capabilities can, in turn, improve sustainability through more efficient resource

utilization and improve resilience through greater preparedness, absorption capacity, and recovery speed.

Despite the growing body of research on electricity-distribution efficiency, resilience, organizational performance, demand flexibility, physical infrastructure, human resource management, and strategic agility, these domains have often been examined separately. Studies on distribution-company performance have emphasized efficiency and environmental conditions [1-3], while resilience-oriented research has examined physical robustness and risk management [6, 7]. Other studies have focused on demand behavior and flexibility [4, 5], human and organizational determinants [8, 9, 15], and emerging forms of strategic and digital agility [10-14]. Furthermore, limitations in the transfer of academic and innovative knowledge into electricity distribution organizations have been identified as an additional challenge [16]. What remains insufficiently developed is an integrated empirical framework explaining how strategic agility can simultaneously influence load management and physical asset management and how these capabilities contribute to sustainability and resilience under imbalance and fault crises.

Addressing this gap is particularly relevant for regional electricity distribution systems in Tehran, where high demand concentration, operational complexity, infrastructure pressure, and the need for rapid coordination can magnify the consequences of system imbalance and technical faults. Developing an integrated structural model can therefore provide both theoretical and practical value by identifying the pathways through which strategic and operational capabilities contribute to sustainable and resilient electricity distribution. Such a model can also help distinguish between direct organizational effects and indirect effects transmitted through load management and physical asset management, thereby providing a clearer understanding of how electricity distribution organizations can convert strategic responsiveness into measurable system outcomes.

Accordingly, the aim of this study was to model the sustainability and resilience of regional electricity distribution systems in the face of imbalance and fault crises by examining the role of strategic agility and the mediating contributions of load management capability and physical asset management capability.

2. Methodology

This study was an applied quantitative investigation conducted using a cross-sectional, descriptive-correlational design with an explanatory modeling approach. The primary purpose was to develop and empirically test a structural model explaining the sustainability and resilience of regional electricity distribution systems under conditions of power imbalance and operational faults, with particular emphasis on the role of strategic agility in load management and physical asset management. The study population consisted of managers, supervisors, engineers, technical experts, planning specialists, system operation personnel, maintenance professionals, asset-management experts, and load-management specialists employed in electricity distribution and related regional power organizations in Tehran, Iran. Individuals were considered eligible for participation if they had at least three years of professional experience in the electricity sector, were directly involved in at least one of the domains of distribution-system operation, system planning, load management, maintenance, physical asset management, crisis management, reliability, or network resilience, and had sufficient familiarity with operational challenges associated with supply-demand imbalance, equipment failures, and service interruptions. Employees occupying purely administrative positions without direct involvement in technical, operational, planning, or managerial activities related to the electricity distribution system were excluded. A total of 384 participants were included in the final analysis. The sample size was selected to provide adequate statistical power for structural equation modeling and to permit the simultaneous estimation of multiple direct, indirect, and mediating relationships among the study constructs. Participants were recruited using stratified purposive sampling to ensure adequate representation of operational, engineering, planning, maintenance, asset-management, and managerial functions. Within the identified organizational units, eligible participants were approached and invited to complete the study questionnaire. Participation was voluntary, respondents were informed about the academic purpose of the research, and confidentiality and anonymity of individual responses were ensured. Questionnaires with substantial missing information or patterned and inconsistent responses were excluded during the initial data-screening process, and only complete and analytically valid questionnaires were retained for the final dataset.

Data were collected using a structured researcher-developed questionnaire designed on the basis of the conceptual framework of the study and the principal dimensions associated with sustainable and resilient electricity distribution systems. The instrument consisted of two sections. The first section obtained participants' professional and demographic characteristics, including age, educational level, field of specialization, organizational position, years of professional experience, functional area, and extent of involvement in electricity-network planning and operation. The second section measured the principal latent constructs of the proposed model, namely electricity distribution system sustainability, system resilience, imbalance and fault crisis exposure, strategic agility, load management capability, and physical asset management capability. All substantive items were rated on a five-point Likert scale ranging from 1, indicating strongly disagree, to 5, indicating strongly agree, with higher scores representing a stronger presence of the corresponding organizational or technical capability. Electricity distribution system sustainability was conceptualized as the ability of the distribution system to maintain reliable, efficient, economically viable, environmentally responsible, and operationally sustainable electricity delivery over time while effectively utilizing network resources. The items therefore assessed continuity of service, efficient resource utilization, reduction of technical and operational losses, maintenance of service quality, adaptability to changing demand patterns, and the capacity to sustain acceptable network performance under resource constraints. System resilience referred to the capability of the distribution network to anticipate, absorb, withstand, respond to, recover from, and adapt to disturbances. Its items addressed preparedness for critical events, redundancy, flexibility in network operation, fault isolation capability, restoration speed, continuity of critical services, learning from disruptions, and adaptive reconfiguration following operational disturbances.

The imbalance and fault crisis construct assessed the extent to which the regional electricity distribution system was exposed to and capable of managing circumstances involving mismatches between electricity supply and demand, peak-load pressure, unexpected demand growth, generation or supply limitations affecting distribution operations, equipment failures, feeder outages, voltage disturbances, network congestion, and cascading or recurrent faults. Items were formulated to capture both the severity of these pressures and their implications for the stability and continuity of electricity distribution. Strategic

agility was defined as the organization's capability to rapidly perceive environmental and operational changes, make timely strategic decisions, reallocate resources, coordinate organizational units, and implement flexible responses to emerging technical and managerial challenges. This construct incorporated strategic sensitivity, rapid decision-making, resource fluidity, cross-functional coordination, proactive planning, flexibility in operational procedures, and the capacity to revise priorities in response to changing supply-demand and network conditions. In the proposed conceptual framework, strategic agility represented a central organizational capability through which electricity distribution organizations could strengthen the effectiveness of load management and physical asset management and thereby improve system sustainability and resilience.

Load management capability was assessed through items reflecting the organization's ability to monitor and forecast electricity demand, manage peak loads, implement demand-side management programs, prioritize critical loads, redistribute loads across available network capacity, respond rapidly to supply-demand imbalances, employ real-time operational information, and coordinate load-control decisions with broader system conditions. The construct was designed to represent both preventive and responsive dimensions of load management, including forecasting accuracy, demand flexibility, peak-demand reduction, operational coordination, and adaptive load allocation during emergency conditions. Physical asset management capability represented the systematic management of transformers, feeders, substations, switching equipment, cables, protection systems, and other critical infrastructure throughout their operational life cycle. The corresponding items evaluated asset-condition monitoring, preventive and predictive maintenance, risk-based maintenance prioritization, equipment-health assessment, replacement and rehabilitation planning, failure-history utilization, critical-asset identification, spare-parts preparedness, optimal allocation of maintenance resources, and integration of asset information into operational decision-making. Stronger physical asset management capability was therefore interpreted as a greater organizational ability to prevent failures, reduce equipment-related interruption risks, extend asset life, and accelerate system restoration following faults.

Content validity of the questionnaire was examined prior to the main data collection by a panel of university academics and senior professionals with expertise in power-system management, electricity distribution, energy

management, crisis management, strategic management, and physical asset management. The experts evaluated the items with respect to relevance, clarity, conceptual correspondence, comprehensiveness, and suitability for the organizational and technical context of regional electricity distribution. Items considered ambiguous, repetitive, or weakly aligned with their intended constructs were revised or removed. A pilot administration was subsequently conducted with a group of eligible electricity-sector professionals who were not included in the final sample to assess wording clarity, completion time, internal consistency, and practical applicability of the instrument. Construct validity in the main study was evaluated using measurement-model assessment within partial least squares structural equation modeling. Indicator loadings, Cronbach's alpha, composite reliability, and average variance extracted were examined to establish indicator reliability, internal consistency, and convergent validity. Discriminant validity was evaluated using the heterotrait-monotrait ratio and cross-construct relationships. Acceptable measurement quality was defined by standardized outer loadings that were preferably above 0.70, Cronbach's alpha and composite reliability coefficients of at least 0.70, average variance extracted values of at least 0.50, and heterotrait-monotrait ratios below the accepted discriminant-validity threshold. These procedures ensured that the measurement instrument adequately represented the theoretical constructs incorporated into the structural model.

Data analysis was performed using IBM SPSS and SmartPLS software. Data screening was first undertaken to identify missing values, invalid responses, extreme observations, and potential data-entry errors. Descriptive statistics, including frequency, percentage, mean, standard deviation, skewness, and kurtosis, were calculated to describe the participants and summarize the distributions of the principal study variables. The suitability of the data for multivariate analysis was then evaluated, with particular attention to distributional characteristics, multicollinearity, and potential common method bias. Variance inflation factor values were examined to identify problematic collinearity among predictor constructs. Because the conceptual framework included several latent variables and simultaneous direct and indirect relationships and was primarily intended to explain and predict sustainability and resilience in the electricity distribution system, partial least squares structural equation modeling was employed as the principal analytical procedure. Analysis was conducted in two consecutive stages consisting of evaluation of the

measurement model and evaluation of the structural model. For the measurement model, indicator loadings, Cronbach's alpha, ρ_A , composite reliability, average variance extracted, and the heterotrait-monotrait ratio were calculated to assess indicator reliability, internal consistency reliability, convergent validity, and discriminant validity.

Following confirmation of satisfactory measurement properties, the structural model was assessed by examining collinearity statistics, standardized path coefficients, coefficients of determination, effect sizes, predictive relevance, and overall model fit. The coefficient of determination was used to determine the proportion of variance explained in the endogenous constructs of load management capability, physical asset management capability, electricity distribution system sustainability, and system resilience. Effect size statistics were examined to determine the relative contribution of individual exogenous constructs to the explanatory power of the model, while predictive relevance was assessed to determine whether the proposed model demonstrated adequate out-of-sample-oriented predictive capability for the endogenous variables. The standardized root mean square residual was also examined as an index of approximate model fit. The principal structural relationships tested whether crisis conditions associated with electricity imbalance and network faults influenced sustainability and resilience, whether strategic agility enhanced load management and physical asset management capabilities, and whether stronger load management and physical asset management contributed to higher levels of sustainability and resilience. The analysis additionally examined whether load management and physical asset management transmitted part of the effect of strategic agility to sustainability and resilience, thereby testing the proposed mediating mechanisms of the conceptual model. Indirect effects were evaluated using a nonparametric bootstrapping procedure with 5,000 resamples, and standardized path coefficients, t statistics, confidence intervals, and probability values were reported for all hypothesized relationships. Statistical significance was determined at the 0.05 level. The combined measurement and structural assessment provided the empirical basis for determining the explanatory capacity, predictive adequacy, and theoretical consistency of the proposed model of sustainability and resilience in regional electricity distribution systems under imbalance and fault crises.

3. Findings and Results

A total of 384 valid questionnaires were included in the final analysis. Of the participants, 287 (74.7%) were men and 97 (25.3%) were women. The mean age of the participants was 41.26 ± 7.84 years, with ages ranging from 27 to 59 years. Regarding educational attainment, 62 participants (16.1%) held a bachelor's degree, 236 (61.5%) held a master's degree, and 86 (22.4%) held a doctoral or equivalent professional degree. In terms of organizational position, 68 participants (17.7%) were managers or senior administrators, 91 (23.7%) were supervisors or unit heads, 157 (40.9%) were engineers or technical specialists, and 68 (17.7%) were planning, maintenance, asset-management, or system-operation experts. The participants had an average of 15.42 ± 6.73 years of professional experience in the

electricity sector. A total of 89 participants (23.2%) had less than 10 years of professional experience, 166 (43.2%) had 10–19 years, and 129 (33.6%) had 20 years or more. With regard to functional specialization, 101 participants (26.3%) were primarily involved in network operation and control, 79 (20.6%) in planning and load management, 86 (22.4%) in maintenance and physical asset management, 61 (15.9%) in reliability, protection, and crisis management, and 57 (14.8%) in managerial or strategic functions. Overall, the demographic and professional profile of the sample indicated substantial representation of experienced technical and managerial personnel with direct involvement in electricity distribution system operation, planning, resilience, load management, and physical asset management.

Table 1. Descriptive Statistics and Correlations among the Main Study Variables

Variable	Mean	SD	Min	Max	Skewness	Kurtosis	1	2	3	4	5	6
1. Imbalance and fault crisis exposure	3.71	0.69	1.63	5.00	-0.31	-0.27	1.00					
2. Strategic agility	3.66	0.64	1.75	5.00	-0.24	-0.16	-0.29**	1.00				
3. Load management capability	3.73	0.61	1.88	5.00	-0.27	-0.12	-0.33**	0.63**	1.00			
4. Physical asset management capability	3.69	0.66	1.71	5.00	-0.21	-0.30	-0.36**	0.59**	0.56**	1.00		
5. System sustainability	3.62	0.63	1.81	5.00	-0.18	-0.25	-0.43**	0.58**	0.65**	0.62**	1.00	
6. System resilience	3.67	0.65	1.75	5.00	-0.22	-0.19	-0.48**	0.61**	0.68**	0.66**	0.72**	1.00

As presented in Table 1, the mean scores of the principal constructs ranged from 3.62 for system sustainability to 3.73 for load management capability, indicating that respondents generally evaluated the investigated organizational and technical capabilities at levels above the theoretical midpoint of the five-point scale. The highest mean was observed for load management capability ($M = 3.73$, $SD = 0.61$), followed by imbalance and fault crisis exposure ($M = 3.71$, $SD = 0.69$), physical asset management capability ($M = 3.69$, $SD = 0.66$), system resilience ($M = 3.67$, $SD = 0.65$), strategic agility ($M = 3.66$, $SD = 0.64$), and system sustainability ($M = 3.62$, $SD = 0.63$). The skewness and kurtosis coefficients of all constructs remained within acceptable ranges, with absolute skewness values below 0.50 and absolute kurtosis values below 0.31, indicating no substantial departure from approximately symmetric distributions. The correlation analysis showed that imbalance and fault crisis exposure was significantly and negatively associated with strategic agility

($r = -0.29$, $p < 0.01$), load management capability ($r = -0.33$, $p < 0.01$), physical asset management capability ($r = -0.36$, $p < 0.01$), system sustainability ($r = -0.43$, $p < 0.01$), and system resilience ($r = -0.48$, $p < 0.01$). Conversely, strategic agility demonstrated significant positive correlations with load management capability ($r = 0.63$, $p < 0.01$), physical asset management capability ($r = 0.59$, $p < 0.01$), sustainability ($r = 0.58$, $p < 0.01$), and resilience ($r = 0.61$, $p < 0.01$). The strongest bivariate association was observed between system sustainability and resilience ($r = 0.72$, $p < 0.01$), followed by the correlation between load management capability and resilience ($r = 0.68$, $p < 0.01$). These preliminary results were consistent with the conceptual expectation that stronger strategic and operational capabilities would be associated with more sustainable and resilient electricity distribution systems, whereas greater exposure to imbalance and fault crises would be associated with poorer system outcomes.

Table 2. Measurement Model Assessment for the Study Constructs

Construct	Number of Items	Loading Range	Cronbach's Alpha	rho_A	Composite Reliability	AVE	HTMT Maximum
Imbalance and fault crisis exposure	7	0.714–0.846	0.889	0.895	0.913	0.602	0.641
Strategic agility	8	0.731–0.872	0.917	0.921	0.932	0.632	0.747
Load management capability	8	0.738–0.881	0.923	0.926	0.936	0.648	0.779
Physical asset management capability	9	0.706–0.864	0.925	0.929	0.938	0.629	0.756
System sustainability	8	0.742–0.885	0.928	0.931	0.941	0.667	0.821
System resilience	9	0.751–0.893	0.938	0.940	0.948	0.669	0.821

The structural model results are shown in Table 3. Imbalance and fault crisis exposure exerted a statistically significant negative direct effect on both system sustainability ($\beta = -0.214$, $t = 4.756$, $p < 0.001$) and system resilience ($\beta = -0.267$, $t = 6.209$, $p < 0.001$). The stronger adverse effect on resilience indicated that intensification of supply-demand imbalances, peak-load pressure, equipment failures, feeder outages, network congestion, and related disturbances particularly weakened the system's capacity to withstand and recover from disruptive events. Strategic agility demonstrated substantial positive effects on both operational mediators. Its effect on load management capability was $\beta = 0.628$ ($t = 17.444$, $p < 0.001$), representing one of the strongest paths in the structural model, while its effect on physical asset management capability was $\beta = 0.592$ ($t = 15.179$, $p < 0.001$). These results indicated that organizations characterized by greater strategic sensitivity, rapid decision-making, resource fluidity, and cross-functional coordination were considerably more capable of adjusting loads and managing critical physical infrastructure. Strategic agility also had significant direct effects on system sustainability ($\beta = 0.178$, $t = 3.560$, $p <$

0.001) and resilience ($\beta = 0.196$, $t = 4.083$, $p < 0.001$), although the magnitude of these direct effects was smaller than its influence through operational capabilities. Load management capability was positively associated with both sustainability ($\beta = 0.337$, $t = 6.481$, $p < 0.001$) and resilience ($\beta = 0.358$, $t = 7.306$, $p < 0.001$), demonstrating that improved forecasting, demand-side management, peak reduction, critical-load prioritization, and operational load redistribution were important predictors of both long-term system performance and crisis-response capacity. Physical asset management capability also significantly predicted sustainability ($\beta = 0.293$, $t = 5.980$, $p < 0.001$) and resilience ($\beta = 0.276$, $t = 5.872$, $p < 0.001$). Accordingly, better condition monitoring, preventive and predictive maintenance, risk-based prioritization, failure-history utilization, and replacement planning were associated with improved continuity, efficiency, reliability, and recovery capability. The effect-size estimates showed that strategic agility had large effects on load management and physical asset management, while the operational capabilities generally had small-to-moderate effects on the two final system outcomes.

Table 3. Structural Model Path Coefficients and Hypothesis Testing

Structural Path	β	SE	t	p	95% CI	f ²	Result
Imbalance and fault crisis exposure → System sustainability	-0.214	0.045	4.756	<0.001	-0.301 to -0.126	0.081	Significant
Imbalance and fault crisis exposure → System resilience	-0.267	0.043	6.209	<0.001	-0.350 to -0.182	0.126	Significant
Strategic agility → Load management capability	0.628	0.036	17.444	<0.001	0.556 to 0.696	0.650	Significant
Strategic agility → Physical asset management capability	0.592	0.039	15.179	<0.001	0.513 to 0.665	0.539	Significant
Strategic agility → System sustainability	0.178	0.050	3.560	<0.001	0.080 to 0.275	0.046	Significant
Strategic agility → System resilience	0.196	0.048	4.083	<0.001	0.101 to 0.289	0.061	Significant
Load management capability → System sustainability	0.337	0.052	6.481	<0.001	0.233 to 0.437	0.139	Significant
Load management capability → System resilience	0.358	0.049	7.306	<0.001	0.261 to 0.451	0.174	Significant
Physical asset management capability → System sustainability	0.293	0.049	5.980	<0.001	0.196 to 0.387	0.112	Significant
Physical asset management capability → System resilience	0.276	0.047	5.872	<0.001	0.183 to 0.367	0.105	Significant

The structural model results are shown in Table 3. Imbalance and fault crisis exposure exerted a statistically significant negative direct effect on both system

sustainability ($\beta = -0.214$, $t = 4.756$, $p < 0.001$) and system resilience ($\beta = -0.267$, $t = 6.209$, $p < 0.001$). The stronger adverse effect on resilience indicated that intensification of

supply-demand imbalances, peak-load pressure, equipment failures, feeder outages, network congestion, and related disturbances particularly weakened the system's capacity to withstand and recover from disruptive events. Strategic agility demonstrated substantial positive effects on both operational mediators. Its effect on load management capability was $\beta = 0.628$ ($t = 17.444$, $p < 0.001$), representing one of the strongest paths in the structural model, while its effect on physical asset management capability was $\beta = 0.592$ ($t = 15.179$, $p < 0.001$). These results indicated that organizations characterized by greater strategic sensitivity, rapid decision-making, resource fluidity, and cross-functional coordination were considerably more capable of adjusting loads and managing critical physical infrastructure. Strategic agility also had significant direct effects on system sustainability ($\beta = 0.178$, $t = 3.560$, $p < 0.001$) and resilience ($\beta = 0.196$, $t = 4.083$, $p < 0.001$), although the magnitude of these direct effects was smaller than its influence through operational capabilities. Load

management capability was positively associated with both sustainability ($\beta = 0.337$, $t = 6.481$, $p < 0.001$) and resilience ($\beta = 0.358$, $t = 7.306$, $p < 0.001$), demonstrating that improved forecasting, demand-side management, peak reduction, critical-load prioritization, and operational load redistribution were important predictors of both long-term system performance and crisis-response capacity. Physical asset management capability also significantly predicted sustainability ($\beta = 0.293$, $t = 5.980$, $p < 0.001$) and resilience ($\beta = 0.276$, $t = 5.872$, $p < 0.001$). Accordingly, better condition monitoring, preventive and predictive maintenance, risk-based prioritization, failure-history utilization, and replacement planning were associated with improved continuity, efficiency, reliability, and recovery capability. The effect-size estimates showed that strategic agility had large effects on load management and physical asset management, while the operational capabilities generally had small-to-moderate effects on the two final system outcomes.

Table 4. Indirect Effects, Explained Variance, Predictive Relevance, and Model Fit

Model Component	Effect / Index	Value	t	p	Interpretation
Strategic agility → Load management → Sustainability	Indirect β	0.212	5.931	<0.001	Significant partial mediation
Strategic agility → Physical asset management → Sustainability	Indirect β	0.173	5.294	<0.001	Significant partial mediation
Strategic agility → Load management → Resilience	Indirect β	0.225	6.438	<0.001	Significant partial mediation
Strategic agility → Physical asset management → Resilience	Indirect β	0.163	5.018	<0.001	Significant partial mediation
Load management capability	R^2	0.394	—	—	Moderate explanatory power
Physical asset management capability	R^2	0.350	—	—	Moderate explanatory power
System sustainability	R^2	0.613	—	—	Substantial explanatory power
System resilience	R^2	0.668	—	—	Substantial explanatory power
Load management capability	Q^2	0.248	—	—	Predictive relevance
Physical asset management capability	Q^2	0.216	—	—	Predictive relevance
System sustainability	Q^2	0.397	—	—	Strong predictive relevance
System resilience	Q^2	0.438	—	—	Strong predictive relevance
Overall model	SRMR	0.061	—	—	Acceptable model fit
Overall model	NFI	0.912	—	—	Acceptable model fit

The results of the mediation, explanatory-power, predictive-relevance, and model-fit analyses are summarized in Table 4. Bootstrapping demonstrated that both load management capability and physical asset management capability significantly transmitted the effects of strategic agility to system sustainability and resilience. The indirect effect of strategic agility on sustainability through load management was positive and statistically significant ($\beta = 0.212$, $t = 5.931$, $p < 0.001$), while the indirect effect through physical asset management was also significant ($\beta = 0.173$, $t = 5.294$, $p < 0.001$). Because the direct effect of strategic agility on sustainability remained statistically significant after inclusion of these mediators, the

findings supported partial rather than full mediation. An analogous pattern emerged for system resilience. Strategic agility had a significant indirect effect on resilience through load management capability ($\beta = 0.225$, $t = 6.438$, $p < 0.001$) and through physical asset management capability ($\beta = 0.163$, $t = 5.018$, $p < 0.001$). These findings indicated that strategic agility influenced system-level outcomes not only directly but also by strengthening concrete operational capabilities through which strategic decisions were translated into changes in demand control and infrastructure management. The coefficient of determination for load management capability was $R^2 = 0.394$, indicating that strategic agility explained 39.4% of its variance, whereas the

R^2 value of 0.350 for physical asset management capability indicated that 35.0% of its variance was explained by strategic agility. More importantly, the complete structural model explained 61.3% of the variance in system sustainability and 66.8% of the variance in system resilience, demonstrating substantial explanatory power for the two principal dependent constructs. Predictive-relevance statistics were positive for all endogenous constructs, with Q^2 values of 0.248 for load management capability, 0.216 for physical asset management capability, 0.397 for sustainability, and 0.438 for resilience. Thus, the model showed particularly strong predictive relevance for the final

system-level outcomes. Finally, the standardized root mean square residual was 0.061, remaining below the commonly accepted threshold of 0.08, while the normed fit index was 0.912. Together, these indices indicated an acceptable correspondence between the proposed theoretical structure and the observed data. Overall, the results supported the proposed conceptual model and demonstrated that sustainability and resilience in regional electricity distribution systems were jointly shaped by crisis exposure, strategic agility, load management capability, and physical asset management capability.

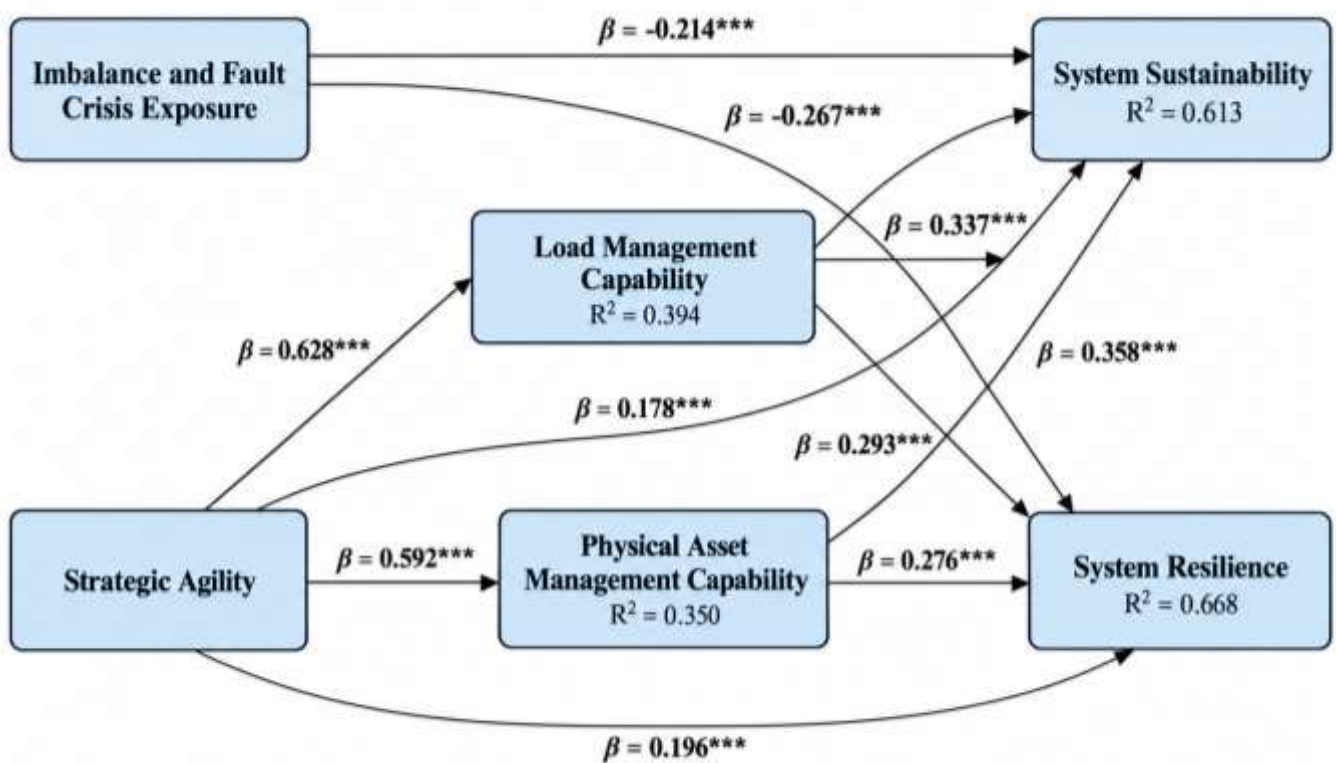


Figure 1. Final Structural Model of Strategic Agility, Load Management, Physical Asset Management, Sustainability, and Resilience in Regional Electricity Distribution Systems

The final structural model demonstrated that strategic agility functioned as a central upstream capability in the proposed framework, with strong positive paths toward load management capability and physical asset management capability and additional positive direct paths toward system sustainability and resilience. Load management and physical asset management subsequently exerted independent positive effects on both system-level outcomes, confirming their operational role in translating strategic responsiveness into reliable and sustainable distribution-system performance. In contrast, imbalance and fault crisis exposure

demonstrated direct negative effects on both sustainability and resilience, with the magnitude of its adverse association being greater for resilience. The pattern of direct and indirect coefficients further showed that the contribution of strategic agility to sustainability and resilience was partly transmitted through the two operational mechanisms. Among these mechanisms, load management produced the larger indirect effect on both sustainability and resilience, whereas physical asset management provided an additional complementary pathway. The model therefore suggested that strategic agility alone was insufficient to explain favorable system outcomes

unless strategic responsiveness was converted into effective demand-side action and systematic management of physical infrastructure. Collectively, the structural relationships, explained-variance coefficients, predictive-relevance statistics, and model-fit indices provided empirical support for the proposition that sustainable and resilient electricity distribution systems depend on the simultaneous development of strategic responsiveness, adaptive load-management capacity, and disciplined physical asset management, particularly under conditions characterized by persistent supply-demand imbalance and operational faults.

4. Discussion and Conclusion

The present study developed and empirically tested a structural model of sustainability and resilience in regional electricity distribution systems under conditions of imbalance and operational faults, with particular attention to the role of strategic agility and the mediating contributions of load management capability and physical asset management capability. The findings showed that exposure to imbalance and fault crises exerted significant negative effects on both system sustainability and system resilience. In contrast, strategic agility had significant positive direct effects on both outcomes and, more importantly, strongly predicted load management capability and physical asset management capability. Both operational capabilities significantly enhanced sustainability and resilience, while the mediation analysis demonstrated that strategic agility influenced the two principal system outcomes partly through stronger load management and more effective management of physical assets. The structural model explained 61.3% of the variance in system sustainability and 66.8% of the variance in system resilience, indicating substantial explanatory power. These results support an integrated interpretation in which the ability of electricity distribution systems to remain sustainable and resilient depends not only on the intensity of external and operational pressures but also on the organizational capacity to respond quickly and translate strategic responsiveness into effective operational action.

The first major finding was that imbalance and fault crisis exposure significantly reduced system sustainability. This relationship is theoretically plausible because persistent mismatches between demand and available supply, overloaded network components, equipment failures, congestion, and repeated disturbances increase technical losses, maintenance requirements, service interruptions, and

resource inefficiencies. Such conditions can undermine the long-term viability of distribution operations by increasing pressure on infrastructure and reducing the capacity of utilities to optimize resources. This result is consistent with earlier studies emphasizing the importance of environmental and operational conditions in electricity distribution performance. Bahrini et al. showed that the external environment can directly influence performance management in electricity distribution companies, suggesting that organizational outcomes are partly shaped by the degree of turbulence and pressure surrounding the operating system [1]. Similarly, Fallahi et al. demonstrated substantial variation in efficiency across electricity distribution companies and emphasized the importance of systematic resource utilization and performance assessment [2]. The present result extends these observations by indicating that operational crises associated with imbalance and faults do not merely affect short-term performance but also have direct consequences for the broader sustainability of the distribution system.

The negative relationship between imbalance and fault crisis exposure and system resilience was even stronger than its effect on sustainability. This pattern indicates that resilience is particularly sensitive to operational pressure because resilience directly concerns the ability of the system to absorb, respond to, and recover from disruptive events. Recurrent faults, overloaded equipment, limited reserve capacity, and unstable load conditions can reduce redundancy and narrow the range of corrective actions available to operators. The finding aligns with the work of Karami and Separi, who emphasized the importance of durability and resilience in electricity distribution systems exposed to severe disturbances such as storms [7]. It is also consistent with the risk-management perspective proposed by Valizadeh and Hosseini, who emphasized structured organizational risk management in electricity distribution companies [6]. From this perspective, resilience should be understood not merely as a property of physical infrastructure but as the outcome of preparedness, resource availability, risk identification, rapid response, and recovery capability. When imbalance and fault exposure increases, these capacities are placed under greater stress, making the system more vulnerable unless adaptive organizational mechanisms are simultaneously strengthened.

A second key result was the strong positive effect of strategic agility on load management capability. This was one of the strongest structural relationships in the model, indicating that strategically agile electricity distribution

organizations are substantially better able to forecast demand, respond to peak-load conditions, prioritize critical loads, reallocate available capacity, and coordinate demand-side interventions. The result is compatible with the broader strategic management literature, in which agility is conceptualized as the organizational capacity to sense change rapidly and reconfigure resources accordingly. Tenggono et al. emphasized the role of dynamic managerial capabilities in advancing strategic agility and digital readiness, showing that adaptive managerial capability can strengthen organizational responsiveness in changing environments [10]. Shao likewise argued that digital transformation can enhance organizational agility by improving responsiveness, information flow, and strategic decision-making [11]. In electricity distribution systems, these mechanisms may translate into more rapid use of load information, faster coordination among technical units, and more flexible implementation of operational responses during periods of demand-supply imbalance.

The importance of load management is further supported by previous studies on dynamic electricity consumption and demand-side flexibility. Zhang et al. demonstrated that electricity consumption behavior is dynamic and can be systematically grouped to improve understanding of demand patterns [4]. This supports the present interpretation that effective load management requires analytical sensitivity to changing consumption behavior rather than reliance on static assumptions. Abdelmotteleb et al. also showed the value of customer engagement in the provision of distribution-level flexibility products, highlighting demand-side participation as a practical source of flexibility for electricity networks [5]. The present findings complement these studies by showing that the organizational capability required to exploit such flexibility is strongly related to strategic agility. In other words, advanced demand-management tools may provide limited value if the organization lacks the ability to recognize emerging conditions, make timely decisions, and mobilize resources across functional boundaries.

Strategic agility also had a strong positive effect on physical asset management capability. This finding suggests that agile organizations are more capable of prioritizing maintenance, reallocating technical resources, responding to asset-condition information, and accelerating repair or replacement decisions. Physical asset management in electricity distribution is inherently dynamic because asset criticality changes with network loading, equipment health, system topology, and operational risk. Strategic agility can improve this process by enabling management to respond to

emerging risks without being constrained by rigid planning structures. This interpretation is consistent with the project-based risk-management approach discussed by Valizadeh and Hosseini [6], as well as with the resilience-oriented infrastructure perspective of Karami and Separi [7]. Together, these studies suggest that technical resilience is strengthened when physical infrastructure management is integrated with organizational decision-making and risk prioritization.

The results further showed that strategic agility directly improved system sustainability and resilience. Although these direct effects were smaller than the effects observed through load management and physical asset management, both remained statistically significant. This pattern indicates that strategic agility contributes to system outcomes through multiple mechanisms. Some effects appear to operate through specific operational capabilities, while others may reflect broader organizational advantages such as faster communication, improved coordination, flexible allocation of human and financial resources, and more rapid strategic adaptation. This finding is in line with Shayanmehr et al., who identified strategic agility as an important mechanism linking human resource management strategies with organizational resilience [12]. It is also consistent with the broader resilience and agility framework proposed by Kaya and Yalçın, in which strategic agility forms part of an adaptive system connecting technological capability, managerial responsiveness, and organizational resilience [13].

The positive relationship between strategic agility and resilience can also be explained through digital and analytical capability. Karami argued that AI-driven human resource analytics can strengthen workforce resilience and agility by enabling more evidence-based and adaptive management [14]. Although the present study focused on electricity distribution rather than human resource analytics specifically, the underlying mechanism is comparable. Agile electricity distribution organizations are increasingly dependent on real-time data, predictive maintenance information, automated monitoring, demand forecasts, and operational dashboards. When these data are integrated into rapid decision-making structures, organizations can identify risks earlier and respond more effectively. Shao's analysis of digital transformation and organizational agility similarly supports the view that digital capability can strengthen the speed and quality of organizational responses [11]. Thus, strategic agility in the electricity sector may increasingly

depend on the integration of managerial flexibility with advanced digital decision support.

Another important finding was that load management capability significantly improved both system sustainability and system resilience. Its effect on resilience was slightly stronger than its effect on sustainability, suggesting that effective load management is particularly important during operational disturbances. This is understandable because the ability to reduce peak demand, prioritize essential loads, reconfigure load allocation, and use demand-side flexibility can prevent disturbances from escalating. Load management can therefore act as both a preventive and a responsive mechanism. Zhang et al.'s findings on dynamic electricity consumption behavior support the importance of understanding and managing changing demand patterns [4], while Abdelmotteleb et al.'s study of customer flexibility demonstrates the practical relevance of demand participation in distribution-level operations [5]. The present findings extend these studies by showing that load management capability is not only associated with operational efficiency but is also a significant determinant of broader sustainability and resilience outcomes.

The positive effect of load management on sustainability can be explained through reduced system stress and more efficient resource utilization. Effective demand management can reduce overload, defer unnecessary infrastructure expansion, lower technical losses, and improve the utilization of existing assets. These effects are closely related to the efficiency concerns emphasized by Pourabadolahankooch et al., who examined efficiency and scale among Iranian electricity distribution companies and showed that structural and managerial differences can substantially influence organizational performance [3]. Similarly, the performance-evaluation framework proposed by Fallahi et al. reinforces the importance of efficient transformation of resources into electricity-distribution outputs [2]. In this sense, load management can be regarded as a sustainability mechanism because it helps utilities achieve more reliable service without proportionately increasing infrastructure or resource consumption.

Physical asset management capability also significantly improved both sustainability and resilience. This finding confirms the central importance of asset-condition monitoring, predictive and preventive maintenance, risk-based prioritization, equipment replacement planning, and critical-asset identification. Electricity distribution systems depend on large portfolios of physical assets, and their failure can disrupt entire sections of the network. Effective

asset management reduces the probability of failure, improves reliability, lowers emergency maintenance costs, and supports faster restoration. These findings are consistent with the resilience perspective of Karami and Separi, who emphasized the need to improve distribution-system durability against external disturbances [7]. They also align with the organizational risk-management model proposed by Valizadeh and Hosseini, which highlighted the importance of systematic management of risk in electricity distribution organizations [6]. The present study demonstrates that these principles are relevant not only to individual fault prevention but also to broader system sustainability and resilience.

The mediation results provide one of the most important contributions of the study. Strategic agility significantly influenced sustainability and resilience through both load management capability and physical asset management capability. This indicates that agility alone is insufficient unless it is translated into operational mechanisms. The stronger indirect effect through load management suggests that demand-side responsiveness may represent a particularly important pathway through which strategic agility improves system outcomes. Nevertheless, the significant mediation through physical asset management confirms that infrastructure-related capability is also essential. These findings support a multi-capability interpretation of strategic agility. An electricity distribution organization may detect threats rapidly and make timely decisions, but these advantages produce meaningful system outcomes only when the organization can operationalize them through effective demand control and asset management.

The organizational and human dimensions of this model are also consistent with prior research in the electricity sector. Samavi emphasized strategic factors associated with efficient human resource management in Iranian electricity distribution companies [8], while Rezaei Dizgah et al. demonstrated the relationship between organizational culture and employee safety performance [9]. Yahya Pour et al. further emphasized the importance of environmentally oriented human resource management in electricity distribution organizations [15]. These studies collectively support the argument that electricity distribution performance depends not only on equipment and engineering systems but also on organizational culture, employee capability, managerial systems, and strategic alignment. The present findings extend this perspective by demonstrating how an organizational capability such as

strategic agility can influence technical and operational outcomes through identifiable intermediate mechanisms.

The findings also have implications for institutional learning and knowledge integration. Moghaddas Nodeh identified challenges in university-industry collaboration in the Tehran Province Electricity Distribution Company [16]. Such barriers can restrict the transfer of advanced knowledge in areas such as predictive maintenance, optimization, artificial intelligence, demand forecasting, and resilience planning. Given the present finding that strategic agility and operational capabilities jointly explain a substantial proportion of sustainability and resilience, the ability of electricity distribution organizations to acquire and apply external knowledge may be an important background condition for strengthening these capabilities. This is particularly relevant as the electricity sector becomes increasingly digital and data-driven.

The substantial R^2 values obtained for sustainability and resilience indicate that the proposed model captured a meaningful proportion of variation in these system-level outcomes. The model therefore supports an integrated framework in which crisis exposure, strategic agility, load management, and physical asset management operate jointly rather than independently. The positive predictive relevance indices and acceptable model-fit statistics further strengthen confidence in the explanatory adequacy of the model. Taken together, the findings suggest that sustainable and resilient electricity distribution systems are produced through the interaction of technical robustness, adaptive demand management, systematic asset management, and organizational agility. This integrated interpretation provides a broader perspective than approaches that examine only infrastructure reliability, only demand management, or only organizational performance in isolation.

The study was subject to several limitations that should be considered when interpreting the results. First, the cross-sectional design limits causal inference because all variables were measured at a single point in time, and therefore the estimated structural relationships should be interpreted as theoretically supported associations rather than definitive causal effects. Second, the study relied primarily on questionnaire-based assessments provided by managers and technical personnel, which may introduce common method variance, perceptual bias, and socially desirable responding. Third, the sample was restricted to professionals working in electricity distribution and related regional power organizations in Tehran, which may limit the generalizability of the findings to other provinces, countries,

regulatory environments, or electricity-system structures. Fourth, the proposed model focused on selected organizational and operational variables and did not explicitly incorporate other potentially important determinants such as distributed renewable generation, cybersecurity risk, climate exposure, financial capacity, regulatory quality, automation maturity, or network topology. Finally, although the sample size was adequate for PLS-SEM, broader multi-regional samples could provide stronger evidence regarding the stability of the estimated structural relationships.

Future research should test the proposed model using longitudinal, panel, or repeated-measures designs to determine how strategic agility, load management, physical asset management, sustainability, and resilience evolve over time and during actual crisis episodes. Comparative studies across provinces, utilities, and countries would also be valuable for examining whether the identified structural relationships remain stable under different regulatory, technological, climatic, and market conditions. Future models could incorporate additional variables such as digital maturity, artificial intelligence capability, smart-grid infrastructure, distributed energy resources, cybersecurity preparedness, organizational learning, financial flexibility, and regulatory support. Multi-group analysis could be used to compare utilities with different levels of digitalization, network age, demand growth, or exposure to extreme events. Researchers could also combine survey data with objective engineering indicators such as SAIDI, SAIFI, energy not supplied, outage duration, asset failure rates, technical losses, peak-demand reduction, and maintenance expenditure to strengthen the empirical validity of the model and reduce reliance on self-reported measures.

From a practical perspective, electricity distribution organizations should treat strategic agility as a core managerial capability and institutionalize mechanisms for rapid sensing, decision-making, resource reallocation, and cross-functional coordination. Utilities should strengthen real-time load monitoring, demand forecasting, peak-management programs, critical-load prioritization, and customer flexibility mechanisms so that load management can function as an active resilience tool rather than merely an operational support activity. Physical asset management should be upgraded through condition-based maintenance, predictive analytics, asset-health indexing, risk-based replacement planning, and systematic prioritization of critical infrastructure. Strategic, technical, maintenance, and operations units should share integrated data and decision

platforms so that emerging risks can be detected early and addressed through coordinated action. Scenario-based crisis exercises, contingency planning, rapid-response protocols, and post-event learning systems should also be institutionalized to convert organizational agility into measurable improvements in sustainability and resilience.

Authors' Contributions

Authors equally contributed to this article.

Acknowledgments

Authors thank all participants who participate in this study.

Declaration of Interest

The authors report no conflict of interest.

Funding

According to the authors, this article has no financial support.

Ethical Considerations

All procedures performed in this study were under the ethical standards.

References

- [1] M. Bahrini, M. Nikpei, and B. Baharvand, "The impact of external environment on performance management in Lorestan Province Electricity Distribution Company," in *3rd International Conference on Modern Research in Management, Economics, and Accounting*, 2015. [Online]. Available: <https://en.civilica.com/doc/554695/>.
- [2] A. Fallahi, F. A. U. S. H. Fallahi, S. F. Ghaderi, and R. Ebrahimi, "Application of a robust data envelopment analysis model for performance evaluation of electricity distribution companies," *International Journal of Energy Sector Management*, vol. 15, no. 4, pp. 724-742, 2019, doi: 10.1108/IJESM-08-2018-0008.
- [3] M. Pourabadolahankooch, E. Nowbahar, S. Sajoodi, and R. Khalafi, "Efficiency and scale: Evidence from electricity distribution companies in Iran," *Iranian Journal of Energy Economics*, vol. 10, no. 39, pp. 71-97, 2021. [Online]. Available: https://jiece.atu.ac.ir/article_14274.html.
- [4] Y. Zhang, Q. Ai, and Z. Li, "Grouping of Dynamic Electricity Consumption Behaviour: An α -divergence Based Hierarchical Clustering Model," *Iet Generation Transmission & Distribution*, vol. 15, no. 22, pp. 3164-3175, 2021, doi: 10.1049/gtd2.12248.
- [5] I. Abdelmoteleb, E. Fumagalli, and M. Gibescu, "Assessing customer engagement in electricity distribution-level flexibility product provision: The Norwegian case," *Sustainable Energy, Grids and Networks*, vol. 29, p. 100564, 2022/03/01/ 2022. [Online]. Available: <https://doi.org/10.1016/j.segan.2021.100564>.
- [6] M. Valizadeh and S. H. Hosseini, "A project-based model for the growth of organizational risk management in electricity distribution companies," in *In Fifteenth National Conference on Electricity Distribution Networks*, 2010, pp. 42-60.
- [7] M. A. Karami and F. Separi, "Durability and Resiliency Improvement in Mazandaran Electricity Distribution Company Against Storm," pp. 91 (4 .)-91 (4 .), 2016, doi: 10.1049/cp.2016.0691.
- [8] H. Samavi, "Strategic Factors of Efficient Human Resource Management in Iranian Electricity Distribution Companies," in *The First International Conference on the Leap of Management Sciences, Economics, and Accounting*, Sari, 2021.
- [9] M. Rezaei Dizgah, M. Ajali, and M. Homayounfar, "The effect of organizational culture on the safety performance of employees of Guilan Province Electricity Distribution Organization," *Journal of Occupational Health and Health Promotion*, vol. 6, no. 2, pp. 98-110, 2022, doi: <https://doi.org/10.18502/ohhp.v6i2.10298>.
- [10] E. Tenggono, B. W. Soetjipto, and L. Sudhartio, "Dynamic Managerial Capabilities In action: Advancing Strategic Agility and Digital Readiness in Healthcare Organizations," *Journal of Organizational Change Management*, 2025, doi: 10.1108/jocm-12-2024-0772.
- [11] W. Shao, "The Role of Digital Transformation in Enhancing Organizational Agility and Competitive Advantages: A Strategic Perspective," presented at the Proceedings of the 3rd International Conference on Financial Technology and Business Analysis, 2025. [Online]. Available: <https://doi.org/10.54254/2754-1169/154/2024.19552>.
- [12] Shayanmehr, N. Jafari, and Khodami, "The Effect of Human Resource Management Strategies on Organizational Resilience with Strategic Agility," *Strategic Management Studies Quarterly*, vol. 16, no. 63, pp. 39-60, 2025.
- [13] E. Ç. Kaya and H. Yalçın, "Constructing an AI-Driven Meta-Theory of SME Resilience and Strategic Agility: A Computational Synthesis of Global Research," *Administrative Sciences*, vol. 16, no. 5, p. 236, 2026, doi: 10.3390/admsci16050236.
- [14] M. Karami, "AI-Driven HR Analytics for Workforce Resilience and Agility: A Strategic Framework for the Digital Era," *Strategic HR Review*, vol. 25, no. 4, pp. 162-166, 2026, doi: 10.1108/SHR-11-2025-0119.
- [15] M. Yahya Pour, M. Tabari, A. Mehrara, M. Bagherzadeh, and E. Baloei Jamkhaneh, "Designing a Green Human Resource Management Excellence Model in Northern Iran's Electricity Distribution Companies," *Ethical Research Quarterly*, vol. 12, no. 4, pp. 278-304, 2022.
- [16] M. Moghaddas Nodeh, "Investigating challenges of university-industry collaboration: Case study of Tehran Province Electricity Distribution Company," *Innovation Management*, vol. 8, no. 1, pp. 8-106, 2019.