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Region-Specific Optimization of Coincidence Factors in LV Distribution Networks: A Case Study of Zonguldak Using bPRO EDŞ

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WHAT IS ALREADY KNOWN ON THIS TOPIC:

- *Coincidence factors are widely used in internal electrical wiring to estimate simultaneous electricity use, but their application in external electricity distribution networks is often inconsistent and lacks region-specific calibration.*

WHAT DOES THIS STUDY ADD ON THIS TOPIC:

- *This study introduces a field-validated methodology for deriving optimized coincidence factors using real consumption data from over 5000 residential units in Zonguldak Province, showing significant cost savings without compromising technical performance.*

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ABSTRACT

This study investigates the impact of applying optimized coincidence factors on the efficiency and cost-effectiveness of electricity distribution networks. Coincidence factors quantify the probability of multiple consumers drawing power simultaneously. Their absence or inappropriate application, particularly in multi-residential systems, often results in oversized cables and inflated infrastructure costs. While Turkey's Electrical Internal Installation Regulation provides guidelines for internal wiring, a standardized methodology for their use in distribution systems remains absent. Using empirical data collected from 5422 residential units in Zonguldak Province, this study analyzed two scenarios using the bPRO-EDŞ software: one assuming full simultaneity (coincidence factor = 1.0), and another incorporating locally optimized values based on actual demand behavior. The technical and financial outcomes of both scenarios were assessed. Results revealed significant cost savings without compromising system reliability. In an urban case, total cable-related investment dropped from 665 633.63 TL to 375 347.48 TL. Similarly, a rural example demonstrated a reduction from 161 950.39 TL to 110 732.89 TL. These findings underscore the critical importance of data-driven, region-specific planning for sustainable energy infrastructure. The methodology presented in this paper offers a replicable model for other provinces, promoting nationwide improvements in the design, planning, and economic viability of electricity distribution networks. It emphasizes the role of empirical data and modern planning tools in transforming traditionally overengineered systems into lean, resilient, and cost-effective infrastructures.
***Index Terms*—**bPRO-EDŞ, coincidence factor, cost optimization, electricity distribution, load demand, rural–urban networks

I. INTRODUCTION

As global energy demand continues to rise and urbanization intensifies, the optimization of electricity distribution systems becomes increasingly critical [1]. Efficient and reliable distribution networks are essential not only to ensure consistent power delivery to end users but also to minimize infrastructure costs and energy losses. A key yet often overlooked element in distribution system planning is the application of appropriate coincidence factors—parameters that account for the probability that connected loads will operate simultaneously.

In many countries, including Turkey, the design of internal electrical installations typically involves well-defined coincidence factors as outlined in national regulations [2]. However, the application of such factors in external electricity distribution networks remains ambiguous and inconsistently practiced. This oversight often results in oversized conductors and overengineered systems that unnecessarily inflate investment costs. For instance, using a 100% simultaneity assumption across all consumer points leads to redundant design margins that do not reflect real-world consumption behavior.

Furthermore, the absence of region-specific coincidence factor guidelines fails to account for the substantial variability in consumption patterns driven by geographic, economic, and demographic differences [3]. Urban areas may exhibit peak demands during evening hours due to lighting and appliance use, while rural regions may demonstrate more scattered loads influenced by agricultural activities. Therefore, a one-size-fits-all approach undermines the technical and economic performance of distribution planning.

This study aims to fill this gap by investigating and optimizing coincidence factors for electricity distribution networks in both urban and rural areas of Zonguldak Province, Turkey. Real-world consumption data from 5422 residential units were analyzed to derive more realistic values. These optimized factors were then applied using the bPRO-EDŞ software to evaluate their technical and financial impact. The scientific contributions of this study are summarized as follows:

1. It provides the first large-scale empirical derivation of coincidence factors based on real consumption data in Zonguldak Province, covering both urban and rural areas.
2. It quantifies the technical and economic benefits of optimized coincidence factors using a practical simulation tool (bPRO-EDŞ), demonstrating substantial cost savings in cable sizing and infrastructure investment.
3. It presents a replicable, data-driven methodology that bridges the gap between theoretical assumptions and field-based distribution design practices.
4. It offers actionable insights for policymakers and utility planners by demonstrating how region-specific load behavior can inform more efficient and sustainable network planning.

The remainder of this paper is structured as follows: Section 2 presents the literature review, highlighting key studies on coincidence factors and distribution planning. Section 3 describes the methodology and tools used in data collection and simulation. Section 4 outlines the results and discussion, including cost analyses under different scenarios. Finally, Section 5 concludes the study and offers recommendations for policy and future research.

II. LITERATURE REVIEW

The development of efficient electricity distribution networks hinges on accurate demand modeling and tailored infrastructure planning. A central concept in this planning process is the coincidence factor, which adjusts expected load based on the probability of simultaneous usage. However, the application of these factors remains inconsistent; especially in Turkey's distribution network planning; leading to systematic overdesign and increased costs. Recent research has highlighted the importance of applying empirically derived, region-specific coincidence factors to improve network reliability and financial efficiency. This literature review synthesizes key contributions in this domain, focusing on methodologies for factor estimation, use of machine learning, and case-based modeling.

Artificial intelligence-based protection schemes, when integrated into distribution networks with high DER penetration, can significantly enhance fault detection accuracy, reduce relay operation times, and minimize miscoordination, all while achieving cost-effective system upgrades. This techno-economic synergy, demonstrated using smart relays trained via MLP models, offers a replicable foundation for future data-driven grid optimization strategies [4].

Research based on field measurements has been instrumental in identifying the limitations of standard assumptions. For instance, Cevat ŞAHİN (2017) conducted field measurements in Istanbul and Izmir, identifying significant mismatches between real consumption and theoretical estimates used in internal wiring regulations [5]. Similarly, Yapicioğlu (2019) found that only 5.67% of buildings reached their calculated demand, suggesting a 33% potential cost reduction through optimized coincidence factors [6].

The increasing integration of renewables and electric vehicles (EVs) has necessitated a reevaluation of simultaneity assumptions. Several studies have examined networks integrating solar power and EV charging, emphasizing the importance of adjusted coincidence assumptions for reliable operation [7, 8]. In particular, recent research by Comech et al. (2024) demonstrated that rural EV integration with high simultaneity leads to undervoltage and overloading risks [9].

The integration of EV charging infrastructure into distribution systems necessitates strategic placement to avoid adverse impacts such as increased energy losses, reactive power burdens, and infrastructure overinvestment. By optimizing the deployment of fast charging stations and incorporating solar-based distributed generation, distribution networks can enhance self-sufficiency and reliability while minimizing power loss and economic strain [10].

Advanced analytics, including machine learning, have played a growing role in optimization. For instance, Kaya (2023) modeled coincidence behavior in Çankırı using artificial neural networks, providing more accurate representations of residential load patterns [11]. Bi et al. (2025) applied deep transfer reinforcement learning to enhance reactive power control, demonstrating the potential of intelligent algorithms for real-time grid optimization [12].

AI-driven optimization techniques, such as those employing genetic algorithms, have shown notable effectiveness in enhancing the operational efficiency of distribution networks by strategically allocating distributed resources like BESS, EV charging stations, and DG units. This optimization led to significant reductions in active energy losses and improved voltage profiles, validating the importance of data-driven, location-specific planning strategies in modern distribution systems [13].

Furthermore, numerous studies have focused on demand forecasting and EV charging infrastructure planning using machine learning approaches [14, 15]. A comprehensive review by Raza and Khosravi (2015) highlighted the effectiveness of AI-driven demand estimation techniques in improving grid efficiency and supporting smarter energy management strategies [16].

The integration of deep learning algorithms such as LSTM into energy consumption forecasting has proven to significantly enhance prediction accuracy, especially for short-term household demand. These data-driven models enable smarter grid management and support the formulation of optimized energy usage and infrastructure planning strategies, minimizing unnecessary overengineering in distribution systems [17].

Further advancements in network planning tools have significantly contributed to long-term forecasting and investment strategies. Kazemzadeh, Amjadian, and Amraee (2020) proposed a hybrid load forecasting methodology that effectively predicted Iran's annual peak load and energy demand with improved accuracy [18]. In Turkey, Tor et al. (2018) developed a dynamic investment planning algorithm for medium-voltage (MV) distribution networks, which was successfully tested in pilot regions under the Akdeniz EDAŞ utility [19]. Complementing these efforts, Konar (2021) emphasized the necessity of grounding distribution project designs in real-time demand measurements, advocating for more data-driven infrastructure planning to replace generalized assumptions [20].

Rural electrification remains a critical area of focus in energy planning. Several studies have addressed challenges such as loss prevention, renewable integration, and infrastructure expansion in rural settings. Aksu (2019), Özkök (2015), and Türk (2009) explored strategies for minimizing technical losses and examined the feasibility of integrating photovoltaic (PV) systems into rural grids [21–23]. Building on this, Güneş (2019) and Şimşek, Gani, and Şekkeli (2019) conducted transformer capacity analyses using real-world parameters; including power factor and load diversity; thereby enhancing the accuracy of rural distribution system design [24, 25].

In parallel, infrastructure cost minimization has emerged as a key concern. Pekiner (1993) applied nonlinear optimization techniques to reduce the capital costs of urban cable systems [26]. Further contributions by Akbulut (2019) and Gönen, Ten, and Mehrizi-Sani (2024) emphasized how strategic planning decisions influence both technical losses and investment outcomes [27, 28]. Additionally, Daylak (2016) investigated the use of voltage regulators and distributed generation sources in reducing losses through multi-objective optimization methods, offering a robust framework for cost-effective network enhancement [29].

Beyond conventional distribution planning, recent research has explored distributed control systems in microgrids. The integration of deep neural networks into distributed control strategies significantly enhances the performance of microgrids by enabling real-time predictions of power demand and generation. This predictive capability ensures dynamic power distribution, maintains voltage and frequency within acceptable limits, and reduces reliance on conventional communication infrastructure, ultimately fostering more adaptive and resilient energy systems [30].

In summary, while the reviewed literature provides a solid foundation for understanding the value of coincidence factors, most prior research either targets internal building installations or narrow technical dimensions. This study expands upon those efforts by using empirical data from Zonguldak Province and simulation tools like bPRO-EDŞ to optimize coincidence factors across both urban and rural networks, offering a scalable, practice-oriented methodology.

III. METHODOLOGY

The methodology of this study was designed to investigate the optimization of coincidence factors in electricity distribution networks through a comprehensive technical and spatial analysis. Zonguldak Province was selected as the pilot region due to its diverse demographic and infrastructural characteristics. The study relied on detailed field data from both urban and rural zones, and simulations were performed using professional engineering software to assess technical and economic impacts.

A. Study Area and Data Collection

Zonguldak, located in northwestern Turkey, includes both urban centers and rural settlements, making it a representative case for understanding regional variations in electricity consumption behavior. The dataset comprised:

- Urban network data: 433 buildings in 32 transformer zones, totaling 4054 residences.
- Rural network data: 1368 residences in 22 transformer zones.

These 64 transformer zones represented the electricity usage habits of nearly 16 000 people. Data were collected through collaboration with the regional distribution authority, ensuring both spatial diversity and statistical validity. Identifiable data such as subscriber numbers or transformer IDs were removed in accordance with data privacy policies. The focus remained entirely on technical values such as contracted capacity and measured peak demand.

Fig. 1 illustrates the geographic distribution of the data collection points across Zonguldak. The selected sites reflect a balance between coastal, mountainous, and interior regions to ensure representativeness.

To strengthen the robustness of the analysis, the dataset used in this study offers substantial representativeness across geographic, demographic, and infrastructural dimensions. The inclusion of 5422 residential units spanning 64 transformer zones ensures a statistically meaningful sample that captures both densely populated urban centers and sparsely distributed rural settlements. This diversity reflects actual load behavior across varying socio-economic contexts. The data were sourced directly from the regional electricity distribution company, ensuring a high degree of authenticity and technical accuracy. As such, the dataset not only meets statistical reliability thresholds but also enhances the generalizability of the study's conclusions to other provinces with similar characteristics.

B. Analytical Approach and Software Tools

The analysis proceeded under two modeling assumptions:

1. Scenario 1: Full simultaneity—assuming all loads operate concurrently (coincidence factor = 1).
2. Scenario 2: Realistic operation—applying optimized coincidence factors derived from actual field measurements.

The following steps were undertaken:

- Contracted and peak demand powers were calculated for each building.
- Diversity indices were determined at building, transformer, and district levels.
- Preliminary analysis and statistical modeling were performed using Microsoft Excel.
- Final technical evaluations were conducted using the bPRO-EDŞ software, a nationally recognized engineering platform for designing and analyzing distribution networks.

This dual-scenario analysis enabled comparison between conventional and optimized planning methods.

Although the bPRO-EDŞ software offers a robust framework for distribution network design and evaluation, it has certain limitations. Specifically, the tool is primarily oriented toward static load analysis and does not dynamically model load variations or include certain emerging load types such as EV charging patterns or responsive demand-side behaviors. While this constraint does not affect the validity of the current comparative analysis, it suggests that future studies could benefit from integrating more dynamic simulation platforms to capture broader behavioral nuances. bPRO-EDŞ was selected for this study due to its compliance with national standards,

Fig. 1. Data collection regions.

local utility adoption, and proven accuracy in thermal and voltage constraint evaluations.

C. Factors Influencing Demand Growth

Understanding future demand is critical for defining robust coincidence factors. The analysis took into account foreseeable changes in energy usage habits, categorized as follows:

Positive Drivers of Increased Demand:

- Rising adoption of EVs with home charging infrastructure.
- Shift from conventional heating to heat pumps.
- Increased air conditioning use due to climate variability.
- Proliferation of energy-intensive home appliances.

Negative Drivers Reducing Demand:

- Widespread use of energy-efficient LED lighting.
- Integration of rooftop PV systems, reducing grid dependency.
- Deployment of smart home automation for demand-side management.

These elements were modeled into the estimation of future demand scenarios, especially for urban areas where a 50% increase in average residential energy use is projected by 2050.

IV. TECHNICAL ANALYSIS AND SCENARIO-BASED COST COMPARISONS

This section evaluates technical and cost outcomes from applying the optimized coincidence factors versus the traditional 100% simultaneity assumption. Using bPRO-EDŞ simulations, side-by-side comparisons were conducted for representative cases in both urban and rural settings.

A. Urban Network: Simulation and Cost Evaluation

In the base case scenario assuming full simultaneity (coincidence factor = 1.0), the urban network was modeled with oversized cable profiles to meet theoretical maximum load conditions. The thermal loading analysis (Fig. 2) reveals that large cable cross-sections (e.g., $3 \times 240 + 120$ mm^2) are required to maintain safe operating temperatures. This not only increases material costs but also complicates installation due to additional weight and rigidity.

Subsequently, the low-voltage (LV) drop analysis (Fig. 3) demonstrates that, while the oversized infrastructure meets voltage regulations, the design efficiency is low. Voltage levels remain within permissible limits, but only at the expense of significantly overdimensioned infrastructure.

The cost implications of this design approach are presented in Table I, which outlines the quantities, unit prices, and installation costs of the required materials. The total estimated cost of 665 633.63 TL highlights the financial burden associated with conventional design assumptions.

In contrast, the optimized scenario applied an empirically derived coincidence factor of 0.60, reflecting actual simultaneity behavior in multi-unit buildings. Fig. 4 presents the updated thermal analysis, which confirms that smaller conductors (e.g., $3 \times 120 + 70$ mm^2) adequately handle thermal constraints, maintaining performance within safe margins.

Voltage drop values for the optimized case are visualized in Fig. 5. Despite the downsized cable profiles, all voltage values remain well within regulatory thresholds (e.g., <5% for LV feeders), affirming the technical sufficiency of the refined design.

The revised single-line diagram, shown in Fig. 6, illustrates the streamlined configuration enabled by the optimized coincidence

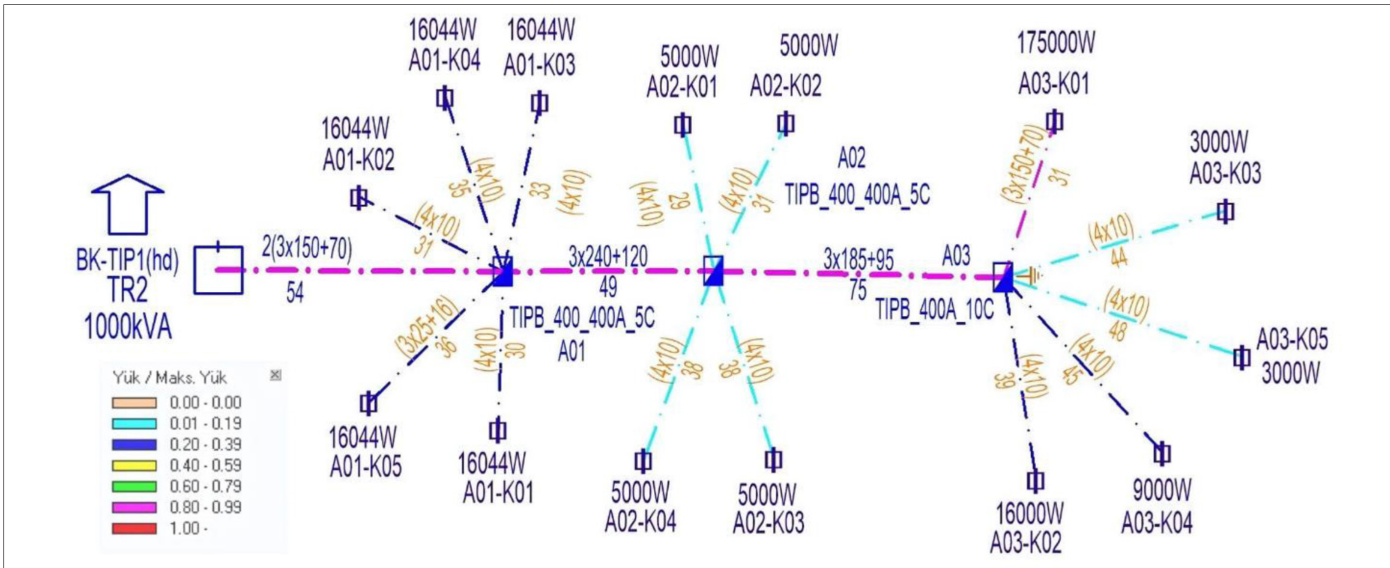

Fig. 2. LV cable thermal analysis for the urban area without applying the coincidence factor (bPRO EDŞ output).

factors. Table II provides the updated bill of materials and associated costs, amounting to 375 347.48 TL. This represents a cost reduction of 43.6%—a significant economic gain without compromising network integrity.

B. Rural Network: Simulation and Cost Evaluation

The rural case study, conducted in the Devrek district, followed a similar dual-scenario evaluation approach. Fig. 7 and 8 show thermal and voltage oversizing under the 100% coincidence assumption, similar to the urban scenario.

The corresponding cost summary is detailed in Table III, where the total project cost under this assumption was calculated as 161 950.39 TL.

When redesigned with an optimized coincidence factor (approximately 0.60), the thermal and voltage conditions shown in Fig. 9 and 10; remained well within engineering limits, even with smaller conductor profiles.

Table IV outlines the revised material and installation costs under this optimized design, totaling 110 732.89 TL. This equates to a cost savings of more than 31.6%, reinforcing the financial and technical benefits of data-driven planning in rural contexts.

These results underscore the value of localized optimization and provide compelling justification for updating distribution planning standards.

C. Synthesis and Broader Implications

The findings from both urban and rural simulations affirm the central thesis of this study: that adopting regionally optimized coincidence factors, grounded in empirical field data, yields significant

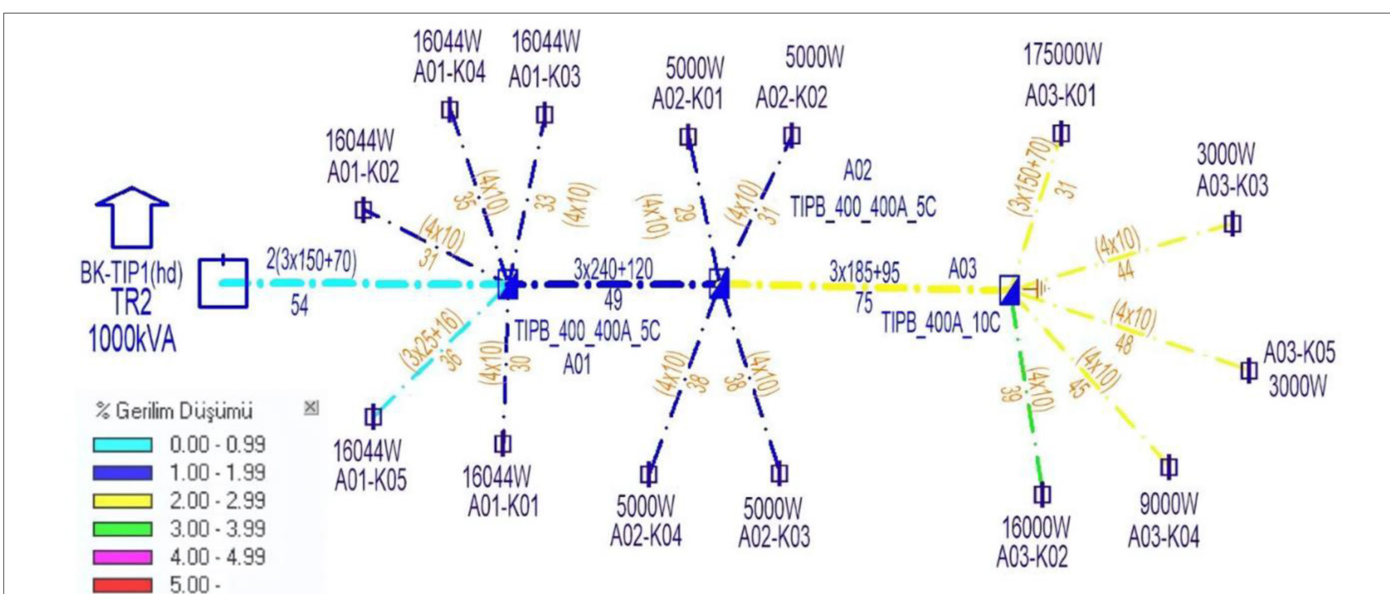

Fig. 3. LV cable voltage drop analysis for the urban area without applying the coincidence factor (bPRO EDŞ output).

TABLE I. COST ESTIMATION FOR THE URBAN AREA WITHOUT APPLYING THE COINCIDENCE FACTOR (BASED ON BPRO EDŞ ANALYSIS)

Item No	Type of Material	Unit	Quantity	Material Unit Price (TL)	Material Amount (TL)	Installation Unit Price (TL)	Installation Amount (TL)	Total Amount (TL)
Cost Estimation								
30.2.1	2 m galvanized grounding rod (65 × 65 × 7 mm)	Piece	1.00	₺688.33	₺688.33	₺653.83	₺653.83	₺1.342.16
32.12.080	3 × 150 + 70 mm² 0.6/1 kV YVV (NYY) cable with screened neutral	Metre	2.00	₺2237.03	₺4474.06	₺137.75	₺275.50	₺4749.56
32.12.081	3 × 185 + 95 mm² 0.6/1 kV YVV (NYY) cable with screened neutral	Metre	2.00	₺2750.39	₺5500.78	₺153.34	₺306.68	₺5807.46
32.12.082	3 × 240 + 120 mm² 0.6/1 kV YVV (NYY) cable with screened neutral	Metre	2.00	₺3599.65	₺7199.30	₺176.98	₺353.96	₺7553.26
32.16.007	1 × 50 mm² 0.6/1 kV YVV (NYY) screened cable	Metre	20.00	₺209.17	₺4183.40	₺59.33	₺1186.60	₺5370.00
32.16.080	3 × 150 + 70 mm² 0.6/1 kV YVV (NYY) cable with screened neutral	Metre	108.00	₺2237.03	₺241 599.24	₺115.10	₺12 430.80	₺254 030.04
32.16.081	3 × 185 + 95 mm² 0.6/1 kV YVV (NYY) cable with screened neutral	Metre	73.00	₺2750.39	₺200 778.47	₺130.92	₺9557.16	₺210 335.63
32.16.082	3 × 240 + 120 mm² 0.6/1 kV YVV (NYY) cable with screened neutral	Metre	47.00	₺3599.65	₺169 183.55	₺154.51	₺7261.97	₺176 445.52
					₺633 607.13		**₺32 026.50**	**₺665 633.63**

improvements in both technical reliability and cost efficiency within electricity distribution networks.

In the urban context, where residential clusters tend to exhibit diversified usage patterns, the application of a standard 1.0 coincidence factor led to substantial overdesign. This manifested in the form of oversized cables, increased installation complexity, and inflated project costs. In contrast, the use of optimized factors, such as 0.60 for clusters of 3–6 buildings, enabled the selection of more suitable cable cross-sections without compromising voltage stability or thermal safety.

The rural case reinforced similar conclusions, albeit under different usage dynamics. Here, consumption profiles are shaped by seasonal demands and specific agricultural activities. By aggregating demand at the village level, the study derived tailored coincidence factors that aligned more accurately with actual load behavior. These adjustments resulted in up to 31.6% cost savings while maintaining full technical compliance.

Collectively, these simulations underscore the economic and operational inefficiencies embedded in traditional, static design

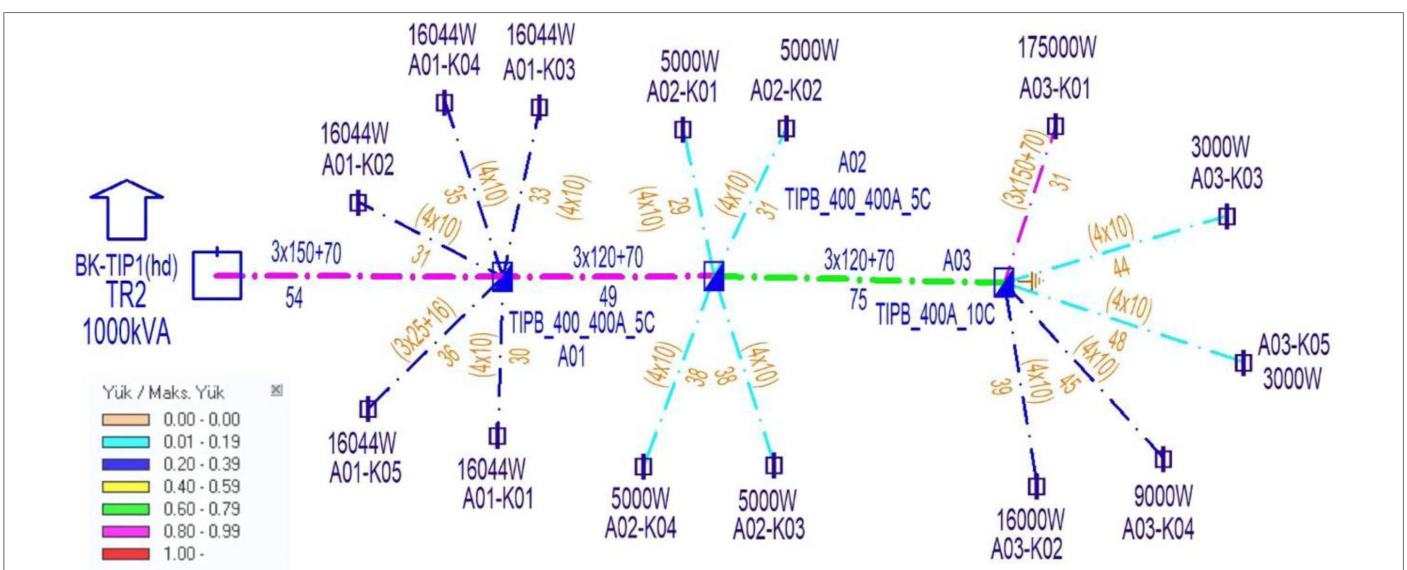

Fig. 4. LV cable thermal analysis for the urban area with a 60% coincidence factor applied (bPRO EDŞ output).

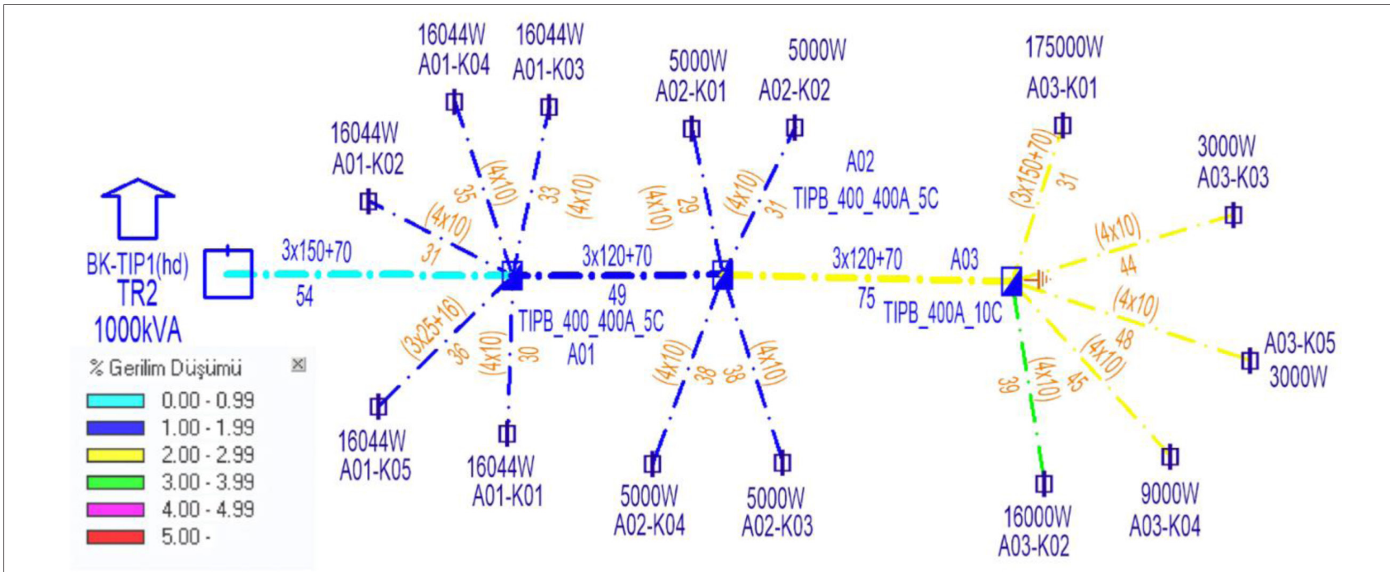

Fig. 5. LV cable voltage drop analysis for the urban area with a 60% coincidence factor applied (bPRO EDŞ output).

methodologies. The study demonstrates how tools such as bPRO-EDŞ, when coupled with real consumption data, enable a paradigm shift toward more rational and adaptive infrastructure planning.

In light of future demand growth, driven by trends such as electrification of transport, climate-responsive appliances, and smart energy systems, these results highlight an urgent need to institutionalize localized coincidence factor modeling as part of national grid planning policies. This approach not only supports long-term infrastructure sustainability but also contributes to optimizing public investment in energy systems.

V. RESULTS AND DISCUSSION

A. Urban Network Findings and Interpretation

Across eight districts in Zonguldak revealed significant discrepancies between contracted and actual demand values. As illustrated in Table V, the total contracted power across 433 buildings was 26 654.86 kWh, while the recorded peak demand was only 10 222.06 kWh, yielding an average coincidence factor of 0.38. This finding underscores a prevalent overdesign in conventional network planning, where assumptions of full simultaneity are not aligned with actual user behavior.

Fig. 11 visualizes the district-based demand-to-contracted ratios. Districts such as Kilimli and Çaycuma exhibit especially low demand utilization—well below 30%—suggesting that their infrastructures may be significantly oversized. In contrast, Kilimli, with a relatively higher coincidence factor of 0.57, still falls short of justifying a 1.0 factor, thus reinforcing the inefficacy of a uniform design assumption.

Fig. 12 presents transformer-level comparisons, highlighting that many transformers operate at less than 40% of their capacity. This transformer-level granularity affirms that the inefficiencies are not confined to district averages but persist across specific local infrastructures.

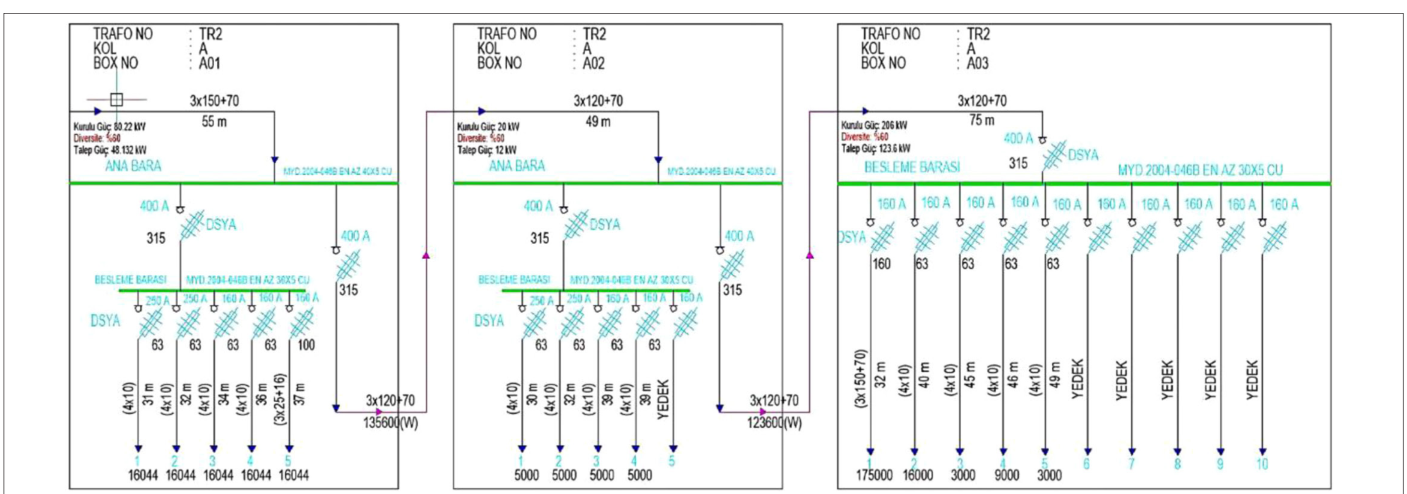

Fig. 6. Single-line diagram of the field distribution box (generated via bPRO EDŞ).

TABLE II. COST ESTIMATION FOR THE URBAN AREA WITH A 60% COINCIDENCE FACTOR APPLIED (BASED ON BPRO EDŞ ANALYSIS)

Item No	Type of Material	Unit	Quantity	Material Unit Price (TL)	Material Amount (TL)	Installation Unit Price (TL)	Installation Amount (TL)	Total Amount (TL)
Cost Estimation								
30.2.1	2 m galvanized grounding rod (65 × 65 × 7 mm)	Piece	1.00	688.33	688.33	653.83	653.83	1342.16
32.12.079	3 × 120 + 70 mm² 0.6/1 kV YVV (NYY) cable with screened neutral	Metre	4.00	1823.28	7293.12	128.00	512.00	7805.12
32.12.080	3 × 150 + 70 mm² 0.6/1 kV YVV (NYY) cable with screened neutral	Metre	1.00	2237.03	2237.03	137.75	137.75	2374.78
32.16.007	1 × 50 mm² 0.6/1 kV YVV (NYY) screened cable	Metre	20.00	209.17	4183.40	59.33	1186.60	5370.00
32.16.079	3 × 120 + 70 mm² 0.6/1 kV YVV (NYY) cable with screened neutral	Metre	120.00	1823.28	218 793.60	105.39	12 646.80	231 440.40
32.16.080	3 × 150 + 70 mm² 0.6/1 kV YVV (NYY) cable with screened neutral	Metre	54.00	2237.03	120 799.62	115.10	6215.40	127 015.02
					353 995.10		**21 352.38**	**375 347.48**

Further investigation into simultaneity across building clusters is illustrated in Fig. 13. The X-axis represents the number of residential units connected to each transformer zone. The left Y-axis shows the total contracted power (blue bars) and actual measured demand (orange bars) in kilowatts (kW). The right Y-axis (gray line) indicates the calculated diversity factor (demand/contracted). The figure illustrates how diversity improves as the number of units increases, supporting the use of adjusted coincidence factors in planning.

Table VI synthesizes these observations into a set of recommended coincidence factors, suggesting: 0.55 for 2–3 buildings, 0.60 for 4–6 buildings, and 0.75 for 7 or more. These refined coefficients allow for a more rational allocation of conductor sizes and protective devices in new designs, without compromising operational reliability.

Fig. 14 presents the total contracted power and actual peak demand (bars) as a function of the number of buildings served per transformer zone (X-axis). The gray line shows the resulting diversity factor, indicating the degree to which actual demand deviates from contracted capacity. Higher building counts correlate with greater diversity, justifying more efficient system design through tailored coincidence factors. As the number of buildings increases, the observed simultaneity factor stabilizes, especially beyond seven units. This suggests a reduction in peak simultaneity due to diversified consumption behaviors across larger building clusters.

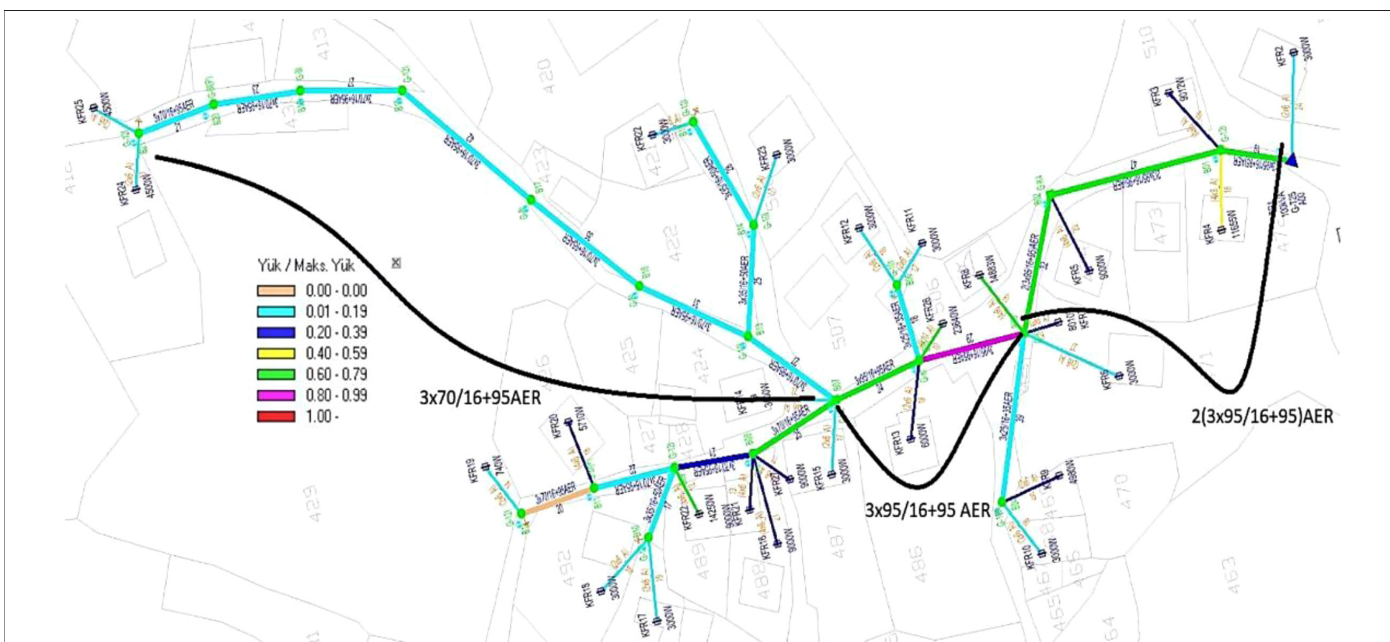

Fig. 7. LV cable thermal analysis for the rural network without applying the coincidence factor (bPRO EDŞ output).

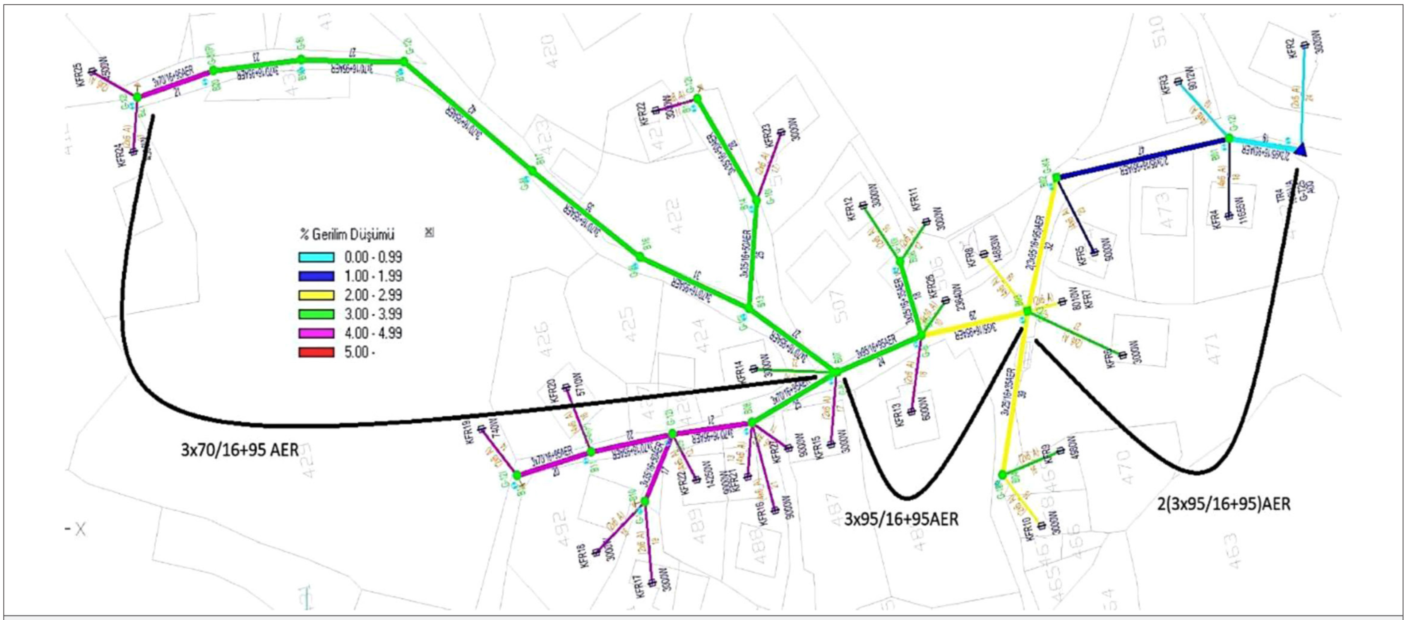

Fig. 8. LV cable voltage drop analysis for the rural network without applying the coincidence factor (bPRO EDŞ output).

Additionally, the figure integrates projected increases in urban energy demand, estimated at 50% by 2050, highlighting the necessity of forward-looking planning. These insights support the implementation of scalable and future-resilient coincidence coefficients, aligned with both present consumption realities and anticipated technological adoption.

B. Rural Network Findings and Interpretation

The rural electricity distribution network analysis revealed distinct consumption patterns that diverge significantly from urban behaviors. This divergence stems primarily from the influence of agricultural and livestock activities, seasonal demand shifts, and the typically lower density of household appliances. Instead of assessing individual residential units, the rural evaluation focused on aggregated data at the village level to better reflect actual field conditions and network topology.

Table VII reveals notable district-level disparities between contracted and actual demand, confirming the necessity of location-specific modeling over uniform assumptions. For instance, the Ereğli and Gökçebey regions demonstrate relatively high coincidence factors (above 0.70), which are likely attributable to intensive farming operations and denser village structures. In contrast, Kilimli and Devrek display much lower coincidence ratios (around 0.35 to 0.45), suggesting that applying a fixed factor of 1.0 across all rural areas would misrepresent actual load profiles.

Fig. 15 graphically illustrates the variation in coincidence factors by district. This visual reinforces the inconsistencies in applying universal coefficients and highlights the danger of overdesign. The graph shows how transformer loads in low-demand districts significantly lag behind their contracted capacity, signaling excess investment in materials and infrastructure that do not align with field realities.

This observation is further confirmed in Fig. 16, which compares transformer contracted capacities with recorded peak demands. Across the sampled regions, no transformer reaches full utilization. Many operate at or below 50% of their rated capacity. Such widespread underuse supports the conclusion that the assumption of

TABLE III. COST ESTIMATION FOR THE RURAL NETWORK WITHOUT APPLYING THE COINCIDENCE FACTOR (BASED ON BPRO EDŞ ANALYSIS)

Item No	Type of Material	Unit	Quantity	Material Unit Price (TL)	Material Amount (TL)	Installation Unit Price (TL)	Installation Amount (TL)	Total Amount (TL)
Cost Estimation								
9.5.0.15	3 × 25/16 + 35 mm^2 (0.460 kg/m) Alpek cable	Metre	57.00	₺78.18	₺4456.26	₺40.96	₺2334.72	₺6790.98
9.5.0.16	3 × 35/16 + 50 mm^2 (0.620 kg/m) Alpek cable	Metre	70.00	₺95.01	₺6650.70	₺47.74	₺3341.80	₺9992.50
9.5.0.18	3 × 70/16 + 95 mm^2 (1.060 kg/m) Alpek cable	Metre	294.00	₺175.40	₺51 567.60	₺66.46	₺19 539.24	₺71 106.84
9.5.0.24	3 × 95/16 + 95 mm^2 (1.410 kg/m) Alpek cable	Metre	249.00	₺239.32	₺59 590.68	₺58.11	₺14 469.39	₺74 060.07
					₺122 265.24		**₺39 685.15**	**₺161 950.39**

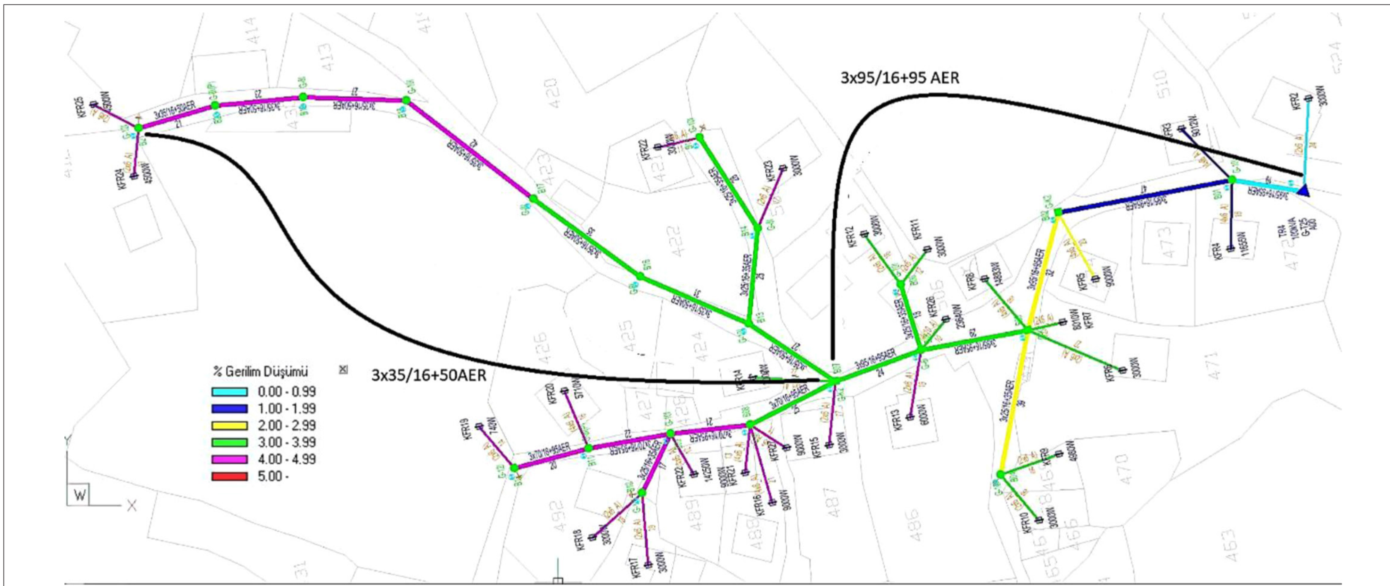

Fig. 9. LV cable voltage drop analysis for the rural network with the coincidence factor applied (bPRO EDŞ output).

100% simultaneity in rural design is neither technically justified nor economically viable.

To mitigate this issue, Table VIII proposes optimized coincidence factors for each district. These values were derived based on current consumption trends, complemented by a forward-looking projection of a 10% increase in rural electricity demand due to gradual modernization. For example, while Ereğli maintains a recommended factor of 0.85, Kilimli is set at 0.60, reflecting the stark difference in load behavior.

These refinements are not only cost-effective but also enhance the realism and adaptability of network design. By aligning planning parameters with on-ground realities, utilities can avoid excessive infrastructure deployment while maintaining high reliability.

Special planning considerations are reserved for high-demand installations, such as collective farms or large-scale irrigation systems, where near-simultaneous equipment operation is common. For such cases, the coincidence factor remains fixed at 1.0 to ensure adequate capacity and operational safety.

Overall, the rural findings strongly reinforce the necessity of abandoning uniform assumptions in favor of empirical, data-driven planning. When applied systematically, such an approach yields substantial infrastructure savings while safeguarding technical standards, offering a scalable model for broader implementation across rural regions nationally.

The recommended coincidence factors presented in Table VI and Table VIII were empirically derived based on actual consumption data

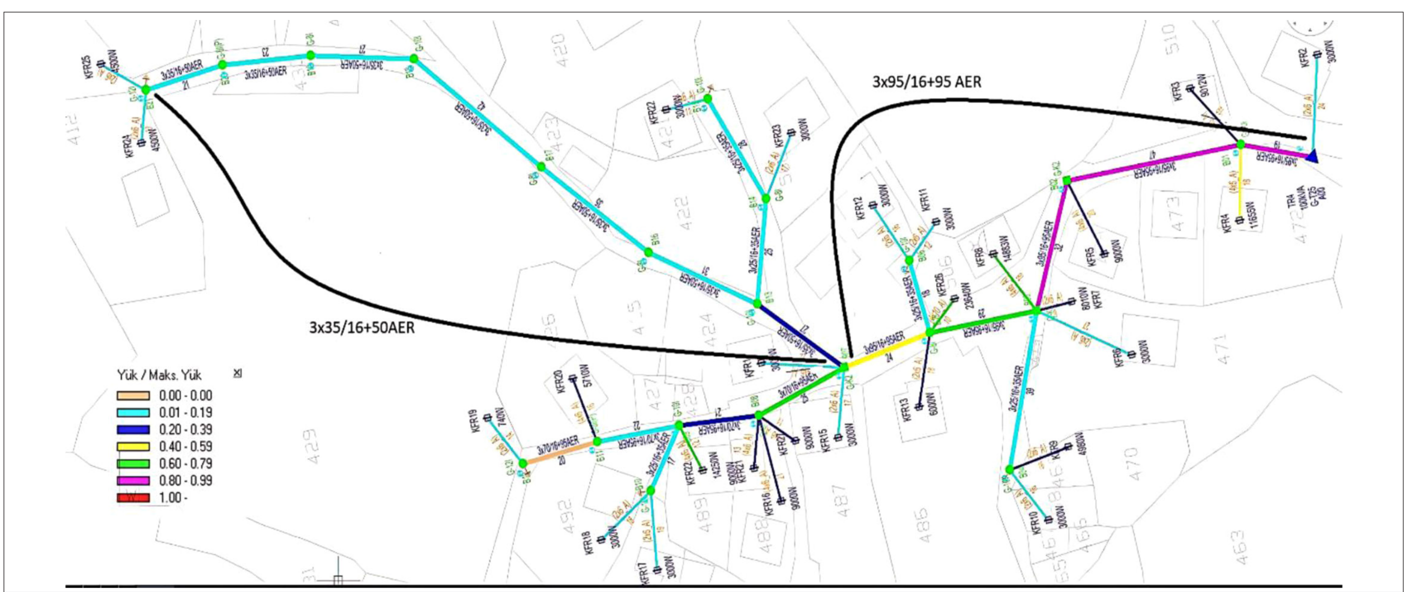

Fig. 10. LV cable thermal analysis for the rural network with the coincidence factor applied (bPRO EDŞ output).

TABLE IV. COST ESTIMATION FOR THE RURAL NETWORK WITH A 60% COINCIDENCE FACTOR APPLIED (BASED ON BPRO EDŞ ANALYSIS)

Item No	Type of Material	Unit	Quantity	Material Unit Price (TL)	Material Amount (TL)	Installation Unit Price (TL)	Installation Amount (TL)	Total Amount (TL)
Cost Estimation								
9.5.0.15	3 × 25/16 + 35 mm² (0.460 kg/m) Alpek cable	Metre	127.00	₺78.18	₺9928.86	₺40.96	₺5201.92	₺15130.78
9.5.0.16	3 × 35/16 + 50 mm² (0.620 kg/m) Alpek cable	Metre	206.00	₺95.01	₺19 572.06	₺47.74	₺9834.44	₺29 406.50
9.5.0.18	3 × 70/16 + 95 mm² (1.060 kg/m) Alpek cable	Metre	88.00	₺175.40	₺15 435.20	₺66.46	₺5848.48	₺21 283.68
9.5.0.24	3 × 95/16 + 95 mm² (1.410 kg/m) Alpek cable	Metre	151.00	₺239.32	₺36 137.32	₺58.11	₺8774.61	₺44 911.93
					₺81 073.44		**₺29 659.45**	**₺110 732.89**

TABLE V. DISTRICT-BASED COINCIDENCE FACTOR ANALYSIS

District	Contracted Power	Demand	Diversity, %
Alaplı	846.968	351.717	41.53
Çaycuma	7751.8842	3199.752	41.28
Devrek	1718.3524	583.591	33.96
Ereğli	2161.96	744.757	34.45
Gökçebey	5687.4772	2079.322	36.56
Kilimli	927.584	536.696	57.86
Kozlu	4550.0084	1578.309	34.69
Merkez	3010.6254	1147.917	38.13
Total	**26 654.8596**	**10 222.06**	**38.35**

collected from 64 transformer zones across urban and rural districts in Zonguldak Province. For each zone, the peak measured demand was compared to the contracted capacity, and coincidence ratios were computed accordingly. These ratios were statistically averaged across clusters of buildings (grouped by number of consumers per distribution box) to yield representative values. Seasonal variations and projected future increases in residential electricity use, due to electrification trends, were also factored into the final recommendations. While the bPRO-EDŞ software does not calculate coincidence factors automatically, the derived values were externally computed and manually input to simulate realistic planning conditions.

C. Recommendations for Future Research

While this study offers robust evidence on the benefits of empirically derived coincidence factors in distribution planning, several directions remain open for future exploration:

- **Regional Expansion**: Replicating this methodology across different provinces—particularly in regions with varying climate, socio-economic status, and consumption patterns—would allow for the creation of a national coincidence factor database. Such a database could support a regulatory framework that accommodates regional diversity.
- **Temporal Dynamics**: Future studies should investigate how coincidence factors vary over time (e.g., hourly, seasonally), particularly in rural areas with agricultural cycles and in urban zones influenced by heating/cooling demand.
- **Integration with Smart Grid Technologies**: Incorporating real-time metering and demand response systems into coincidence factor modeling could further enhance planning precision. These

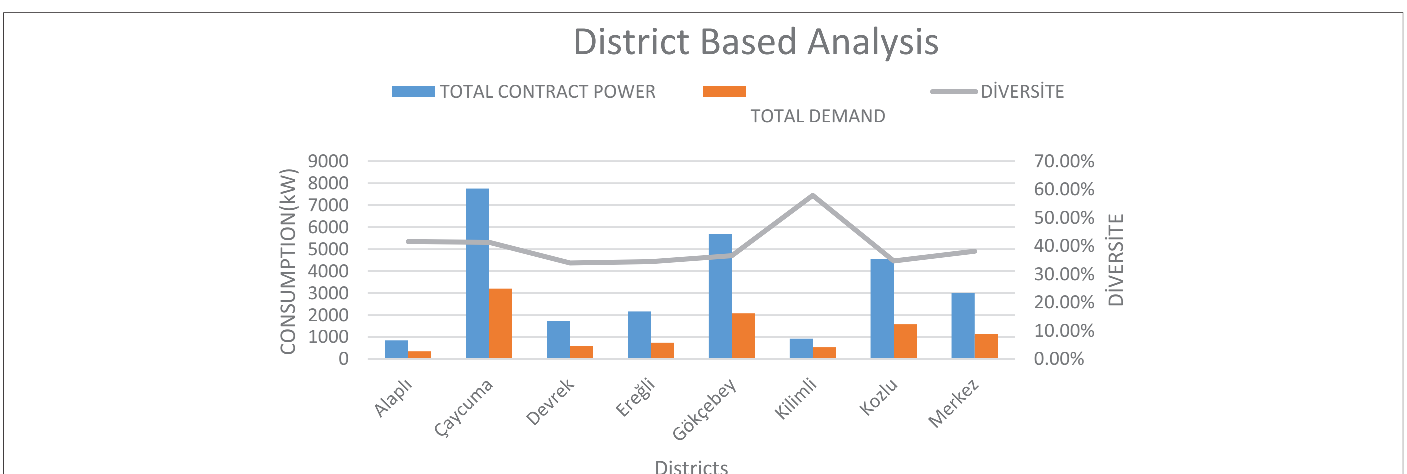

Fig. 11. District-based graphical representation of coincidence factors based on contracted and demand power.

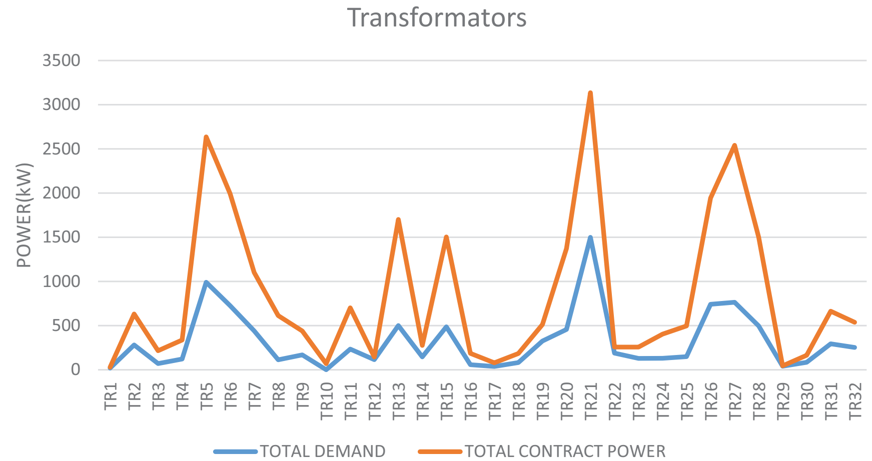

Fig. 12. Transformer-based graphical representation of contracted and demand power.

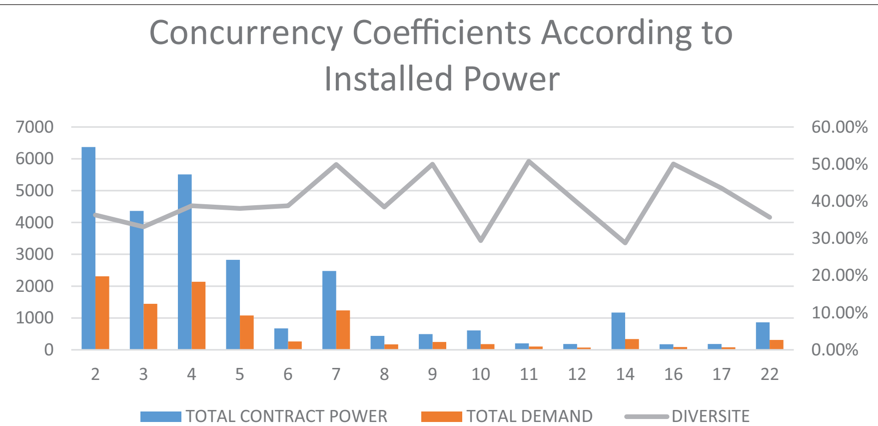

Fig. 13. Distribution of contracted and actual demand power across different transformer zones based on installed load.

systems may enable adaptive network control based on actual usage behavior.

- **Machine Learning Applications**: Leveraging AI and machine learning to predict future load patterns and derive dynamic coincidence factors could automate and improve the forecasting process, especially in fast-growing urban centers.
- **Policy and Standardization Impacts**: An in-depth evaluation of how national and international design standards may need to be revised to integrate empirical coincidence modeling would benefit regulatory bodies and infrastructure planners alike.

By addressing these areas, future research can further refine distribution network planning and contribute to a more resilient, efficient, and economically sustainable energy infrastructure.

VI. CONCLUSION

This study has demonstrated that conventional electricity distribution planning—based on the assumption of full simultaneity (coincidence factor = 1.0)—leads to systematic overdesign, inflated infrastructure requirements, and unnecessary capital expenditures. By analyzing real consumption data from 5422 residences across both urban and rural transformer zones in Zonguldak Province, empirically derived coincidence factors were proposed and applied through dual-scenario simulations using the bPRO-EDŞ software.

The results are conclusive: applying optimized coincidence factors that reflect local consumption behavior led to significant reductions in material costs—43.6% in urban and 31.6% in rural networks—while maintaining full compliance with thermal and voltage standards. These findings confirm that adapting coincidence factors to region-specific demand profiles not only preserves technical reliability but also unlocks considerable economic efficiencies.

Incorporating field-based coincidence factors into standard planning practices represents a vital step toward more sustainable, data-driven energy infrastructure. As future residential demand is expected to increase due to EVs, climate-responsive technologies, and modern living standards, dynamic planning approaches will become even more critical. It is therefore recommended that national

TABLE VI. RECOMMENDED COINCIDENCE FACTORS FOR URBAN ELECTRICITY NETWORKS IN ZONGULDAK PROVINCE

Number of Buildings	Coincidence Factors
2, 3	55%
4, 5, and 6	60%
7 and above	75%

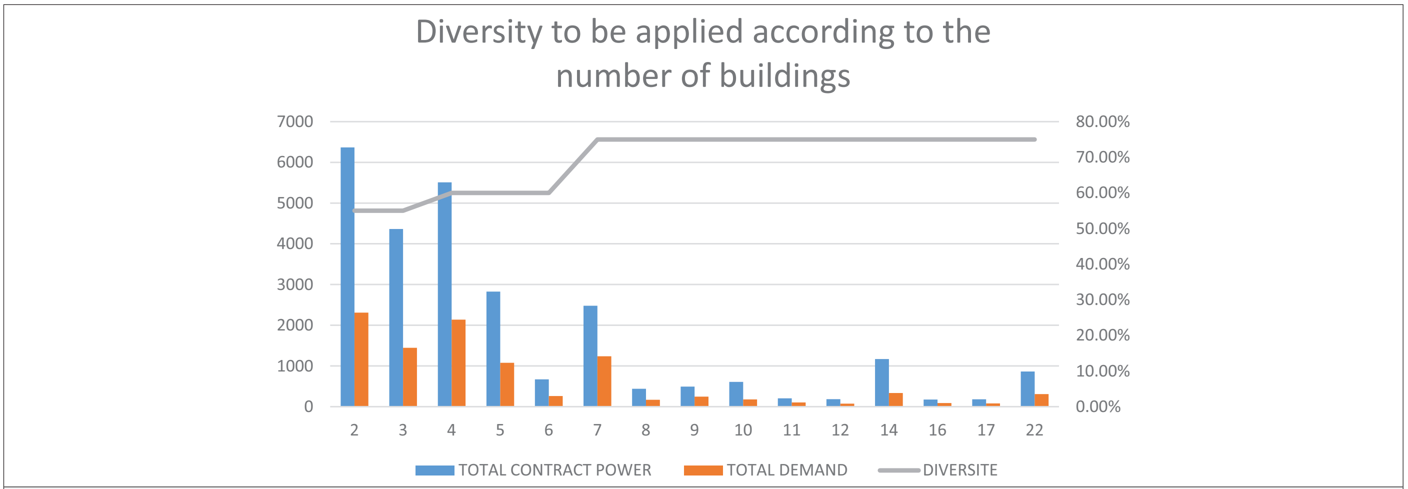

Fig. 14. Variation in demand diversity according to the number of connected buildings.

TABLE VII. DISTRICT-BASED COINCIDENCE FACTOR VALUES DETERMINED FROM RURAL AREA DATA IN ZONGULDAK PROVINCE

District	Contracted Power	Demand	Applied Coincidence Factor, %
Alaplı	2036.2922	880.838	43.26
Çaycuma	1013.2518	469.747	46.36
Devrek	692.254	308.024	44.50
Ereğli	832.8460006	620.573	74.51
Gökçebey	839.9996	622.99	74.17
Kilimli	590.99	207.044	35.03
Kozlu	1366.668	899.017	65.78
Central District	762.463	431.734	56.62

TABLE VIII. RECOMMENDED COINCIDENCE FACTOR VALUES FOR RURAL LOW-VOLTAGE (LV) DISTRIBUTION NETWORKS

District	Calculated Coincidence Factor, %	Recommended Coincidence Factor, %
ALAPLI	64.97	70
ÇAYCUMA	79.53	85
DEVREK	50.68	60
EREĞLİ	84.48	85
GÖKÇEBEY	83.96	85
KİLİMLİ	50.03	60
KOZLU	70.46	75
Central District	69.06	75

and regional energy authorities adopt localized coincidence modeling as a core planning principle, ensuring that grid expansion efforts align with real-world usage and long-term investment optimization.

To translate the study's insights into actionable energy planning practices, the following policy recommendations are proposed:

1. Mandate the use of region-specific coincidence factors in distribution network design standards, replacing the outdated 100% simultaneity assumption.
2. Encourage local electricity authorities to build and maintain real consumption datasets at the transformer zone level to enable data-driven planning.

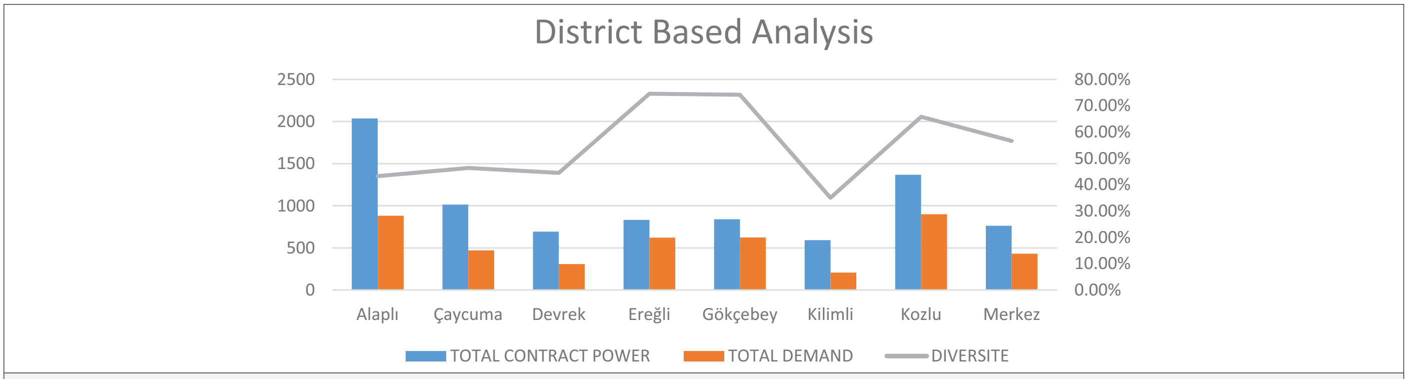

Fig. 15. District-based coincidence factor analysis for rural electricity networks.

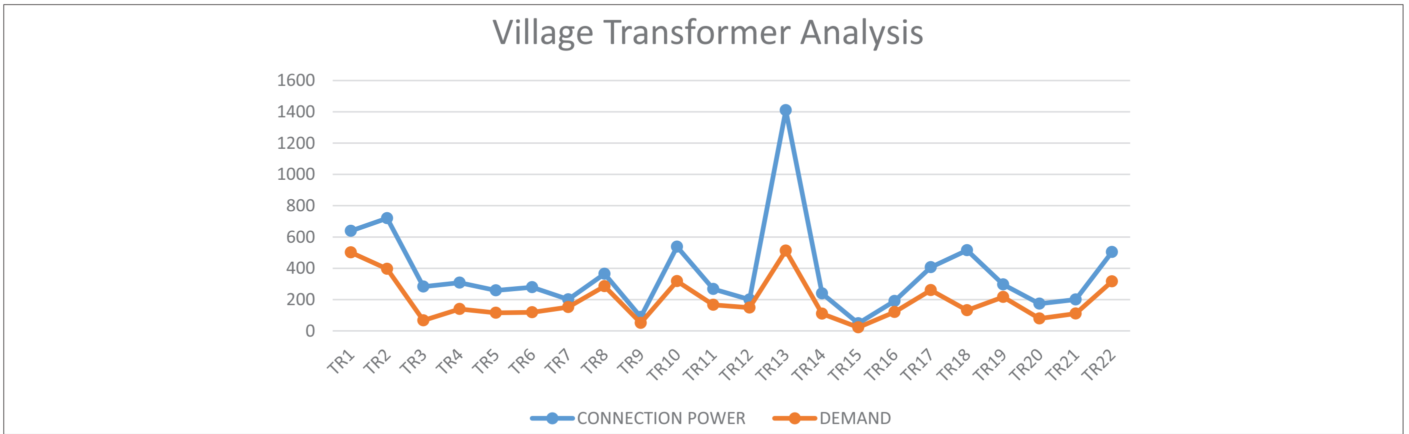

Fig. 16. Comparison of connection capacity and demand values of rural transformers.

3. Integrate coincidence factor optimization into national grid expansion policies, prioritizing cost-effective and resilient infrastructure development.
4. Update planning software used by engineering firms and utilities to accommodate variable coincidence factors as standard input parameters.
5. Promote pilot studies in other provinces to validate the replicability of this methodology and guide broader regulatory adoption.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – O.K., F.A.; Design – O.K., F.A.; Supervision – F.A.; Resources – O.K.; Materials – O.K.; Data Collection and/or Processing – O.K.; Analysis and/or Interpretation – O.K., F.A.; Literature Search – O.K.; Writing – O.K., F.A.; Critical Review – F.A.

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