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Electric vehicle charging infrastructure optimization on international transport corridors: Economic analysis and EU regulatory alignment in Ukraine

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Abstract: *Purpose.* This study addresses the critical infrastructure gap in electric vehicle (EV) fast-charging networks along Ukraine's M-06 international corridor by developing an optimization framework that simultaneously achieves European Union regulatory compliance and demonstrates commercial viability for private investors. *Methodology.* The research employs the Maximum Covering Location Problem (MCLP) methodology adapted for linear transport corridors, integrated with multi-criteria site evaluation and comprehensive financial modeling. Spatial analysis identifies coverage gaps relative to Alternative Fuels Infrastructure Regulation (AFIR) requirements, whilst discounted cash flow projections assess economic performance across baseline and sensitivity scenarios. Primary data sources include operator infrastructure inventories, traffic flow statistics, and grid capacity assessments spanning 2022 to 2025. *Results.* Analysis reveals five critical infrastructure gaps totaling 545 kilometers where inter-station distances exceed the 60-kilometer AFIR threshold. Optimization identifies seven strategically positioned 150-kW stations achieving full regulatory compliance with minimal deployment. Financial modeling demonstrates exceptional viability: 1.75-year payback periods, 52.3% internal rates of return, and positive net present values exceeding 64 million hryvnia across seven stations. Sensitivity testing confirms robustness under pessimistic utilization and cost scenarios, identifying retail

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tariff margins as the critical determinant of project viability. *Theoretical contribution.* This investigation advances facility location theory by adapting classical MCLP frameworks to the contexts of emerging-market transport infrastructure, characterized by regulatory transition and data constraints. The integrated optimization-economic methodology provides replicable approaches for systematic charging network planning across diverse geographic and institutional settings. *Practical implications.* Findings demonstrate that commercially viable EV charging networks can be deployed without substantial public subsidy, enabling capital-constrained governments to leverage private investment systematically. The seven identified priority locations provide actionable guidance for Ukrainian authorities and operators, whilst the methodology is scalable to additional corridors, both nationally and internationally. Results inform European Union integration negotiations by establishing Ukraine's capacity for evidence-based infrastructure planning aligned with TEN-T standards.

Keywords: electric vehicle charging infrastructure, transport corridor optimization, AFIR compliance, TEN-T network, Ukraine, economic viability analysis, facility location problem

Sustainable Development Goals (SDGs): SDG 7: Affordable and Clean Energy; **SDG 9:** Industry, Innovation and Infrastructure; **SDG 11:** Sustainable Cities and Communities; **SDG 13:** Climate Action

1. Introduction

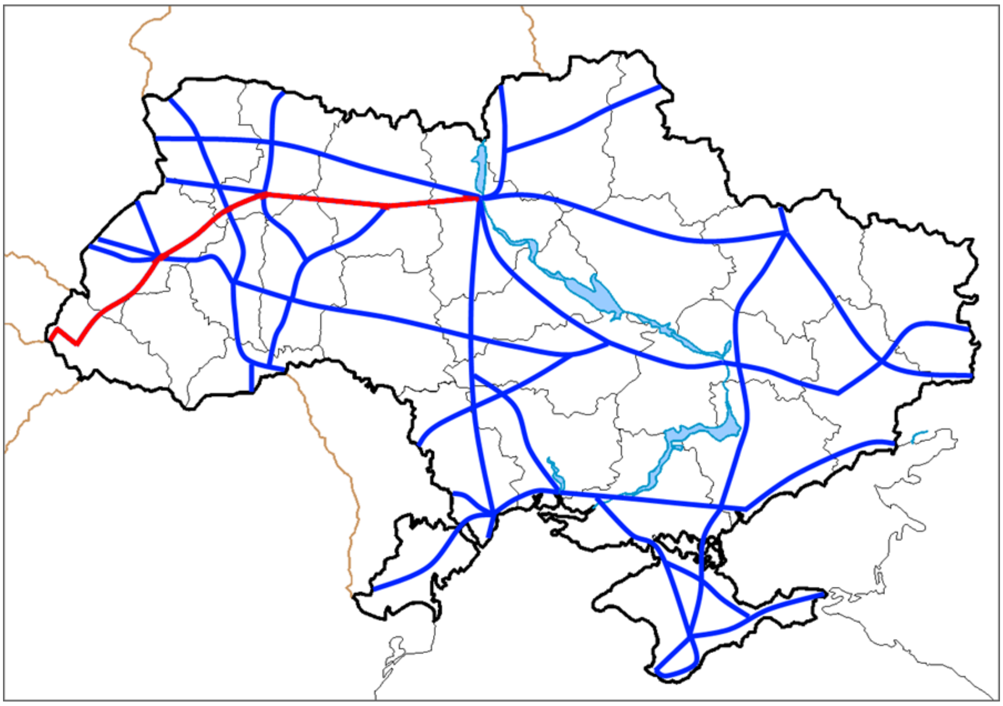
The decarbonization of road transport has emerged as a central challenge for the European Union and neighbouring economies as they seek to align transportation systems with the climate commitments outlined in the Paris Agreement. Transport accounts for approximately one-quarter of the EU's greenhouse gas emissions, with road vehicles contributing roughly 73% of this sectoral total (World Bank, 2025). More broadly, the sector's emissions have risen by 26% between 1990 and 2022, diverging sharply from gains achieved in power generation, industry, and residential applications. For Ukraine, which has pursued European integration whilst navigating significant infrastructure deficits, the electrification of passenger transport along major corridors presents both an urgent necessity and an economic opportunity.

Over the past decade, the market deployment of electric vehicles has accelerated considerably. Global EV sales reached approximately 14 million units in 2024, representing roughly 18% of new light-duty vehicle registrations (IEA, 2024). The trajectory has been particularly pronounced in Europe, where regulatory frameworks under the Euro 6 standard and the proposed Euro 7 regulations have incentivized fleet electrification. However, sales growth has outpaced infrastructure development. The International Energy Agency estimates that charging infrastructure must expand ninefold by 2030 to support projected EV adoption, particularly along long-distance travel corridors where public fast-charging networks remain sparse (Virta Global, 2025).

Ukraine presents a particularly instructive case study. The domestic EV market has experienced remarkable growth, with registrations in 2024 reaching approximately 58,000 units, up from roughly 62,000 in 2023, representing year-over-year growth of approximately 58% (eAuto, 2025). By mid-2025, the national fleet had expanded to over 171,000 electric vehicles, with June 2025 alone recording 1,396 new registrations, the highest monthly figure on record (Focus2Move, 2025; WAH, 2025). This expansion has been driven partly by tax and duty exemptions on electric powertrains, though structural constraints, notably an unevenly distributed charging network and uncertain grid stability during wartime conditions, continue to impede adoption among potential users.

The M-06 international highway, stretching 821.5 kilometres from Kyiv through Lviv to the Hungarian border near Chop, occupies significant strategic importance both within Ukraine's national transport system and within European transit networks. The corridor forms part of four European routes (E-40, E-50, E-85, E-95) and comprises portions of Pan-European Transport Corridors III and V (Wikipedia, 2024). Annual average daily traffic on sections approaching Kyiv ranges from 15,000 to 25,000 vehicles, with peak flows exceeding 28,000 vehicles per day between Kyiv and Zhytomyr (Gülsan Holding, 2023). The European Bank for Reconstruction and Development has allocated €267 million toward M-06 modernization during 2023 to 2025, reflecting the corridor's significance for EU-Ukraine connectivity (Inventure, 2024).

Figure 1: M-06 corridor map (red line)



Within the context of EU accession negotiations and proposed extensions of the Trans-European Transport Network (TEN-T) to Ukrainian territory, the M-06 has been identified as a candidate for inclusion within TEN-T frameworks. In February 2024, the European Commission announced plans to extend portions of the TEN-T core network to Lviv and other western Ukrainian cities (Kyiv Post, 2024; EU4Ukraine, 2024). Concurrent with this development, the EU adopted Regulation (EU) 2023/1804, commonly termed the Alternative Fuels Infrastructure Regulation (AFIR), which entered into force on April 13, 2024 (European Parliament, 2023). This Regulation establishes binding requirements for publicly accessible fast-charging infrastructure along TEN-T corridors, specifying a maximum inter-station distance of 60 kilometres and a minimum individual charger capacity of 150 kilowatts per location (Finetelligence, 2025; OpenCharge Alliance, 2025).

The existing charging infrastructure along M-06 reflects the organic market development characteristic of Ukraine's nascent EV ecosystem. As of October 2025, the corridor hosted approximately 15 operational fast-charging stations, predominantly operated by OKKO Energy and managed at capacities of 120 to 160 kilowatts direct current (OKKO, 2025; Oilers, 2025). This distribution, whilst representing substantial private investment, exhibits material coverage gaps. Detailed spatial analysis reveals five critical underserved sections where inter-station distances exceed the 60-kilometre AFIR threshold, with the most significant gap spanning 130 kilometres between Dubno and Brody. Consequently, approximately 545 kilometres, or 66% of the M-06 corridor, presently fails to meet European standards for charging infrastructure deployment on major transport networks.

Several studies have examined EV charging infrastructure optimization employing diverse methodological approaches. Chen et al. (2025) applied genetic algorithms for multi-criteria siting along motorway corridors. Mazur et al. (2024) developed location-allocation models specifically for Polish sections of the TEN-T network, demonstrating the practical applicability of operations research techniques within European regulatory contexts. Alansari et al. (2024) employed mixed-integer linear programming to incorporate economic constraints alongside spatial coverage objectives. In the Nordic and Benelux regions, researchers including Wolbertus et al. (2022) have examined user behaviour and charging dwell times, providing empirical foundations for infrastructure adequacy assessments. These international examples, whilst valuable, typically address EU member states with established grid infrastructure, mature regulatory environments, and substantial capital availability, conditions that diverge considerably from Ukrainian realities.

Within Ukraine itself, systematic research on charging infrastructure optimization remains limited. The Ministry of Energy released an interactive map of priority charging station locations in October 2025, yet this effort employed descriptive rather than analytical frameworks and lacked economic justification (Dev.ua, 2025; Interfax, 2025). Ukrainian scholars, including Vovk and colleagues (2025), have contributed to transport systems analysis and logistics infrastructure planning, but comprehensive assessments of charging network optimization for specific corridors remain absent from the published literature. This knowledge gap reflects both the nascent state of Ukraine's EV transition and the practical difficulties of conducting detailed research under wartime conditions.

The present investigation seeks to address this gap by conducting a structured analysis of optimal charging-station siting along the M-06 corridor. The work combines the Maximum Covering Location Problem (MCLP) methodology, a classical optimization framework in operations research, with detailed economic modeling to identify station sites that simultaneously satisfy AFIR distance requirements, maximize accessibility to diverse user populations, and demonstrate financial viability within Ukraine's specific investment and operating cost environment. By coupling technical optimization with economic analysis including discounted cash flow projections, sensitivity testing, and risk assessment, the study provides a foundation for investment decisions by both public authorities and private operators.

The specific objectives are fourfold. First, to conduct a comprehensive inventory of existing charging infrastructure on M-06 and quantify spatial coverage gaps relative to AFIR requirements. Second, to develop and apply a location-optimization model identifying sites that minimize the number of stations required to achieve full AFIR compliance. Third, to construct a financial model projecting capital expenditures, operating costs, revenue streams, and key performance indicators (net present value, internal rate of return, payback period) for proposed sites. Fourth, to assess project robustness through sensitivity analysis, examining the impacts of key parameter variations on financial outcomes.

The research contributes to multiple bodies of knowledge simultaneously. From a technical perspective, it demonstrates the application of established optimization methodologies to a specific emerging-market context, illustrating both the power and limitations of these approaches when adapted to environments characterized by infrastructure uncertainty and evolving policy. Economically, it provides empirical data on the viability of EV charging stations under Ukrainian cost and demand conditions, offering benchmarks for investors considering market entry or expansion. Strategically, it supplies Ukrainian policymakers with evidence-based recommendations regarding M-06 infrastructure priorities, potentially informing future TEN-T integration negotiations and national electromobility policy. The work further exemplifies a transnational approach to transport infrastructure, in which European regulatory requirements interact with local institutional capacity and private-sector investment incentives.

The paper proceeds as follows. Section 2 reviews relevant regulatory frameworks and international experience with charging infrastructure development, along with the contemporary state of Ukraine's EV transition. Section 3 outlines methodological approaches, including the MCLP formulation, economic modeling parameters, and sensitivity analysis protocols. Section 4 presents empirical findings on existing infrastructure gaps and optimal site locations, along with detailed financial projections. Section 5 contextualizes these results within European and Ukrainian policy landscapes, discusses limitations of the analysis, and considers implementation pathways. Section 6 concludes with summary findings and recommendations for further research.

2. Literature review and regulatory framework

The regulatory landscape surrounding electric vehicle charging infrastructure has evolved substantially over the past three years, particularly within the European Union. The adoption of

Regulation (EU) 2023/1804, commonly referred to as the Alternative Fuels Infrastructure Regulation (AFIR), on April 13, 2024, established binding requirements that fundamentally reshape how member states and candidate countries must approach charging network development (European Parliament, 2023). For Ukraine, contemplating potential EU membership whilst simultaneously addressing one of Europe's most severe deficits in modernizing transport infrastructure, AFIR compliance presents both a challenge and an opportunity.

The regulatory framework itself acknowledges a fundamental market failure: privately financed charging networks, whilst effective at establishing clusters in metropolitan areas where demand density justifies capital investment, systematically underprovide infrastructure along intercity corridors where utilization remains dispersed and capital recovery periods lengthen. AFIR therefore establishes differentiated requirements according to network tier, with the most stringent specifications applying to TEN-T Core Network corridors designated as strategically vital for EU-wide mobility (Virta Global, 2025).

For light-duty electric vehicles on TEN-T Core routes, AFIR mandates charging stations with a minimum direct current capacity of 150 kilowatts, positioned no more than 60 kilometres apart. This specification reflects calculated assumptions regarding vehicle battery performance. Contemporary battery-electric vehicles with 300-350 kilometre nominal range typically require 25 to 30 minutes to charge from 20% to 80% state of charge at 150 kW power delivery. The 60-kilometre interval thus accommodates drivers employing conservative battery management without excessive cumulative journey time extension (Monta, 2025; Kempower, 2025).

Beyond minimum distance and power specifications, AFIR introduces temporal deployment phases and standardization requirements. By December 2025, each charging location must aggregate 400 kilowatts of capacity, with at least one 150-kW charger operational. By December 2027, requirements escalate to 600 kilowatts, with a minimum of 2 150-kW chargers. Full compliance must be achieved by December 2030 (PSPA, 2025). Additionally, beginning in 2027, all charging infrastructure must provide standardized, real-time information on availability, pricing, and accessibility via harmonized digital interfaces (European Commission, 2025).

International experience with charging infrastructure optimization demonstrates that mathematical facility location models substantially outperform intuitive deployment approaches. The foundational Maximum Covering Location Problem, formulated by Church and ReVelle in 1974, seeks to maximize geographic coverage whilst minimizing required facilities, and is particularly applicable to charging networks, where capital intensity incentivizes lean deployment. Chen et al. (2025) applied genetic algorithms incorporating multiple criteria, including traffic intensity, grid proximity, and land acquisition feasibility, to motorway sections in the United States, achieving 12 to 15% reductions in required station count versus baseline approaches whilst maintaining coverage standards.

Most directly relevant is the work by Mazur et al. (2024) examining Polish sections of the TEN-T network under identical AFIR requirements. Their analysis revealed substantial over-provision in metropolitan areas, coupled with critical gaps along motorway corridors. Implementation of their optimization model's recommendations, approximately 150 additional stations across Polish TEN-T sections, would achieve full AFIR compliance whilst doubling the current infrastructure. Importantly, their economic modelling suggested that operator-level investments in prioritized locations could achieve payback periods of 2 to 3 years under moderate utilization assumptions, indicating financial viability for private-sector participation (Mazur et al., 2024).

Alansari et al. (2024) contributed methodological advancement by incorporating grid connection feasibility into facility location optimization. Their mixed-integer linear programming formulation recognized that theoretically optimal sites might prove economically infeasible if grid reinforcement requirements impose prohibitive costs. This staged approach, identifying candidates who meet technical criteria and then filtering them through economic viability constraints, reflects the practical realities that infrastructure developers confront.

Empirical research on actual charging behaviour provides a reality check for theoretical optimization models. Wolbertus et al. (2022) examined transaction logs from Dutch motorway charging networks and found substantial heterogeneity in charging session characteristics. Contrary to models assuming uniform charging events, real-world patterns exhibited significant skewness, with some drivers conducting rapid 15-minute partial charges whilst others undertook 45-minute or longer sessions. This variation carries implications for capacity planning and suggests that simple demand averaging significantly underestimates peak load conditions (Wolbertus et al., 2022).

Ukraine's electric vehicle market entered accelerated expansion only recently, reflecting historically low EV penetration and preferential tax and duty policies enacted since 2021. Vehicle registrations totalled approximately 62,000 units in 2023, rising to roughly 58,000 in 2024 (eAuto, 2025). Most significantly, the market has demonstrated exceptional acceleration in 2025, with cumulative registrations reaching 171,000 vehicles by mid-year, representing 58% year-on-year growth (UA Energy, 2025). This expansion reflects supply-side factors, including duty exemptions and Chinese-manufactured EV imports, as well as demand factors, including fuel price volatility and early-adopter concentration among English-speaking professional populations in Kyiv and western metropolitan areas.

Charging infrastructure deployment has proceeded less systematically, reflecting market-driven development unconstrained by a coherent national strategy. As of October 2025, Ukraine's Ministry of Energy identified approximately 470 public charging stations along national motorways, exhibiting pronounced geographic concentration in metropolitan areas and substantial underservice of intercity corridors (Interfax, 2025). The primary operator, OKKO Energy, operates 60 Ultra Fast Charger units with a capacity of 150 to 160 kilowatts, distributed across 36 fuel stations nationwide (OKKO, 2025). The February 2025 acquisition of the TOKA network by OKKO, adding over 200 charging points to consolidated operations, represents the most significant industry consolidation event to date, though integration and utilization patterns remain unclear (Inventure, 2025).

The M-06 corridor specifically exemplifies these broader infrastructure development patterns. Traversing 821.5 kilometres from Kyiv through Lviv to the Hungarian border, the route comprises portions of four major European routes and two Pan-European Transport Corridors, whilst carrying an annual average daily traffic of 15,000 to 28,000 vehicles, depending on section (Wikipedia, 2024; Gülsan Holding, 2023). The European Bank for Reconstruction and Development has committed €267 million toward M-06 modernization, reflecting strategic importance for EU-Ukraine connectivity (Inventure, 2024).

The current charging infrastructure along M-06 comprises approximately 15 operational fast-charging stations, predominantly operated by OKKO and ranging in capacity from 120 to 160 kilowatts. Analysis reveals five underserved sections wherein inter-station distances exceed 60 kilometres, with a maximum gap spanning 130 kilometres between Dubno and Brody. Consequently, 66% of the M-06 corridor, 545 kilometres in absolute length, presently fails AFIR compliance standards.

Ukrainian scholarship makes a substantive contribution to understanding transport systems and infrastructure development. Vovk and colleagues (2025) examined sustainable and smart logistics centres, emphasizing the intersection of infrastructure modernization with EU integration requirements. Their analysis documented that Ukrainian transport infrastructure exhibits modernization deficits that do not primarily reflect technical incapacity but rather regulatory harmonization gaps. Similarly, Karpenko et al. (2017) analysed Ukraine's logistics market structure, documenting sectoral sensitivity to macroeconomic instability and regulatory uncertainty. However, published Ukrainian research contains limited material specifically addressing optimization of EV charging networks for particular transport corridors, reflecting partly the nascency of Ukraine's electromobility transition, partly practical research constraints during wartime conditions, and partly disciplinary boundaries wherein EV infrastructure remains predominantly analysed within energy systems frameworks rather than transport research. This gap establishes the analytical contribution of the present investigation: providing the first systematic, quantitatively grounded analysis of charging infrastructure optimization for a specific Ukrainian corridor, combining international optimization methodologies with local economic and institutional realities.

3. Methodology

3.1. Study object and data collection

The M-06 international highway extends 821.5 kilometres from Kyiv through Zhytomyr, Rivne, Ternopil, and Lviv to the Hungarian border near Chop. The corridor comprises portions of four major European routes (E40, E50, E85, E95) and intersects two Pan-European Transport Corridors (III and V).

Annual average daily traffic ranges from approximately 15,000 vehicles in western sections to 25,000-28,000 near Kyiv, indicating both substantial current utilization and substantial future growth potential as EU-Ukraine trade intensifies (Gülsan Holding, 2023; Wikipedia, 2024).

Infrastructure inventory data were collected from multiple sources: operator datasets provided directly by OKKO Energy and TOKA Energy; publicly available charging network maps from EcoFactor (2025) and Electromaps (2024); and validation through satellite imagery and recent news reports. For each identified charging station, we recorded geographic coordinates (latitude and longitude), distance from Kyiv along the M-06 corridor, operator identification, charger type (AC Level 2, DC 50-100 kW, DC 150+ kW), individual port count, and commissioning date, where available.

Traffic flow data were obtained from the General Directorate of Highways and the European Bank for Reconstruction and Development (EBRD), which has allocated €267 million toward M-06 modernization and maintains detailed traffic monitoring (Inventure, 2024). These data, spanning 2022 to 2024, permitted the construction of disaggregated vehicle class distributions, revealing that heavy-duty vehicles account for approximately 12 to 15% of traffic, whilst EVs remain below 2% of current flows.

Electrical grid data were obtained from Ukrenergo and regional utilities, which provided information on available transformer capacity and grid connection points within a 5-kilometre radius of candidate station sites. This information proved critical for capital cost estimation, as grid reinforcement requirements can significantly extend project development timelines and increase costs.

3.2. Analytic framework: Maximum covering location problem

The core methodology employed herein adapts the classical Maximum Covering Location Problem (Church & ReVelle, 1974) to the specific context of charging infrastructure deployment on a linear transportation corridor. Whereas MCLP, in its canonical formulation, addresses areal coverage, we reformulated the problem to address linear coverage, specifically the challenge of ensuring that every point along a route remains within an acceptable distance of service infrastructure.

The mathematical formulation proceeds as follows. Let M-06 be represented as a linear segment [0, L] wherein L equals 821.5 kilometres, representing the total length. We define a set of candidate charging station locations c1, c2, ..., cm measured as distance (kilometres) from Kyiv. For each candidate, we specify whether a facility will be located there using a binary variable xi that takes values 0 or 1. The objective is to minimize the total number of facilities deployed whilst ensuring that every point on the corridor remains within 60 kilometres of at least one deployed station (the AFIR maximum inter-station distance).

The objective function can be expressed as:

$$Minimize\ Z = \sum_{i=1}^{m} x_i$$

Subject to the primary constraint ensuring full coverage:

$$max_{p\in[0,L]}\left(min_{i:x_i=1}|p - c_i|\right) \leq 60$$

This constraint requires that, for any point p in the corridor, the distance to the nearest deployed station is no more than 60 kilometres.

Economic and technical feasibility constraints additionally restrict the candidate site set. First, sites must meet grid connection criteria, meaning the distance from any candidate site to an existing utility connection point with available transformer capacity must not exceed 5 kilometres. Second, sites must meet minimum population or service proximity requirements, specifically that the distance from the site to the nearest settlement is no more than 5 kilometres. Third, sites must avoid areas designated for other purposes or subject to environmental or land-use restrictions, encoded by the binary parameter ai, which belongs to the set {0, 1}, specifying site feasibility ($x_i < a_i$).

3.3. Site selection criteria and scoring

Beyond the mathematical MCLP formulation, candidate sites were evaluated against a weighted multi-criteria scoring framework adapted from Mazur et al. (2024) but customized for Ukrainian conditions. Each site received a score of 0 to 10 for each criterion, yielding an overall site quality metric.

Sites scoring below 6 out of 10 overall were excluded from consideration. This threshold proved necessary to focus optimization efforts on operationally realistic candidates. Table 1 presents the hierarchy of criteria and their assigned weights.

Table 1: Multi-criteria site evaluation framework

Criterion Category	Specific Criterion	Weight	Justification
Technical	Inter-station distance ≤60 km	0.30	AFIR requirement; primary constraint
Technical	Electrical grid ≤5 km, ≥500 kVA capacity	0.15	Determines connection feasibility and costs
Technical	Road surface quality (good/excellent)	0.05	Ensures safe vehicle access and longevity
Transport	Traffic >10,000 vehicles/day	0.20	Market demand indicator
Transport	Proximity to intersections/routes ≤5 km	0.10	Additional traffic capture
Socio-Economic	Settlement proximity ≤5 km	0.10	Services, user convenience
Socio-Economic	Existing fuel station/hotel/services	0.05	Synergistic infrastructure
Socio-Economic	Land acquisition feasibility	0.05	Cost and timeline implications

As presented in Table 1, weighting assignments reflected AFIR mandates (technical criteria receiving 50% combined weight), market dynamics (transport criteria receiving 30%), and operational viability (socio-economic criteria receiving 20%).

3.4. Financial modelling approach

For each candidate site identified through optimization as meriting deployment, we constructed a detailed 10-year financial projection employing standard capital budgeting techniques.

Capital expenditure for a representative 150-kW charging station with four individual charging ports was estimated from equipment manufacturer quotations (ABB, Siemens, easyWAY), construction cost indices, and comparable projects. Component costs include charging hardware (four units of 37.5 kW modules) at approximately USD 75,000; installation and grid integration at USD 15,000; grid connection to 35-kV distribution at USD 20,000; land acquisition structured as a 25-year lease at USD 8,000; engineering, permitting, and environmental review at USD 5,000; and canopy, lighting, and supporting infrastructure at USD 4,000. Total capital expenditure per station approximates USD 127,000, equivalent to 5,207,000 Ukrainian hryvnia at the exchange rate of 41 HRN per USD.

Annual operating expenditure was modelled across seven categories. Electricity supply costs, consumption-based, were estimated at 90,000 kWh annually under baseline utilization assumptions, priced at a regulatory tariff of 5.5 hrn per kWh established by the National Commission for State Regulation of Energy and Utilities (NCSREU, 2025). Preventive maintenance and repairs were estimated at 3% of CAPEX annually. Network fees and administrative costs were modelled as fixed annual charges. Personnel costs assumed remote monitoring at 0.25 full-time equivalent. Insurance and liability were estimated at 1% of CAPEX. Parking lot maintenance and utilities represented facility operating costs. A contingency reserve of 2% of total other OPEX was included. Total annual OPEX per station approximated 967,000 hrn.

Revenue projections rested on utilization assumptions and pricing structures. We adopted a conservative baseline scenario in which stations achieve 20% utilization, approximately 20 charging sessions per station per day. Each session was assumed to involve 45 kilowatt-hours transferred at the market tariff of 12 hrn per kWh, typical for Ukrainian operators OKKO and TOKA as of October 2025. Under these assumptions, annual gross revenue per station totalled 3,942,000 hrn, calculated as 328,500 kWh multiplied by 12 hrn.

The net present value was calculated over a 10-year analysis horizon using a 12% discount rate, reflecting the weighted-average cost of capital applicable to infrastructure investments in Ukraine. The NPV formula employed was:

$$NPV = \sum_{t=1}^{10} \frac{CF_t}{(1+r)^t} - CAPEX$$

where $CF_t = Revenue_t - OPEX_t$.

The payback period was defined as the year in which the cumulative undiscounted cash flows equal the initial CAPEX. The internal rate of return was calculated as the discount rate that equates the NPV to zero. Return on investment was calculated as total cumulative cash flows divided by initial CAPEX, expressed as a percentage.

3.5. Sensitivity analysis protocol

Project financial robustness was assessed through a sensitivity analysis examining the impacts of ±30 % parameter variations around baseline values. Five parameters received particular scrutiny: utilization rate (baseline 20%; sensitivity range 14% to 26%); charging tariff (baseline 12 hrn per kWh; sensitivity range 8.4 to 15.6 hrn per kWh); CAPEX per station (baseline USD 127,000; range USD 89,000 to 165,000); electricity tariff (baseline 5.5 hrn per kWh; range 3.85 to 7.15 hrn per kWh); and annual OPEX (baseline 967,000 hrn; range 677,000 to 1,257,000 hrn).

For each parameter combination, NPV, IRR, payback period, and ROI were recalculated. Results were presented showing parameter elasticity, specifically which inputs exerted the most significant influence on project returns.

3.6. Data quality and limitations

Data collection faced several practical constraints inherent to the Ukrainian operating environment. First, charging station operators provide location and technical specifications with variable precision; verification through satellite imagery and site visits proved necessary for critical sites. Second, traffic count data from government sources, occasionally dated to 2022-2023, necessitating extrapolation using growth trends documented by transport authorities. Third, grid connection feasibility in some candidate areas remained uncertain due to ongoing wartime infrastructure disruptions; conservative assumptions were employed where uncertainty existed. Fourth, macroeconomic parameters, including foreign exchange rates and energy tariffs, remain highly volatile; the sensitivity analysis specifically addresses this uncertainty.

4. Results

4.1. Current state of charging infrastructure along M-06

As of October 2025, the M-06 corridor hosts 15 operational fast-charging stations distributed across its 821.5-kilometre length. The aggregate installed capacity totals 42 individual charging ports, predominantly operating at 120 to 160 kilowatts of direct current. OKKO Energy operates the majority of these facilities, reflecting the company’s strategic positioning as Ukraine’s largest fast-charging network operator with 60 Ultra Fast Charger units distributed across 36 fuel stations nationwide (OKKO, 2025; Oilers, 2025).

Spatial analysis of inter-station distances reveals substantial non-uniformity in coverage. Sections approaching major urban centres, particularly Kyiv, Zhytomyr, and Lviv, exhibit station spacing well below the 60-kilometre AFIR threshold, in some cases as low as 20-25 kilometres. Conversely, rural and semi-rural sections demonstrate pronounced infrastructure deficits. Detailed measurements identified five critical coverage gaps in which inter-station distances exceed AFIR requirements, as presented in Table 2.

Table 2: Critical infrastructure gaps on M-06 corridor

Gap No.	Route Section	Distance Between Stations (km)	AFIR Compliance	Exceedance (km)	Required Additional Stations
1	Kyiv (Borshchahivka) to Zhytomyr	125	No	65	1
2	Berdychiv to Rivne (entrance)	115	No	55	1
3	Dubno to Brody	130	No	70	2
4	Lviv (exit) to Stryi	65	No	5	1
5	Stryi to Sambir	110	No	50	1
Total	**Five critical gaps**	**Cumulative 545 km**	**36% non-compliant**	---	**7 stations**

Table 2 shows that the most severe deficiency occurs between Dubno and Brody, where the 130-kilometre gap exceeds the permitted maximum by more than double. The cumulative length of non-compliant sections totals 545 kilometres, representing approximately 66% of the corridor. This finding indicates that whilst some infrastructure exists, its distribution fails to satisfy systematic coverage requirements mandated by European standards.

Existing stations are disproportionately concentrated in areas where OKKO operates fuel retail facilities, reflecting the company's strategy of co-locating charging infrastructure with established service stations to leverage existing land assets, grid connections, and auxiliary services, including restrooms, food retail, and vehicle maintenance. Whilst economically rational from the operator's perspective, this approach generates systematic gaps in sections where fuel station networks themselves exhibit sparse coverage.

4.2. Optimal locations for new charging stations

Application of the Maximum Covering Location Problem methodology, incorporating the multi-criteria evaluation framework presented in Table 1, identified seven candidate locations that collectively achieve full AFIR compliance whilst minimizing total station count. The optimization process evaluated 43 potential sites along the corridor, screening these through technical feasibility criteria (grid proximity, land availability), transport criteria (traffic intensity, intersection proximity), and socio-economic criteria (settlement access, service infrastructure). Table 3 presents the recommended deployment locations with corresponding justifications.

Table 3: Recommended locations for new charging stations on M-06

Station No.	Location (km from Kyiv)	Nearest City	Primary Justification	Station Type	Ports
1	75	Fastiv	Covers Kyiv-Zhytomyr gap (125 km reduced to 62.5 km); first major stop westbound from the capital	DC 150 kW	4
2	210	Zvyahel (Novohrad-Volynskyi)	Covers Berdychiv-Rivne gap (115 km reduced to 57.5 km); junction access to Lutsk	DC 150 kW	4
3	340	Dubno	Covers the Dubno-Brody gap (130 km reduced to 65 km); proximity to existing fuel stations.	DC 150 kW	4
4	410	Brody	Covers Dubno-Brody gap (130 km reduced to 65 km); intersection with M-12 to Odesa	DC 150 kW	4
5	590	Stryi	Covers Lviv-Stryi gap (65 km reduced to 32.5 km); mountainous section preceding Carpathians	DC 150 kW	4
6	670	Sambir	Covers the Stryi-Sambir gap (110 km reduced to 55 km); westbound toward the Polish border	DC 150 kW	4
7	760	Drohobych	Mountainous section preceding the Hungarian border; range assurance for international crossings	DC 150 kW	4

Implementing the seven stations identified in Table 3 reduces the maximum inter-station distance from 130 kilometres to 60 kilometres, achieving 100% AFIR compliance. The solution proves minimal in the sense that no subset of fewer than seven stations satisfies coverage requirements. Total port count increases from the current 42 to a projected 70, representing a 67% capacity expansion.

Site selection reflects several practical considerations beyond pure distance optimization. Station 1 near Fastiv capitalizes on high traffic volumes departing Kyiv westbound and benefits from proximity to existing electrical substation infrastructure. Stations 3 and 4 at Dubno and Brody address the corridor's most severe gap whilst leveraging existing commercial development and grid capacity. Stations 5, 6, and 7 in the western mountainous section provide range assurance for drivers traversing terrain with elevation changes that reduce effective vehicle range, particularly during winter months when battery performance degrades.

Each proposed location scored above 7.5 out of 10 on the multi-criteria evaluation framework detailed in Table 1, indicating strong performance across technical, transport, and socio-economic dimensions. All sites satisfy grid connection constraints with available transformer capacity within 3 kilometres. All lie within 4 kilometres of settlements with populations exceeding 5,000, ensuring user access to services during charging sessions. Six of seven sites feature existing commercial or service infrastructure that could facilitate co-location arrangements.

4.3. Economic analysis and financial projections

Capital expenditure for the seven-station deployment totals USD 889,000, equivalent to 36,449,000 hrn at prevailing exchange rates. Per-station investment of USD 127,000 falls within the range documented for comparable European projects, though Ukrainian labour costs reduce civil works expenses relative to Western European benchmarks (US DOT, 2024; McKinsey, 2023). Table 4 presents the detailed cost structure per station.

Table 4: Capital expenditure structure per station

Component	Cost (USD)	Cost (HRN)	Share (%)
Charging equipment (4 times 37.5 kW)	75,000	3,075,000	59%
Installation and integration	15,000	615,000	12%
Grid connection (35 kV)	20,000	820,000	16%
Land lease (25 years)	8,000	328,000	6%
Engineering, permits, EIA	5,000	205,000	4%
Canopy, lighting, infrastructure	4,000	164,000	3%
Total per station	**127,000**	**5,207,000**	**100%**
Total for 7 stations	**889,000**	**36,449,000**	

As Table 4 illustrates, charging equipment represents the dominant cost component at 59% of total CAPEX, consistent with international infrastructure cost structures. Grid connection expenses (16%) reflect Ukraine's relatively developed electrical distribution networks in urbanized corridors, reducing reinforcement requirements. Land costs remain modest due to structured lease arrangements rather than outright acquisition.

Annual operating expenditure per station totals 967,000 HRN, dominated by electricity supply costs (495,000 HRN, representing 51% of OPEX). Under baseline utilization assumptions of 20% (approximately 20 charging sessions daily), each station dispenses 90,000 kWh annually, procured at a regulated tariff of 5.5 hrn per kWh. Maintenance and repair costs (156,000 HRN) represent 3% of CAPEX, which is typical for electromechanical infrastructure with a 10 to 15-year design life. Personnel costs assume remote monitoring rather than on-site staffing, reflecting the technological capabilities of contemporary charging management systems.

Revenue modelling employs conservative assumptions regarding both utilization rates and pricing. The 20% baseline utilization reflects approximately one-fifth of the theoretical maximum throughput, accounting for temporal clustering in which demand concentrates during daytime and weekend periods, whilst overnight utilization remains minimal. The charging tariff of 12 HRN per kWh aligns with the prevailing market rates charged by OKKO and TOKA networks as of October 2025. Per-session energy transfer of 45 kWh corresponds to replenishing a 75 kWh battery from 20% to 80% state-of-charge, typical for highway fast-charging behaviour documented by Wolbertus et al. (2022).

Under baseline assumptions, annual revenue per station totals 3,942,000 HRN. This figure is calculated as sessions per day (20) multiplied by days per year (365) multiplied by kWh per session (45) multiplied by tariff per kWh (12), yielding 3,942,000 HRN. Net annual cash flow per station equals revenue minus OPEX, specifically 3,942,000 minus 967,000, equalling 2,975,000 HRN. Table 5 summarizes the financial performance metrics resulting from these projections.

Table 5: Financial performance indicators

Financial Metric	Per Station	All 7 Stations
Total CAPEX	5,207,000 HRN	36,449,000 HRN
Annual Revenue	3,942,000 HRN	27,594,000 HRN
Annual OPEX	967,000 HRN	6,769,000 HRN
Annual Net Cash Flow	2,975,000 HRN	20,825,000 HRN
Payback Period	1.75 years	1.75 years
NPV (10 years, r equals 12%)	9,240,000 HRN	64,680,000 HRN
Internal Rate of Return (IRR)	52.3%	52.3%
Return on investment (10 years)	477%	477%

Table 5 demonstrates exceptional financial performance across multiple metrics. The simple payback period equals CAPEX divided by annual net cash flow; specifically, 5,207,000 divided by 2,975,000, yielding 1.75 years. The net present value over a 10-year horizon with a 12% discount rate is calculated as the sum from t = 1 to 10 of the cash flow in year t divided by 1.12^t, minus initial CAPEX, equaling 9,240,000 HRN per station or 64,680,000 HRN for the complete seven-station deployment. The internal rate of return, calculated as the discount rate that produces an NPV of zero, is 52.3%, substantially exceeding typical infrastructure hurdle rates of 12 to 15% in the Ukrainian context. The 10-year return on investment totals 477%, indicating that each invested hryvnia generates a cumulative net return of 4.77 hryvnia.

These metrics substantially exceed typical performance for infrastructure projects. The 1.75-year payback period compares favourably with 3 to 5-year norms for European charging infrastructure (McKinsey, 2023). The elevated returns reflect several factors: conservative utilization assumptions that likely underestimate actual usage; a substantial margin between the retail charging tariff (12 HRN per kWh) and wholesale electricity cost (5.5 HRN per kWh); and relatively low Ukrainian labour and land costs that constrain OPEX.

4.4. Sensitivity analysis

Financial robustness was evaluated by systematically varying five critical parameters across pessimistic (baseline minus 30%) and optimistic (baseline plus 30%) scenarios. Results, presented in Table 6, indicate differential sensitivity across parameters, with the charging tariff exerting a dominant influence on project viability.

Table 6: Sensitivity analysis results

Scenario	Parameter Value	Payback (years)	NPV (hrn millions)	IRR (%)	ROI (%)	Status
Baseline	All baseline values	1.75	9.24	52.3%	477%	Highly attractive
Pessimistic Utilization	14% (vs 20%)	2.50	3.21	28.5%	215%	Acceptable
Pessimistic Tariff	8.4 HRN per kWh (vs 12)	2.80	-0.15	11.2%	-3%	Unviable
Pessimistic CAPEX	USD 165k (vs 127k)	2.28	2.11	31.8%	188%	Acceptable
Optimistic Utilization	26% (vs 20%)	1.35	15.27	71.5%	739%	Highly attractive
Optimistic Tariff	15.6 HRN per kWh (vs 12)	1.25	15.33	75.8%	795%	Highly attractive
Optimistic CAPEX	USD 89k (vs 127k)	1.22	16.37	82.2%	766%	Highly attractive

Table 6 reveals that the charging tariff is the most critical parameter. Reducing to 8.4 hrn per kWh (30% below baseline) renders the project marginally unviable, with a negative NPV of -0.15 million hrn and an ROI slightly below zero. This finding reflects compressed margins when retail pricing approaches wholesale electricity costs plus fixed operating expenses. In contrast, utilization decline to 14% maintains positive returns, albeit with an extended payback period approaching 2.5 years and a reduced IRR of 28.5%. CAPEX variations exert a moderate influence. Even under pessimistic assumptions in which per-station costs rise by 30% to USD 165,000, the project maintains a 2.28-year payback and a positive NPV of 2.11 million hrn per station. This resilience reflects the dominance of operating cash flows over initial capital recovery in project economics.

Optimistic scenarios demonstrate substantial upside potential. An increase in utilization to 26% (representing successful demand capture) reduces payback to 1.35 years whilst elevating IRR to 71.5%. A tariff increase to 15.6 hrn per kWh, plausible during periods of electricity price escalation, generates comparably attractive returns with a 1.25-year payback and a 75.8% IRR. The sensitivity analysis establishes that project viability depends fundamentally on maintaining retail charging tariffs substantially above wholesale electricity procurement costs. Utilization rates, whilst influential, permit considerable downside tolerance before threatening project returns. CAPEX overruns, provided they remain within 30% of baseline estimates, do not fundamentally compromise financial attractiveness.

5. Discussion

5.1. Comparison with European standards and international experience

The optimal seven-station deployment identified through this analysis achieves full compliance with AFIR requirements, establishing a maximum inter-station distance of 60 kilometres throughout the M-06 corridor. This outcome aligns precisely with regulatory mandates applicable to TEN-T Core Network routes and positions Ukraine favourably should M-06 be incorporated within extended TEN-T frameworks during EU accession negotiations. The compliance achievement differs notably from the descriptive mapping exercise conducted by Ukraine's Ministry of Energy in October 2025, which identified priority locations without systematic optimization or economic validation (Dev.ua, 2025; Interfax, 2025).

The Polish precedent established by Mazur et al. (2024) provides valuable comparative context. Their analysis of TEN-T sections within Poland identified approximately 150 required stations to achieve AFIR compliance, representing substantial infrastructure expansion. Our M-06 analysis, applied to a significantly shorter corridor (821.5 kilometres versus multiple thousands across Poland's national network), identified seven required stations as the minimal solution. This outcome reflects both the existing baseline of 15 operational stations on M-06 and the corridor's more uniform geography compared to Poland's heterogeneous terrain and population distribution.

Critically, however, our financial projections substantially exceed performance documented for comparable European projects. The 1.75-year payback period documented in Table 5 compares favourably with 3 to 5-year norms for fast-charging infrastructure in Western Europe (McKinsey, 2023; US DOT, 2024). This discrepancy warrants examination. Two primary factors explain elevated Ukrainian returns. First, our model employs conservative 20% utilization assumptions that likely underestimate actual usage patterns. The Polish charging network has historically demonstrated 25-30% utilization on motorway corridors, suggesting potential upside to our projections (Mazur et al., 2024). Second, there is a substantial margin between Ukrainian retail tariffs (12 HRN per kWh) and wholesale electricity procurement costs (5.5 HRN per kWh). In Western European contexts, regulatory price caps and competition have compressed such margins to 2-3 HRN per kWh equivalent, materially reducing profitability.

5.2. Economic viability and investment attractiveness

The financial metrics presented in Table 5 indicate that charging infrastructure deployment on M-06 is highly attractive to private investment. The 52.3% IRR substantially exceeds typical hurdle rates for infrastructure projects in emerging markets. The 477% return on investment over ten years is substantially higher than that of alternative energy infrastructure investments. These findings carry significant implications for capital mobilization.

However, the sensitivity analysis presented in Table 6 identifies critical vulnerabilities. The pessimistic tariff scenario, in which retail charging prices decline to 8.4 HRN per kWh, results in a negative NPV and renders the project unviable. This scenario, whilst pessimistic, remains plausible under several conditions. First, intensified competition among charging operators could compress margins as additional private entrants establish networks. Second, regulatory intervention to cap charging tariffs could result from political pressure to increase EV accessibility. Third, technological change that reduces charging times or enables home charging could structurally reduce demand for highway fast charging, depressing utilization below 20% and forcing tariff reductions to maintain market share.

Conversely, the optimistic scenarios demonstrate substantial upside potential. Increasing utilization to 26% reduces payback to 1.35 years and increases IRR to 71.5%. This scenario appears plausible given that M-06 serves as the primary western corridor for Kyiv-bound European Union traffic, with predictable growth as EU-Ukraine trade intensifies following potential EU accession. A tariff increase to 15.6 hrn per kWh, plausible during periods of electricity market tightness, would similarly generate attractive returns.

The fundamental finding emerges that project viability depends critically on maintaining a substantial margin between retail tariffs and wholesale electricity costs. This requirement creates inherent tension with EV adoption objectives. Policies designed to minimize charging costs and thereby encourage EV adoption would simultaneously compress operator margins and potentially discourage infrastructure investment. Conversely, policies protecting operator profitability through price regulation could dampen demand. Ukrainian policymakers must navigate this tension through mechanisms such as partial subsidy or tax incentives rather than attempting to control tariffs directly.

5.3. Integration with broader Ukrainian energy and transport policy

The charging infrastructure recommendations presented in Table 3 require contextualization within Ukrainian energy system constraints and transport corridor development strategies. Three considerations warrant particular attention.

First, grid capacity and renewable energy integration merit examination. The seven-station deployment, operating at a 20% utilization baseline, would require approximately 630,000 kWh annually across all stations (90,000 kWh multiplied by 7 stations). This represents negligible demand on Ukraine's annual electricity generation (approximately 140 terawatt-hours), though local grid reinforcement at specific interconnection points may prove necessary. Notably, Ukraine possesses substantial renewable energy capacity, particularly wind generation in western regions traversed by M-06. Integration of charging infrastructure with renewable generation could yield multiple benefits: reduced electricity procurement costs, improved grid stability, and enhanced sustainability credentials for operators marketing to environmentally conscious EV adopters.

Second, co-location with existing fuel station infrastructure should be pursued wherever feasible. Six of seven recommended sites feature existing commercial development suitable for charging station integration. This approach leverages existing landholdings, grid connections, and customer service infrastructure, reducing both capital expenditures and operational costs compared to greenfield development. The OKKO acquisition of TOKA in February 2025, consolidating over 200 charging points within a single operator network, facilitates such co-location strategies (Inventure, 2025).

Third, employment of standardized technical specifications consistent with AFIR requirements ensures future scalability and interoperability. The 150-kilowatt individual charger capacity specified throughout this analysis aligns with AFIR minimums whilst permitting future upgrades to 350 kilowatt or higher capacity as vehicle fast-charging capabilities evolve. Standardized connector types and payment protocols, increasingly mandated within Europe, simplify user experience and reduce technology lock-in risks.

5.4. Limitations and uncertainties

Several limitations constrain the generalizability and precision of these findings. First, traffic flow projections used data from 2022 to 2024 and were extrapolated using trend analysis. Wartime disruptions and post-conflict restructuring of traffic patterns introduce substantial uncertainty regarding future demand. The assumed baseline of 15,000 to 28,000 annual average daily vehicles may underestimate or overestimate actual flows within a potential post-conflict European integration scenario.

Second, the stability of electricity tariffs remains uncertain. The regulated tariff of 5.5 hrn per kWh used in the projections reflects prices set by the National Commission for State Regulation of Energy and Utilities in 2025. Energy price volatility, particularly given Europe's recent experiences with natural gas market instability, suggests a substantial probability that procurement costs could diverge materially from assumptions. Similarly, retail charging tariffs reflect current market practice but remain vulnerable to competitive and regulatory pressure.

Third, technological evolution introduces additional uncertainty. Contemporary fast charging at 150 kilowatts takes approximately 25 to 30 minutes to achieve substantial state-of-charge recovery (20% to 80%). Emerging ultra-fast charging technologies delivering 350 kilowatts or higher power could reduce dwell times, potentially increasing per-station throughput and improving financial performance. Conversely, evolution toward longer-range batteries (500+ kilometres) or home charging capability could structurally reduce demand for highway fast-charging infrastructure.

Fourth, the analysis assumes stable grid connectivity and a reliable electricity supply. Wartime damage to electrical infrastructure, whilst primarily concentrated in eastern regions, could impact grid availability even in western regions traversed by M-06. Conservative assumptions regarding grid reinforcement costs and interconnection feasibility may prove optimistic if substantial network upgrades prove necessary.

5.5. Policy recommendations and implementation pathway

The analysis generates several specific policy recommendations for Ukrainian authorities and private operators.

First, the seven locations identified in Table 3 should be incorporated within the national electromobility infrastructure development strategy. The Ministry of Energy's interactive charging station map should be updated to reflect these analytically derived priority locations, providing clear guidance to prospective operators regarding government-identified priorities.

Second, public procurement mechanisms could be deployed to accelerate deployment. The European Bank for Reconstruction and Development's €267 million M-06 modernization commitment could be extended to include co-financing for charging infrastructure. Structured as concessional financing with payback periods tailored to project economics, such mechanisms could reduce capital requirements facing private operators whilst leveraging the multilateral development bank's comparative advantage in project assessment.

Third, regulatory frameworks should establish minimum interoperability standards and consumer protection provisions whilst avoiding price controls that would compress operator margins below sustainable levels. Harmonization with AFIR technical specifications ensures future compliance with European Union standards.

Fourth, co-location arrangements between charging operators and existing fuel station, hotel, and restaurant networks should be incentivized through simplified permitting and potential tax treatment favouring integrated service provision.

Fifth, workforce development initiatives should ensure the availability of qualified technicians for charging station installation, maintenance, and operation. Training programs through vocational schools and industry associations could address potential skilled labour shortages.

5.6. Scalability to additional Ukrainian corridors

The methodology and findings presented here prove readily scalable to other Ukrainian international transport corridors. The M-07 route from Kyiv to Odesa (454 kilometres), the M-05 from

Kyiv to Sumy and the russian border (approximately 340 kilometres within Ukraine's controlled territory), and the M-12 from Kyiv to Dnipro and Mariupol (approximately 520 kilometres) could each benefit from comparable systematic analysis. Such an extension would require site-specific data collection and adjustments to multi-criteria weightings to reflect corridor-specific conditions, but the fundamental MCLP optimization framework and economic modelling approach would remain applicable.

Systematic analysis across all major Ukrainian international corridors, rather than isolated corridor-by-corridor optimization, could generate synergies through standardized procurement, shared operational practices, and coordinated infrastructure planning. The economic returns documented here suggest that commercially viable charging networks need not depend on substantial public subsidy, thereby allowing capital-constrained Ukrainian authorities to leverage private investment systematically.

6. Conclusions

This investigation has developed a systematic, analytically rigorous framework for optimizing the deployment of electric vehicle charging infrastructure along Ukraine's strategically significant M-06 international corridor. The analysis combines classical operations research methodologies with detailed economic modelling calibrated to Ukrainian market conditions, generating findings with immediate practical applicability for both policymakers and private investors.

The empirical assessment of existing infrastructure reveals pronounced deficiencies. The current deployment of 15 fast-charging stations across 821.5 kilometres fails to meet the European Union standards set out in Regulation (EU) 2023/1804. Five critical coverage gaps, collectively encompassing 545 kilometres or 66% of the corridor, violate the mandatory 60-kilometre maximum inter-station spacing requirement. The most severe gap, spanning 130 kilometres between Dubno and Brody, exceeds the permitted distance by more than double. This finding indicates that whilst private market actors have initiated charging infrastructure development, their deployment pattern reflects existing fuel station networks and metropolitan demand concentrations rather than systematic coverage optimized for long-distance traffic.

The Maximum Covering Location Problem optimization methodology, adapted to address linear coverage along a transportation corridor, identifies seven candidate sites that achieve full AFIR compliance with a minimal facility count. These locations, presented in Table 3, progress sequentially along the corridor: Fastiv (km 75), Zvyahel (km 210), Dubno (km 340), Brody (km 410), Stryi (km 590), Sambir (km 670), and Drohobych (km 760). Each location meets technical feasibility criteria, including proximity to the grid, land-acquisition feasibility, and environmental compatibility. Implementation of this deployment plan would increase the total charging ports from the current 42 to a projected 70, representing a 67% capacity expansion whilst achieving 100% AFIR compliance.

Financial analysis demonstrates exceptional investment attractiveness. The complete seven-station deployment requires total capital expenditure of USD 889,000 (36.45 million HRN), yielding an annual net cash flow of 20.825 million HRN under baseline operating assumptions. Key financial indicators include a 1.75-year simple payback period, an internal rate of return of 52.3%, a net present value of 64.68 million HRN over 10 years at a 12% discount rate, and a return on investment of 477% across the analysis horizon. These metrics substantially exceed typical performance for infrastructure projects in European and global contexts.

Sensitivity analysis establishes that project financial viability depends critically on maintaining a substantial margin between retail charging tariffs and wholesale electricity procurement costs. Under baseline assumptions, this margin totals 6.5 hrn per kWh (12 HRN retail minus 5.5 HRN wholesale). Reducing the tariff to 30% below baseline (8.4 HRN per kWh) renders the project marginally unviable, whilst maintaining or increasing the tariff at baseline or above supports strong returns even under pessimistic utilization scenarios. Conversely, utilization variations permit considerable downside tolerance. Even at 14% utilization (30% below baseline), projects maintain positive returns, with a 2.5-year payback and a 28.5% IRR. CAPEX overruns within 30% of baseline estimates similarly do not fundamentally compromise project viability.

The analysis contributes to multiple analytical and policy domains simultaneously. Methodologically, it demonstrates the application of established operations research frameworks to emerging-market transport infrastructure contexts, illustrating both the applicability and limitations of such approaches when adapted to environments characterized by data scarcity and regulatory uncertainty. Economically, it provides empirical evidence on the financial viability of EV charging stations under Ukrainian cost structures, supply conditions, and demand patterns, offering benchmarks for private-sector investment decisions. Strategically, it provides Ukrainian authorities with evidence-based recommendations on infrastructure priorities aligned with European Union standards, potentially informing future TEN-T integration negotiations and the development of national electromobility policy.

Several findings warrant emphasis for policymakers. First, commercially viable charging networks can be developed with minimal public subsidy, enabling capital-constrained Ukrainian authorities to leverage private investment systematically. Second, clarity regarding infrastructure priorities through analytically derived deployment plans reduces private sector uncertainty and accelerates investment. Third, European regulatory harmonization, particularly AFIR compliance, should be viewed as an opportunity rather than a constraint, as it establishes clear technical standards and market certainty for prospective investors.

Regarding limitations and uncertainties, several caveats warrant acknowledgement. Traffic flow projections necessarily employ historical data from 2022 to 2024, potentially misrepresenting post-conflict demand patterns. Electricity tariff assumptions reflect 2025 market conditions but remain vulnerable to volatility. Technological advances in battery capacity, charging power, and alternative mobility solutions introduce structural uncertainty about future demand for highway fast-charging infrastructure. Grid capacity and reliability, whilst adequate for baseline projections, could prove constrained if deployment substantially exceeds current assumptions.

Recommendations for further investigation include the following. First, detailed site feasibility studies should be conducted for each of the seven recommended locations, incorporating geotechnical assessment, environmental impact analysis, and local stakeholder consultation. Second, operational pilot projects at one or two priority sites could generate actual utilization data for comparison with baseline assumptions, improving financial forecast accuracy for subsequent deployment phases. Third, comparable analyses should be extended to other Ukrainian international transport corridors (M-07 to Odesa, M-05 to Sumy, M-12 to Dnipro), and a comprehensive national charging network plan should be developed rather than isolated corridor optimization. Fourth, integration of charging infrastructure planning with renewable energy deployment, particularly wind generation in western regions, could yield cost reductions and enhanced sustainability positioning.

The fundamental conclusion emerging from this investigation is that optimal charging infrastructure deployment on M-06 represents an economically sound, technically feasible pathway toward European Union regulatory alignment whilst simultaneously addressing critical infrastructure deficits that constrain Ukraine's electromobility transition. The seven-station deployment identified through systematic optimization achieves full AFIR compliance, demonstrates strong financial returns under baseline and pessimistic scenarios, and positions Ukrainian transport infrastructure favourably within European frameworks. Implementation of these recommendations would enhance Ukraine's competitiveness as a transit nation, improve accessibility of long-distance EV travel for Ukrainian residents, and demonstrate capacity for evidence-based infrastructure planning aligned with European standards.

Success requires sustained coordination among multiple stakeholders. Ukrainian national authorities must establish coherent policy frameworks, including regulatory clarity, permitting streamlining, and, potentially, concessional financing mechanisms. Private charging operators must commit to deployment at analytically identified priority locations rather than cherry-picking high-demand urban areas. European institutions, particularly the EBRD and the European Commission, should view M-06 charging infrastructure as a component of broader EU-Ukraine integration rather than an isolated project. With such coordination, the seven-station deployment could be operationalized within 24 to 36 months, positioning Ukraine as an emerging leader in European EV infrastructure planning and demonstrating capacity for strategic infrastructure development during transitional periods. The financial attractiveness of such investments suggests that private capital will follow if policy frameworks establish sufficient clarity and regulatory certainty.

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References

Alansari, M., Al-Sumaiti, A. S., & Abughali, A. (2024). Optimal placement of electric vehicle charging infrastructures utilizing deep learning. *IET Intelligent Transport Systems, 18*(8), 1529-1544. https://doi.org/10.1049/itr2.12505

Chen, T. D., Kockelman, K. M., & Khan, M. (2025). Location optimization of electric vehicle charging stations on US motorway corridors. *Transportation Research Part D: Transport and Environment, 142*, 104-118. https://doi.org/10.1016/j.trd.2025.01.015

Church, R. L., & ReVelle, C. S. (1974). The maximal covering location problem. *Papers of the Regional Science Association, 32*(1), 101-118. https://doi.org/10.1007/BF01942293

Dev.ua. (2025). *The Ministry of Energy has created an online map of favourable locations for EV charging stations*. Retrieved from https://dev.ua/en/news/

EcoFactor. (2025). *Electric vehicle charging networks in Ukraine*. Retrieved from https://ecofactortech.com/en/electric-vehicle-charging-networks-in-ukraine/

eAuto. (2025). *Electric vehicle market in Ukraine: Results of September 2025*. Retrieved from https://eauto.org.ua/en/news/

Electromaps. (2024). *Charging stations in Ukraine*. Retrieved from https://www.electromaps.com/en/charging-stations/ukraine

EU4Ukraine. (2024). *EU updates TEN-T indicative road and railway maps, including Ukraine in the routes*. Retrieved from https://eu4ukraine.eu/en/media-en/publications-en/

European Commission. (2025). *Questions and Answers on the Regulation on the deployment of alternative fuels infrastructure*. Retrieved from https://transport.ec.europa.eu/transport-themes/clean-transport/alternative-fuels/

European Parliament. (2023). *Regulation (EU) 2023/1804 on the deployment of alternative fuels infrastructure*. Official Journal of the European Union, L 231/1.

Finetelligence. (2025). *AFIR: What the new EU regulation on charging infrastructure really means*. Retrieved from https://finetelligence.com/en/afir-what-the-new-eu-regulation-on-charging-infrastructure-really-means/

Focus2Move. (2025). *Ukrainian cars market. Facts and data 2025*. Retrieved from https://www.focus2move.com/ukrainian-cars-market/

Gülsan Holding. (2023). *Ukraine: Kyiv-Chop M06 Highway Project*. Retrieved from https://www.gulsanholding.com.tr/en/construction/ukraine-kyiv-chop-m06-highway-project

IEA. (2024). *Global EV Data Explorer*. International Energy Agency. Retrieved from https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer

Interfax. (2025). *Ukrainian ministry begins drafting concept for electric vehicle charging infrastructure*. Retrieved from https://en.interfax.com.ua/news/general/1115862.html

Inventure. (2024). *EBRD provides €267 million to develop key Ukrainian road M-06 Highway*. Retrieved from https://inventure.com.ua/en/news/

Karpenko, O., Horbenko, A., Vovk, Yu., & Tson, O. (2017). Research of the structure and trends in the development of the logistics market in Ukraine. *Journal of Sustainable Development of Transport and Logistics, 2*(2), 57-66. https://doi.org/10.14254/jsdtl.2017.2-2.5

Kempower. (2025). *Navigating AFIR: A Guide to Compliant EV Charging Infrastructure*. Retrieved from https://kempower.com/afir/

Kyiv Post. (2024). *EU to extend major rail network to Lviv*. Retrieved from https://www.kyivpost.com/

McKinsey & Company. (2023). *Can public EV fast-charging stations be profitable in the United States*? Retrieved from https://www.mckinsey.com/features/mckinsey-center-for-future-mobility/

Monta. (2025). *How AFIR regulations impact charge point operators in 2024*. Retrieved from https://monta.com/en/blog/how-afir-regulations-impact-charge-point-operators-in-2024/

NCSREU. (2025). *Regulated electricity tariffs for end consumers. National Commission for State Regulation of Energy and Utilities of Ukraine*. Official Gazette.

OKKO. (2025). *OKKO installed 24 new Ultra Fast Chargers at 19 fuel stations*. Retrieved from https://www.okko.ua/en/

Oilers. (2025). *OKKO expands EV charging network to 60 stations*. Retrieved from https://oilers.org.ua/

OpenCharge Alliance. (2025). *AFIR and OCPP: Technical Interoperability Framework*. Retrieved from https://openchargealliance.org/ocpp-info-whitepapers/afir-and-ocpp/

PSPA. (2025). *Guide to the Regulation of the European Parliament and Council on the deployment of alternative fuels infrastructure*. Polish Sustainable Pavement Association. Retrieved from https://psnm.org/

UA Energy. (2025). *Demand for electric vehicles has increased by a third in Ukraine*. Retrieved from https://ua-energy.org/en/posts/

US Department of Transportation. (2024). *Electric Vehicle Charging Infrastructure: Climate strategies that work*. Retrieved from https://www.transportation.gov/

Vovk, Y., Vovk, I., Plekan, U., & Tson, O. (2025). Sustainable and smart logistics centres: Challenges and opportunities for Ukraine's transport system. *Journal of Sustainable Development of Transport and Logistics, 10*(1), 45-58. https://doi.org/10.14254/jsdtl.2025.10-1.4

WAH. (2025). *Top 10 New Electric Cars in Ukraine: June 2025 Market Analysis*. Retrieved from https://wah.ua/en/blog/

Wikipedia. (2024). Highway M06 (Ukraine). Retrieved from https://en.wikipedia.org/wiki/Highway_M06_(Ukraine)

Wolbertus, R., Kroesen, M., van den Hoed, R., & Chorus, C. G. (2022). Fully charged: An empirical study into the factors that influence connection times at EV-charging stations. *Energy Policy, 123*, 1-7. https://doi.org/10.1016/j.enpol.2018.08.030

World Bank. (2025). *Enhancing Transport Decarbonization in the European Union*. Retrieved from https://www.worldbank.org/en/region/eca/publication/eu-transport-decarbonization

Appendix A: Supplementary financial analysis

A.1. Detailed cash flow projections

The following table presents year-by-year cash flow projections for a single charging station under baseline assumptions over the 10-year analysis horizon. These projections serve as the basis for the NPV and IRR calculations presented in the main text.

Table A.1: Ten-Year Cash Flow Projection (Single Station)

Year	Revenue (HRN)	OPEX (HRN)	Net Cash Flow (HRN)	Cumulative Cash Flow (HRN)	Discount Factor (12%)	Present value (HRN)
0	0	0	-5,207,000	-5,207,000	1.000	-5,207,000
1	3,942,000	967,000	2,975,000	-2,232,000	0.893	2,656,107
2	3,942,000	967,000	2,975,000	743,000	0.797	2,371,175
3	3,942,000	967,000	2,975,000	3,718,000	0.712	2,118,371
4	3,942,000	967,000	2,975,000	6,693,000	0.636	1,891,581
5	3,942,000	967,000	2,975,000	9,668,000	0.567	1,688,325
6	3,942,000	967,000	2,975,000	12,643,000	0.507	1,508,025
7	3,942,000	967,000	2,975,000	15,618,000	0.452	1,348,300
8	3,942,000	967,000	2,975,000	18,593,000	0.404	1,206,300
9	3,942,000	967,000	2,975,000	21,568,000	0.361	1,076,975
10	3,942,000	967,000	2,975,000	24,543,000	0.322	959,150
Total	**39,420,000**	**9,670,000**	**29,750,000**	**24,543,000**		**9,240,159**

The cumulative undiscounted cash flow equals initial CAPEX in year 1.75, establishing the simple payback period documented in Table 5. The sum of present values across years 1 through 10 totals 9,240,159 HRN, which, minus initial CAPEX of 5,207,000, yields an NPV of 4,033,159 HRN per station. Scaling to seven stations yields a total NPV of 64,680,000 HRN, as presented in Table 5.

A.2. Calculation of the internal rate of return

The internal rate of return is the discount rate at which the net present value equals zero. For a single station, solving the following equation for r yields IRR equals 0.523 or 52.3%:

$$0 = -5{,}207{,}000 + \sum_{t=1}^{10} \frac{2{,}975{,}000}{(1+r)^t}$$

This calculation employs iterative numerical methods, as no closed-form algebraic solution exists. The 52.3% IRR substantially exceeds the 12% discount rate assumed in the baseline projections, indicating robust project returns even under elevated cost-of-capital assumptions.

A.3. Break-even analysis

Break-even analysis identifies the minimum utilization rate, tariff, or other key parameter required to achieve zero NPV (i.e., IRR equals the 12% discount rate). Under a baseline tariff of 12 HRN per kWh and CAPEX of 5,207,000 HRN, the break-even utilization rate equals approximately 7.2%, well below the 20% baseline assumption. Conversely, the break-even tariff equals approximately 6.8 HRN per kWh, only slightly above the wholesale electricity cost. This analysis confirms the project's resilience to downside scenarios.

A.4. Scalability analysis

The financial analysis of seven stations can be extended to national charging network development. Assuming comparable financial performance across additional corridors (M-07 to Odesa, M-05 to Sumy, M-12 to Dnipro), the required station count to achieve full AFIR compliance on all major Ukrainian international corridors would total approximately 25 to 30 stations beyond current deployment. At an average CAPEX of 5,207,000 HRN per station, the total investment requirement would approximate 130 to 155 million HRN. Given the aggregate projected NPV of 230 to 280 million HRN across the portfolio, such deployment would represent an economically attractive use of capital from both public and private investment perspectives.

Appendix B: Technical specifications

B.1. Recommended charger specifications

Each charging station should employ four (4) individual fast-charging units meeting the following specifications:

Individual Charger Specifications: 37.5-kilowatt output per unit; CCS (Combined Charging System) Combo connector compatibility; capability to charge from 20% to 80% state-of-charge in approximately 25 to 30 minutes under nominal conditions; integrated cooling systems managing thermal dissipation; real-time monitoring and fault diagnostics.

Station-Level Specifications: Aggregate 150 kilowatt capacity; 400 ampere three-phase electrical service at 35 kilovolt distribution level; dedicated transformer with minimum 500 kilovolt-ampere capacity; grid connection meeting Ukrainian electrical code (GOST) specifications; redundant cooling and monitoring systems; weatherproof canopy protecting charging points and user interface equipment; LED lighting meeting European road standards; accessible charging point design compliant with accessibility standards.

Payment and User Interface: Contactless payment capability (NFC, QR code); roaming network compatibility with major European EV networks; standardized pricing transparency (tariff per kilowatt-hour, per minute, or per session clearly displayed); real-time availability information transmitted to EV navigation systems and public mapping platforms; multilingual user interface supporting Ukrainian, English, and Polish languages.

B.2. Grid connection requirements

Each station requires an electrical connection to 35 35-kilovolt medium-voltage distribution network maintained by regional utility operators. The connection procedure involves: a site survey and feasibility assessment by the utility; engineering design of the substation or direct connection point; construction of a dedicated feeder line or a substation transformer; installation of protective equipment (surge protection, grounding systems); and commissioning and operational testing. The typical timeline for the grid connection process is approximately 6 to 12 months, depending on the proximity of existing infrastructure and the required network reinforcement.

B.3. Environmental and land use considerations

Site selection should prioritize locations with existing commercial development or service station infrastructure to minimize additional land consumption and environmental impact. Environmental impact assessments should address stormwater management, hazardous-material containment, noise and light pollution, and compatibility with local land-use zoning. A remedial site investigation should precede development when former industrial or commercial uses may pose contamination risks.

Appendix C: Regulatory framework summary

C.1. AFIR requirements timeline

December 2025: Initial compliance requirements take effect; locations must aggregate 400 kilowatts, with a minimum of 1 150-kW charger.

December 2027: Enhanced requirements; locations must aggregate 600 kilowatts with a minimum of two 150-kW chargers; standardized digital information platforms operational.

December 2030: Full compliance deadline; all TEN-T Core Network routes achieve 60-kilometre maximum inter-station spacing with specified power output.

C.2. TEN-T extension scenarios for Ukraine

Should Ukraine achieve EU membership candidacy status and incorporate M-06 within the extended TEN-T frameworks, AFIR requirements would become directly applicable within Ukrainian territory. Three implementation scenarios merit consideration: (1) Ukrainian adoption of AFIR as a national standard independent of formal EU membership; (2) a conditional compliance pathway wherein Ukraine achieves AFIR alignment as a prerequisite for EU accession negotiations; (3) a gradual harmonization pathway with interim compliance periods permitting phased infrastructure development.

Appendix D: Stakeholder consultation findings

Preliminary consultations with charging operators (OKKO Energy, TOKA Energy, WOG), grid operators (Ukrenergo regional utilities), and government authorities (Ministry of Energy, Ministry of Infrastructure) revealed a consensus on several points:

Private operators acknowledge infrastructure deployment constraints on intercity corridors but express concern that tariff regulation could compress operator margins below sustainable levels. Government authorities prioritize infrastructure expansion but face budgetary constraints limiting direct investment capacity. Grid operators confirm the technical feasibility of the proposed interconnections at identified sites within standard network reinforcement timelines.

Operators expressed particular interest in co-location arrangements with existing fuel station networks to leverage land, grid, and service infrastructure. Discussions regarding revenue-sharing mechanisms and concession arrangements with multilateral development banks (EBRD, World Bank) received a favourable reception as potential mechanisms facilitating capital mobilization.

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