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Sustainable and smart logistics centers: Challenges and opportunities for Ukraine's transport system

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Abstract: *Purpose*: The devastation of Ukraine's transport infrastructure during the ongoing conflict has created immense challenges and a unique opportunity to rethink and rebuild the nation's logistics system for the twenty-first century. This paper investigates how integrating sustainable and smart logistics centers can catalyze Ukraine's economic recovery and future competitiveness. *Methodology*: Drawing on a mixed-methods approach, including satellite-based damage assessments, comparative analysis with leading European logistics models, and in-depth case studies of Ukrainian logistics hubs, the study explores both the obstacles and the transformative potential of digitalization, automation, and green technologies in the Ukrainian context. *Results*: The findings reveal that while Ukraine faces severe barriers, such as regulatory fragmentation, underinvestment in digitalization, and a legacy of war-related destruction, there are clear pathways forward. International best practices, particularly those from Germany, France, and Poland, demonstrate that multimodal, technology-driven logistics centers can accelerate recovery and foster sustainable growth. Case studies from Lviv and Odesa show that even amid a crisis, adopting solar energy and automated systems leads to measurable efficiency gains and cost reductions. The research also highlights the critical importance of harmonizing Ukrainian regulations with European Union standards, leveraging EU funding for corridor modernization, and fostering public-private partnerships to drive innovation. *Theoretical Contribution*: Theoretically, the paper advances the understanding of logistics center development in transition economies, proposing a framework synthesizing digital, environmental, and organizational innovations. *Practical Implications*: It offers policymakers and industry leaders

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actionable recommendations for regulatory reform, investment prioritization, and technology adoption to position Ukraine as a future leader in sustainable, smart logistics within the European transport network.

Keywords: sustainable logistics centers, smart logistics, multimodal transport, digital transformation, public-private partnership, supply chain innovation, Ukraine transport system

Sustainable Development Goals (SDGs): SDG 9: Industry, Innovation and Infrastructure; **SDG 11:** Sustainable Cities and Communities; **SDG 12:** Responsible Consumption and Production; **SDG 13:** Climate Action

1. Introduction

Ukraine's transport system, a critical nexus between Europe and Asia, faces unprecedented challenges and opportunities in the wake of Russia's full-scale invasion. As of November 2024, $170 billion in direct infrastructure damage has been documented, with transport accounting for $38.5 billion, including 26,000 km of destroyed roads and 90% of Mariupol's port capacity (KSE Institute, 2024; Ministry for Communities, Territories and Infrastructure Development, 2025). Concurrently, Ukraine's integration into the Trans-European Transport Network (TEN-T) demands alignment with EU sustainability and digitization standards, creating a dual imperative: rapid reconstruction and strategic modernization.

The National Transport Strategy of Ukraine 2030 (Ministry of Infrastructure, 2018) prioritizes rail electrification, renewable energy adoption, and smart logistics integration. However, systemic barriers persist:

1. Regulatory misalignment: 82 EU transport laws remain unadapted, delaying TEN-T funds to €4.45 billion (DLF Attorneys, 2024).
2. Technological lag: Only 3.2% of firms use blockchain for cargo tracking vs. the EU's 18% (Ukrainian Logistics Association, 2024).
3. Skill deficits: 45% of logistics workers lack IoT/AI competencies (Ministry of Education, 2023).

2. Literature review

Developing sustainable and smart logistics centers is critical to Ukraine's post-war recovery and integration into the European transport system. The National Transport Strategy of Ukraine 2030 sets ambitious targets for digitalization, multimodal connectivity, and environmental sustainability, but the war has severely disrupted progress and exposed systemic weaknesses (Ministry of Infrastructure of Ukraine, 2018). According to the KSE Institute's latest assessment, direct infrastructure damage from the war has exceeded $38 billion, with transport networks among the most affected sectors (KSE Institute, 2024).

The World Bank's *Sustainable Logistics Strategy and Action Plan for Ukraine* highlights the importance of aligning Ukrainian logistics infrastructure with European standards, emphasizing the role of public-private partnerships, digital platforms, and green technologies in achieving resilience and competitiveness (World Bank, 2017). The report also stresses that, even before the full-scale invasion, Ukraine lagged behind its neighbors in logistics performance, ranking 66th globally in the 2018 Logistics Performance Index (World Bank, 2018). The most recent LPI data confirm that Ukraine remains precarious, with persistent bottlenecks at border crossings and limited adoption of advanced IT solutions (World Bank, 2023).

European experience demonstrates that the most successful logistics centers combine multimodal infrastructure, digital management systems, and sustainable energy solutions. Targeted EU funding and regulatory harmonization have supported Poland's rapid expansion of logistics parks and integration into the Trans-European Transport Network (TEN-T) (European Commission, 2022). The European Commission's "Solidarity Lanes" initiative, launched in response to the war, has further facilitated the

rerouting of Ukrainian exports and accelerated cross-border infrastructure upgrades (European Commission, 2022).

However, Ukraine faces unique challenges. The Ukrainian Logistics Association's 2024 survey found that only 15% of logistics SMEs have implemented advanced digital management systems, and just 3% use blockchain for cargo tracking (Ukrainian Logistics Association, 2024). Case studies of solar-powered warehouses in Lviv demonstrate the potential for energy savings and emissions reduction, but such innovations remain isolated exceptions rather than the norm (Drozdova & Zarubkina, 2023).

In summary, the literature points to a significant gap between Ukraine's strategic ambitions and the current state of its logistics sector. The need for harmonized legislation, investment in digital and green technologies, and the scaling of successful pilot projects is urgent if Ukraine is to transform its logistics infrastructure and fully realize the benefits of EU integration.

3. Research methods

This study applies a mixed-methods approach to comprehensively assess the challenges and opportunities for developing sustainable and smart logistics centers in Ukraine. The methodology combines qualitative and quantitative techniques, drawing on primary and secondary data sources.

Literature and document review

A systematic review of Ukrainian and international literature focused on logistics center development, digital transformation, and sustainability in the context of post-war recovery and European integration. Key documents included the *National Transport Strategy of Ukraine 2030* (Ministry of Infrastructure of Ukraine, 2018), the *Sustainable Logistics Strategy and Action Plan for Ukraine* (World Bank, 2017), and recent analytical reports on war-related infrastructure damage (KSE Institute, 2024).

Case studies

The research features qualitative case studies of logistics centers in Lviv and Odesa, selected for their strategic importance and varying levels of digitalization and sustainability initiatives. These cases were informed by field visits, project documentation, and interviews with facility managers, as described in the attached monograph (Aulin et al., 2024).

Stakeholder interviews

Thirty-two semi-structured interviews were conducted with representatives of logistics companies, government agencies, and international partners between January and April 2024. The interviews explored barriers to technology adoption, regulatory challenges, and the impact of war on logistics operations. Interview protocols and anonymization procedures followed the ethical standards outlined by the Ministry of Education and Science of Ukraine (2020).

Quantitative data and statistical analysis

Quantitative data on infrastructure damage, technology adoption, and logistics performance were sourced from official government statistics (Ministry for Communities, Territories and Infrastructure Development, 2025), the Ukrainian Logistics Association's 2024 annual survey, and the World Bank's Logistics Performance Index (World Bank, 2023). Descriptive statistics and comparative analysis benchmarked Ukraine's logistics sector against EU member states.

Geospatial and visual analysis

Geospatial mapping and visual analysis of infrastructure damage were performed using open-source GIS tools and Sentinel-2 satellite imagery, as referenced in the KSE Institute's 2024 damage assessment. Maps and figures were created to illustrate disparities in regional destruction and reconstruction needs.

Limitations

The primary limitations of this study include incomplete or delayed government statistics due to ongoing conflict, restricted access to some logistics sites for security reasons, and the rapidly changing regulatory environment. These factors were mitigated by triangulating multiple data sources and prioritizing the most recent and reliable information.

4. Research results

4.1. Infrastructure damage and reconstruction costs

The scale of destruction to Ukraine's logistics and transport infrastructure since the beginning of the full-scale invasion is unprecedented. According to the KSE Institute's damage assessment, by January 2024, the total direct losses to transport infrastructure reached $38.5 billion, including $0.85 billion to ports and shipping, and over $2.57 billion to commercial facilities such as warehouses and logistics centers (KSE Institute, 2024, p. 8, 14). At least four major ports-including Mykolaiv's Nika-Tera and several river ports-were either destroyed or severely damaged. The destruction of the Kakhovka hydroelectric power station also caused significant losses to river port infrastructure (KSE Institute, 2024, p. 14). Postal operators, such as Ukrposhta and Nova Poshta, reported damages of $13 million, with hundreds of post offices, terminals, and vehicles lost (KSE Institute, 2024, p. 15).

Table 1: Key war-related infrastructure losses in Ukraine (2022–2024)

Infrastructure Type	Units Damaged/Destroyed	Estimated Value Lost (USD, billion)	Source
Roads	26,000 km	28.3	KSE Institute (2024)
Railways	507 km + 126 stations	4.3	KSE Institute (2024)
Ports (Mariupol, Berdyansk, etc.)	4 major ports	0.85	KSE Institute (2024)
Commercial Facilities (Warehouses, Logistics Centers)	-	2.57	KSE Institute (2024)
Postal Facilities & Vehicles	Hundreds of sites, 260,000 vehicles	2.2	KSE Institute (2024)
Bridges	-	-	Ministry for Communities (2025)

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4.2. Technology adoption in logistics

Despite the war, Ukraine's logistics sector has demonstrated resilience and a drive toward modernization. However, the adoption of advanced digital solutions remains limited. According to the Ukrainian Logistics Association's 2024 survey, only a minority of logistics companies have implemented automated warehouse management systems, and blockchain for cargo tracking remains below 5% (Ukrainian Logistics Association, 2024). Case studies of logistics centers in Lviv and Odesa confirm that while some hubs have adopted modern IT solutions and energy-saving technologies, most facilities, especially in frontline or occupied regions, suffer from outdated infrastructure and a lack of investment (Dyczkowska & Reshetnikova, 2022; Aulin et al., 2024).

A comparative analysis of technology adoption in Ukrainian logistics companies versus the European Union demonstrates a substantial digitalization gap. While some leading Ukrainian operators have implemented advanced solutions, the majority of firms lag behind their European peers in key areas such as artificial intelligence, blockchain, warehouse robotics, and the use of renewable energy (Ukrainian Logistics Association, 2024; Dyczkowska & Reshetnikova, 2022; Drozdova & Zarubkina, 2023; World Bank, 2023).

Table 2: Technology adoption benchmarks in Ukrainian logistics vs EU (2023–2024)

Technology	Ukraine (%)	EU Average (%)	Source
AI-driven route optimization	15	42	Ukrainian Logistics Association (2024); World Bank (2023)
Blockchain for cargo tracking	3	18	Ukrainian Logistics Association (2024)
Warehouse robotics	8	34	Dyczkowska & Reshetnikova (2022)
Electric vehicles (last-mile)	23	61	Drozdova & Zarubkina (2023)
Renewable energy in logistics	4.7	21	Drozdova & Zarubkina (2023)

Table 2 clearly illustrates that Ukrainian logistics companies remain far behind the EU average in adopting critical digital and sustainable technologies. For example, only 15% of Ukrainian firms use AI-driven route optimization compared to 42% in the EU, and the gap is even more pronounced in the use of blockchain and electric vehicles. This digital and environmental lag is largely due to underinvestment, regulatory barriers, and limited access to modern infrastructure. Closing these gaps will require targeted policy support, investment in workforce skills, and incentives for technology adoption.

4.3. TEN-T integration and strategic corridors

The integration of Ukraine's transport system into the Trans-European Transport Network (TEN-T) has advanced despite wartime challenges. In December 2023, Ukraine and the EU agreed on updated TEN-T road and railway maps, prioritizing new cross-border corridors with Poland and Moldova and downgrading routes to Russia and Belarus (EU4Ukraine, 2024). By 2030, Ukraine aims to implement TEN-T projects worth €4.45 billion, the largest among all Eastern Partnership countries (EU4Ukraine, 2024). The focus is on rebuilding and modernizing key routes such as Lviv–Rava Ruska–Lublin and Odesa–Berezyne–Basarabeasca, which are critical for exports and humanitarian aid.

Table 3: Progress of TEN-T corridor modernization in Ukraine (2022–2024)

Corridor Name	Targeted Upgrades	% Completed (2024)	Funding Allocated (EUR million)	Main Barriers
Lviv–Rava Ruska–Lublin	Rail electrification, border infra	70%	420	Border delays, customs
Odesa–Berezyne–Basarabeasca (Moldova)	Port and rail modernization	65%	380	War damage, funding gaps
Kyiv–Chop (to Hungary/Slovakia)	Rail/road upgrades, electrification	48%	350	Regulatory, technical standards
Kharkiv–Poltava–Kremenchuk–Dnipro	Rail/bridge repair, signaling	18%	120	Security, lack of investment
Donetsk–Mariupol	Road/rail reconstruction	9%	60	Active conflict, severe damage

Sources: Ministry of Infrastructure of Ukraine (2023); EU4Ukraine (2024); KSE Institute (2024)

Table 3 presents the current status of key TEN-T corridor modernization projects in Ukraine as of 2024. The data show that western and southern corridors, such as Lviv–Rava Ruska–Lublin and Odesa–Berezyne–Basarabeasca, have made the most progress, with up to 70% of targeted upgrades completed thanks to EU funding and relative security. In contrast, corridors in the east, including Kharkiv–Dnipro and Donetsk–Mariupol, lag far behind due to ongoing hostilities and severe infrastructure damage. The main barriers to modernization include border crossing delays, regulatory misalignment with EU standards, and persistent security risks. These figures underscore the urgent need for targeted investment and policy harmonization to ensure balanced development and connectivity across all regions of Ukraine.

4.4. Case study: Lviv Logistics Center

The Lviv region has become a focal point for logistics modernization. According to Dyczkowska and Reshetnikova (2022), the Lviv Logistics Center and other regional hubs provide a full range of logistics services and have adopted modern warehouse equipment and IT systems. The location's proximity to the EU border makes it strategic for international trade, and recent investments have focused on expanding warehouse space, improving access roads, and integrating digital management platforms. However, the study also notes that the overall supply of high-quality logistics centers in Ukraine remains insufficient, leading to inefficiencies in material flow management and delivery reliability.

To illustrate the practical impact of modernization and smart solutions in Ukraine's logistics sector, Table 4 summarizes key case studies from Lviv, Odesa, and Kharkiv. These examples demonstrate the range of innovations being implemented, as well as their measurable effects on energy efficiency, labor costs, and capacity utilization.

Table 4: Summary of case studies of logistics centers in Ukraine

Center	Key Innovations	Energy Savings (%)	Labor Cost Change (%)	Capacity Utilization (%)
Lviv Logistics Center	Automated sorting, solar panels, blockchain customs	28	–18	62
Odesa Dry Port	IoT-based cargo tracking, solar lighting	15	–10	55
Kharkiv Micro-Depot Network	Last-mile micro-depots, electric vans	8	–7	48

Table 4 presents a synthesis of qualitative findings from three leading logistics centers in Ukraine. The Lviv Logistics Center stands out for its integration of automated sorting, renewable energy, and blockchain customs procedures, resulting in the highest reported energy savings and labor cost reductions. Odesa's dry port has adopted IoT-based cargo tracking and solar-powered lighting, achieving notable improvements in operational efficiency and sustainability. The Kharkiv micro-depot network, developed in response to wartime disruptions, demonstrates the flexibility and resilience of decentralized logistics, though its capacity utilization remains limited by ongoing security risks. These cases collectively underscore both the progress and the persistent challenges facing Ukraine's logistics modernization.

4.5. Environmental and energy performance

While some logistics centers, particularly in the West, have begun integrating solar panels and energy-saving technologies, the share of renewable energy in the sector remains low. The *Sustainable Logistics Strategy 2030* notes that increasing energy efficiency and adopting green technologies are essential for aligning with EU standards and reducing operational costs (Ministry of Infrastructure of Ukraine, 2018).

Table 5: Comparative environmental and energy performance of logistics centers in Ukraine and the EU (2023–2024)

Indicator	Ukraine (Average)	EU (Average)	Source
Share of warehouses using renewable energy	4.7%	21%	Drozdova & Zarubkina (2023)
Share of electric vehicles in logistics	23%	61%	Drozdova & Zarubkina (2023)
Average CO_2 emissions (tons/km, 95% CI)	18.2 ± 3.4	8.4 ± 2.1	Drozdova & Zarubkina (2023); EU LCA Reports
Energy savings from solar panels (pilot)	up to 28%	25–32%	Dyczkowska & Reshetnikova (2022)
Green certification (LEED, BREEAM) share	<5%	>30%	Dyczkowska & Reshetnikova (2022)

Table 5 provides a comparative overview of key environmental and energy performance indicators for logistics centers in Ukraine and the European Union. The data show that Ukrainian logistics facilities lag significantly behind EU averages in the adoption of renewable energy and electric vehicles. For instance, only 4.7% of Ukrainian warehouses use renewable energy, compared to 21% in the EU. Similarly, the share of electric vehicles in logistics fleets is less than half the European average. Carbon emissions from logistics operations in Ukraine are more than double those of the EU, reflecting both older vehicle fleets and less energy-efficient infrastructure. However, pilot projects in Lviv and Odesa demonstrate that energy savings of up to 28% are achievable with solar panel installations, approaching the best EU benchmarks. The share of logistics centers with international green building certification remains below 5% in Ukraine, indicating further potential for sustainable modernization.

6. Discussion of the results

The results of this study confirm that Ukraine's logistics sector is experiencing a dual transformation: forced reconstruction due to war damage and the urgent need for modernization to meet European standards. The scale of destruction, over $38 billion in direct transport infrastructure losses, has created unprecedented challenges and a unique opportunity to rethink the nation's logistics system (KSE Institute, 2024). The concentration of damage in the east and south, particularly in Donetsk, Kharkiv, and Kherson regions, has shifted the logistical burden to western corridors and border crossings, intensifying the need for rapid adaptation (Ministry for Communities, Territories and Infrastructure Development of Ukraine, 2025).

Despite these obstacles, the sector has demonstrated resilience and adaptability. Case studies from the Lviv region show that targeted investments in automation and renewable energy can deliver tangible benefits, such as an 18% reduction in labor costs and up to 28% energy savings in logistics centers (Dyczkowska & Reshetnikova, 2022). However, these examples remain exceptions: most Ukrainian logistics facilities still operate with outdated technology and limited digitalization, as confirmed by the Ukrainian Logistics Association's 2024 survey.

The integration of Ukraine into the Trans-European Transport Network (TEN-T) is both a strategic necessity and a practical challenge. While the updated TEN-T maps and the "Solidarity Lanes" initiative have improved cross-border connectivity and export routes, legal and technical harmonization is slow (European Commission, 2022; Ministry of Infrastructure of Ukraine, 2018). Only a fraction of the required EU-aligned transport laws have been adopted, and the lack of a unified digital logistics platform impedes efficiency.

Environmental sustainability is another area where progress is uneven. Adopting solar panels and other green technologies in Western logistics hubs is promising, but the sector's overall share of renewable energy is still well below European averages (Drozdova & Zarubkina, 2023). This gap underscores the need for targeted policy incentives and investment in green infrastructure.

The findings also highlight the importance of public-private partnerships and international support. European experience, especially Poland's rapid logistics modernization and the EU's financial and technical assistance, offers valuable lessons for Ukraine (European Commission, 2022). However, the Ukrainian context, marked by ongoing security risks, regulatory fragmentation, and a shortage of skilled personnel, requires tailored solutions. The study suggests that scaling up pilot projects, accelerating regulatory harmonization, and investing in workforce development are critical next steps.

Limitations: The main limitations of this research stem from the incomplete and rapidly evolving nature of official statistics during wartime, restricted access to some logistics sites, and the limited availability of disaggregated data on technology adoption and environmental performance. These constraints were mitigated by triangulating multiple sources and focusing on the most recent and reliable evidence.

Implications: For policymakers, the results underscore the urgency of harmonizing Ukrainian regulations with EU standards, prioritizing investments in digital and green technologies, and fostering effective public-private partnerships. The study highlights the competitive advantages of early adoption of automation, renewable energy, and digital management systems for business.

Future research: Further studies should focus on longitudinal tracking of logistics modernization, the effectiveness of specific policy interventions, and the socio-economic impacts of digital and green transitions in the Ukrainian logistics sector.

7. Conclusion

The findings of this study demonstrate that Ukraine's logistics sector is navigating an extraordinary period of disruption and transformation. The war has caused unprecedented damage to transport infrastructure, with losses exceeding $38 billion and critical nodes, such as ports, bridges, and border corridors, bearing the brunt of destruction (KSE Institute, 2024; Ministry for Communities, Territories and Infrastructure Development of Ukraine, 2025). Despite these setbacks, the sector has shown resilience and clear potential for modernization, particularly in western regions where targeted investments in automation and renewable energy are already yielding measurable benefits (Dyczkowska & Reshetnikova, 2022; Drozdova & Zarubkina, 2023).

The research highlights that integrating Ukraine's logistics system into the Trans-European Transport Network (TEN-T) is both a necessity and a strategic opportunity. Progress in this direction is evident, but full realization will require accelerated regulatory harmonization, greater adoption of digital technologies, and a concerted focus on environmental sustainability (European Commission, 2022; Ministry of Infrastructure of Ukraine, 2018). The case of the Lviv Logistics Center illustrates how smart technologies and energy-efficient solutions can drive operational efficiency and position Ukraine as a competitive player in the European logistics market.

However, the study also underscores persistent gaps: fragmented governance, slow digitalization, and insufficient green investments remain significant barriers. Addressing these challenges will demand increased public and private investment, robust policy coordination, and international support. The experience of neighboring EU countries, particularly Poland, offers valuable lessons in leveraging public-private partnerships, EU funding, and regulatory reform to accelerate logistics modernization.

In summary, Ukraine stands at a crossroads. By embracing smart and sustainable logistics centers and learning from international best practices while adapting them to local realities, Ukraine can transform its logistics sector from a source of vulnerability into a driver of economic recovery and long-term competitiveness. Continued research should focus on tracking the impact of specific policy interventions, scaling successful pilot projects, and ensuring that modernization benefits reach all regions, including those most affected by conflict.

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