

Digitalization and Green Transformation of Freight Logistics: Implementing eFTI and Digital Transport Corridors in Ukraine

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Abstract

Ukraine's freight logistics sector is undergoing a profound transformation driven by European integration processes, the needs of post-war recovery, and the global shift toward sustainable, low-carbon transport solutions. The purpose of this research is to assess the potential of key digital logistics tools to improve efficiency and support the green transformation of Ukraine's freight logistics system. By analysing the documented Polish experience in digital transport adoption, the study identifies a phased implementation strategy for Ukraine's transition toward a sustainable and integrated digital logistics ecosystem. The methodological framework includes a comparative analysis of modern digital solutions and regulatory standards, an assessment of their interoperability with EU frameworks, and scenario modelling to evaluate the interdependent impacts of these technologies. It indicates that the implementation of eFTI-compatible solutions can reduce delivery times by 15–20%, decrease empty-run mileage by 8–12%, and enable more accurate emissions monitoring, which are the key conditions for developing efficient and environmentally sustainable logistics systems. The findings highlight the need for comprehensive public policy measures: developing a national eFTI implementation roadmap, promoting digitalization and green innovation in freight transport, and integrating operational logistics data into transport infrastructure management systems. The results demonstrate that digital transformation is a key prerequisite for increasing logistics productivity and achieving Ukraine's long-term sustainable development goals in line with the EU transport policy.

Keywords: freight logistics; digitalization; eFTI; e-CMR; Digital Transport Corridors (DTCs); sustainable development

1 Introduction

Freight logistics is a fundamental pillar for the efficient operation of both national and global economies, supporting international trade, supply chain continuity, and industrial stability. Over recent decades, global freight volumes have steadily increased, driven by globalization and e-commerce. According to the International Transport Forum Summit (2025), global freight demand is expected to more than double by 2050. However, this growth comes with an environmental cost: the European Environment Agency (2025) reports that the transport sector now represents the largest source of end-use greenhouse gas emissions in the European Union (EU), with a 14% rise in its climate impact. Poor routing, empty runs, border delays, and reliance on paper documents contribute to higher CO₂ and NO_x emissions. In this context, freight logistics is a critical sector for advancing sustainable development solutions (Chountalas et al., 2023; Dasaklis et al., 2024). Consequently, the EU's *Sustainable and Smart Mobility Strategy* emphasizes the importance of the twin green and digital transitions – driven by multimodal shifts, Electronic Freight Transport Information (eFTI), Electronic Consignment Note (e-CMR), and the completion of the Trans-European Transport Network (TEN-T) – as vital tools for the European Green Deal, which aims for a 90% reduction in greenhouse gas emissions from transport by 2050 (European Commission, 2020).

For Ukraine, these global challenges are compounded by an existential crisis. The full-scale invasion of Ukraine has fundamentally altered the geopolitical and logistical map of the country. For decades, Ukraine's freight logistics relied heavily on maritime transport; however, the blockade of Black Sea ports and the complete closure of civil airspace necessitated a sudden modal shift away from these routes, forcing an overwhelming reliance on road and railway freight networks. This shift overwhelmed border crossing points. During peak congestion in late 2023, truck queues at key checkpoints stretched for over 20 kilometres, with waiting times

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exceeding two weeks (State Border Guard Service, 2023). These inefficiencies are not merely logistical inconveniences; they represent a staggering economic loss and a significant environmental liability due to prolonged engine idling and the prevalence of empty runs.

Despite the challenges, the transport sector has shown remarkable resilience. The joint *Fourth Rapid Damage and Needs Assessment (RDNA4)* by the Government of Ukraine and the World Bank (2025) highlighted the sector's high adaptability in responding to changing logistical demands and its resilience in the face of sustained disruptions. This capacity for recovery is evident in general freight volumes, which maintained 90.3% of the previous year's level over the first three quarters of 2025, reflecting a stabilization of critical supply lines across road and rail networks (State Statistics Service of Ukraine, 2025). Such connectivity is imperative because Ukraine occupies a strategically important position, acting as the eastern logistics hub of the extended TEN-T network and a future extension of the EU Single Market. Consequently, Ukraine's integration into this network makes the harmonization of Ukrainian transport policy with European Union standards an urgent priority.

However, this strategic potential is currently hindered by a fragmented approach to foundational digitalization and limited system interoperability. While private, commercial software offers some operational relief, the absence of a phased strategy connecting these basic tools to eventual European regulatory alignment increases the environmental footprint of logistics operations. Furthermore, the absence of standardized emissions data, which is increasingly critical under the EU's *CountEmissionsEU* framework (Soone & Svahn, 2023), risks creating a technical barrier for Ukrainian carriers entering the European market. Addressing the lack of a comprehensive strategy constitutes the core problem of this study.

Therefore, this article aims to substantiate the role of integrating eFTI, e-CMR, and Digital Transport Corridors (DTCs) as a phased pathway for the digital and green transformation of Ukraine's logistics. To achieve this, the study defines four key tasks: (1) analyse contemporary scientific approaches to digitalization and environmentally friendly logistics; (2) assess the interdependent operational and environmental impacts of foundational tools (e-CMR) and advanced regulatory frameworks (eFTI); (3) identify the key challenges and prospects for a phased implementation in Ukraine drawing on the experience of Poland; and (4) develop a conceptual model for Interoperable DTC Ecosystem.

2 Literature Review

The digital transformation of freight logistics not only drives competitiveness and efficiency trusted by all entities concerned (Miklińska, 2025) but has gained critical urgency due to the *European Green Deal* and the imperative to decarbonize the transport sector (European Commission, 2020). Recent scholarship identifies digitalization as a prerequisite for the twin transition – green and digital (Gao, 2025). Numerous publications discuss transport management with regard to the postulates contained in the Sustainable Development Goals (SDGs). Achieving sustainable transport goals is possible by combining concepts such as urban logistics and knowledge management. This combination is understood as the processes of identifying, gathering, and strengthening knowledge (Iwan et al., 2024; Al Mansoori et al., 2020; Farooq, 2022; Neghabadi et al., 2019).

A growing body of research has demonstrated the relationship between the implementation of knowledge-based logistics concepts and a measurable reduction in harmful emissions into the environment (Iwan et al., 2024). Specifically, the implementation of Intelligent Transport Systems (ITS) significantly improves urban quality of life and helps internalize the external environmental costs associated with transport processes. Recent scholarship has extensively explored these data-driven methods for resource optimization and emission reduction. For example, the application implemented by Górka et al. (2026) provides visualizations and specific emission values by integrating weather data with portable TOPO detectors. Similarly, Dudek and Kujawski (2022) investigated the operational impact of intelligent systems, while Zhang et al. (2021) demonstrated that algorithmic optimization reduces carbon intensity even under demand uncertainty. Complementing this, Xu et al. (2023) highlighted the macroeconomic synergy between low-carbon logistics and regional growth. However, scholars argue that these technical solutions must be underpinned by robust legal frameworks, confirming that regulatory tools (eFTI, e-CMR) are no longer administrative aids but foundational elements for sustainable supply chains (Dasaklis et al., 2025; Grzelakowski, 2025).

The basis for integrating data standardization and electronic information exchange across the EU was established by *Regulation (EU) 2020/1056* (European Parliament and Council, 2020). Despite the documented benefits of automation and cost reduction (Miklińska, 2021), researchers underscore the lack of a holistic approach to implementation. For instance, Dasaklis et al. (2024) employed empirical data from Greece to emphasize the need for customizing adoption strategies for different organizational structures, arguing that it is challenged by the incompatibility of legacy systems and the digital divide between large enterprises and small and medium-sized enterprises (SMEs). Similarly, Chountalas et al. (2023) provided a comprehensive overview of eFTI setbacks, ranging from technical interoperability to user adoption barriers.

Consequently, research analyzing the organizational and legal frameworks of electronic communication within EU supply chains offers a scalable digitalization roadmap for Ukraine. However, applying these benchmarks requires adapting to a uniquely challenging operational environment. While EU member states have followed a

gradual development path, Cherniavskiy et al. (2025) argue that the destruction of Ukraine’s physical infrastructure necessitates an accelerated strategy of technological convergence. Yet, current operational constraints dictate that this convergence must be tactically phased, prioritizing the rapid deployment of foundational digital tools before advancing to complex regulatory frameworks. Supporting this approach, Nykonchuk (2025) demonstrated that the systematic digitalization of transport management is a primary driver in reducing energy consumption and environmental impact. By incrementally securing this foundational digital infrastructure, Ukraine can progressively build the capacity to align with the *ALICE Roadmap Towards Zero Emissions 2050* (2019), which promotes comprehensive solutions ranging from smart transportation to energy efficiency. This strategic alignment is further necessitated by the EU’s *CountEmissionsEU* initiative (Soone & Svahn, 2023), which shifts carbon reporting from voluntary estimates to mandatory compliance based on ISO 14083 standards. This regulatory shift highlights exactly why short-term commercial software adoption must eventually evolve into fully integrated DTCs equipped with native carbon-accounting capabilities.

The deployment of electronic communication for freight transport information is merely the prerequisite for the broader objective: the establishment of Digital Transport Corridors (DTCs), which entails the exchange of logistics data across the entire supply chain network. The *EU4Digital Facility* (2023) underscores that for Eastern Partner countries, harmonizing the regulatory framework for this electronic exchange is critical to ensuring interoperability with European systems. This objective aligns with the National Transport Strategy of Ukraine 2030 (Cabinet of Ministers of Ukraine, 2020), which explicitly envisages the integration of Ukrainian infrastructure into the EU’s TEN-T network through the adoption of Intelligent Transport Systems.

A review of the current literature on e-CMR and eFTI reveals a predominance of policy reports and legislative regulations, while case studies and implementation projects are in the minority (Figure 1). Many EU countries are only just beginning the process of preparing electronic platforms for electronic document management and plan to implement them in 2026 and 2027. Evidence from the Polish logistics market indicates a strategic orientation toward eFTI and e-CMR protocols in the context of Electronic Data Interchange (EDI) integration. However, current implementations are largely characterised by pilot initiatives. The certified IT systems required to enable the actual exchange of electronic data are still under development, facing several persistent legal and technological barriers in practice:

- lack of full acceptance of electronic documents in road inspections;
- the need to amend national regulations;
- the need for interoperable IT systems;
- low level of knowledge of eFTI technology among carriers.

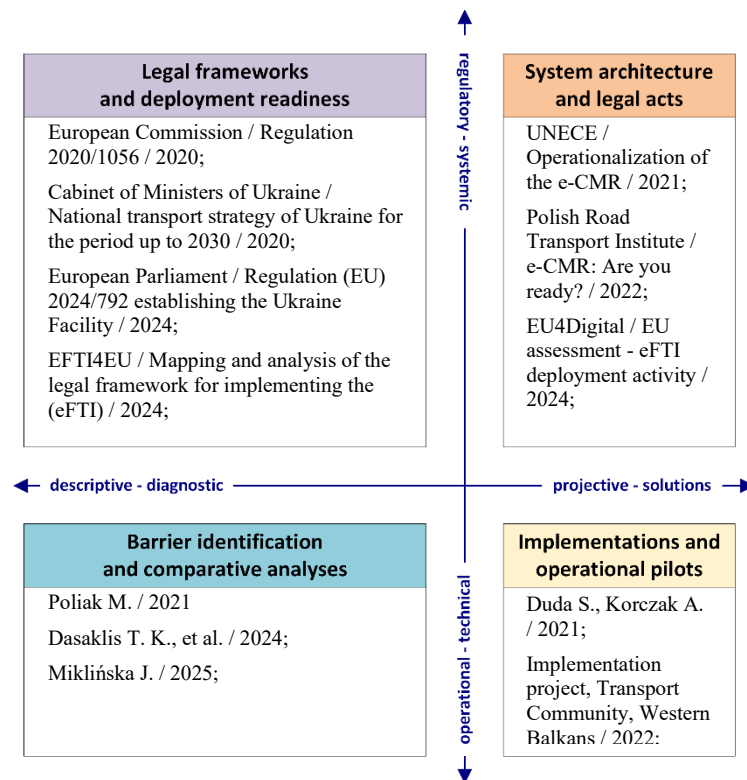


Figure 1. Matrix of studies divided into categories of e-CRM and eFTI implementation status. Own studies.

Interpretation of the matrix:

1-st quadrant – (regulatory + descriptive):

Legal analyses and evaluations of countries’ readiness dominate. Characteristic: no technical models, rather interpretation and assessment.

2-nd quadrant – (systemic + projective):

The most ‘system-building’ work – defining eFTI architecture, data models, platform registries, interoperability. This is where the real design of the EU's digital infrastructure takes place.

3-rd quadrant – (operational + diagnostic):

Research on barriers to adoption, costs, digital competences, and paper vs digital comparisons. This is currently the strongest academic trend.

4-th quadrant – (technical + solutions):

The most practical area — pilot projects, implementations, interoperability tests. The least numerous in terms of literature, but crucial for future empirical research.

3 Research Methodology

This study assesses the operational viability of digital logistics tools using a multi-dimensional system of indicators based on the Triple Bottom Line (TBL) framework. The analysis evaluates operational (delivery time, dwell times, empty runs), economic (administrative costs, paper-handling expenses), and environmental (CO2 reduction via route optimization) impacts. Using scenario analysis, the research compares the Baseline Scenario (S0), which represents the current state of digitalization in Ukrainian freight logistics, with two alternative scenarios that simulate the implementation and integration of specific digital tools – Scenario 1 (S1) for partial digitalization, and Scenario 2 (S2) for systemic integration. Input data for this analysis relied on secondary data derived from international analytical and regulatory sources, including reports from EU4Digital, the World Road Transport Union (IRU), the Organisation for Economic Co-operation and Development (OECD), and the State Statistics Service of Ukraine.

To ensure the reproducibility of the analysis and formalize the estimation logic, this study applies a parametric model in which the total efficiency of the logistics cycle is defined as a function of time, cost, and environmental impact.

3.1 Operational efficiency model (time)

The total transit time (T_{total}) for a standard cross-border freight operation is defined as the sum of three components:

$$T_{total} = T_{move} + T_{border} + T_{admin}$$

Where:

T_{move} represents the physical movement time of the vehicle (driving);

T_{border} represents the dwell time at border control points (queuing and physical inspection);

T_{admin} represents the time allocated to document preparation, manual verification, and error correction.

In the systemic integration scenario (S2), the projected time (T_{S2}) is calculated by applying digitalization coefficients derived from the pilot benchmarks:

$$T_{S2} = T_{move} + [T_{border} \times (1 - \alpha)] + [T_{admin} \times (1 - \beta)]$$

Where:

α is the *Interoperability Coefficient* (estimated at 0.35–0.40), representing the reduction in physical checks due to trusted eFTI pre-arrival data;

β is the *Automation Coefficient* (estimated at 0.60–0.70), representing the elimination of manual paperwork processing.

3.2 Environmental impact model (emissions)

The carbon footprint of the logistics chain (E_{total}) is modelled based on the GLEC Framework principles, separating productive mileage from non-productive (empty) mileage:

$$E_{total} = (D_{loaded} \times F_{load} \times \varepsilon) + (D_{empty} \times F_{empty} \times \varepsilon)$$

Where:

D represents distance travelled;

F represents fuel consumption (L/km);

ε is the standard CO₂ emission factor for diesel fuel (2.68 kg CO₂/L).

The study posits that Digital Transport Corridors (S2) directly impact the Empty Run Ratio (η):

$$D_{empty(S2)} = D_{empty} \times (1 - \gamma_{match})$$

Where:

γ_{match} represents the route optimization factor (0.10–0.12), achieved through better synchronization of return loads via digital platforms.

3.3 Economic cost model for small and medium-sized enterprises (SMEs)

The administrative cost savings (C_{admin}) are derived not from the shipping rate, but from the processing overheads:

$$C_{admin} = (t_{proc} \times W_{rate}) + C_{print} + C_{archive}$$

Where:

t_{proc} is personnel time;

W_{rate} is the hourly wage.

$C_{print/archive}$ are material costs.

The model assumes that under S2, material costs approach zero, while personnel time is reduced by the automation coefficient (β).

The proposed methodology possesses a universal and scalable character, serving as an analytical basis for further empirical investigations into the twin transition of freight logistics in Ukraine. Based on this framework, future research can expand to include:

- Quantitative assessment: measuring actual changes in operational, economic, and environmental indicators following the full-scale implementation of e-CMR and eFTI.
- DTCs efficiency: analysing the specific efficiency gains of DTCs along designated TEN-T routes.
- Real-data integration: incorporating real-time data from logistics operators and government bodies into the evaluation model.
- Multimodal expansion: extending the model to cover synchromodal operations, specifically accounting for rail and inland water transport.

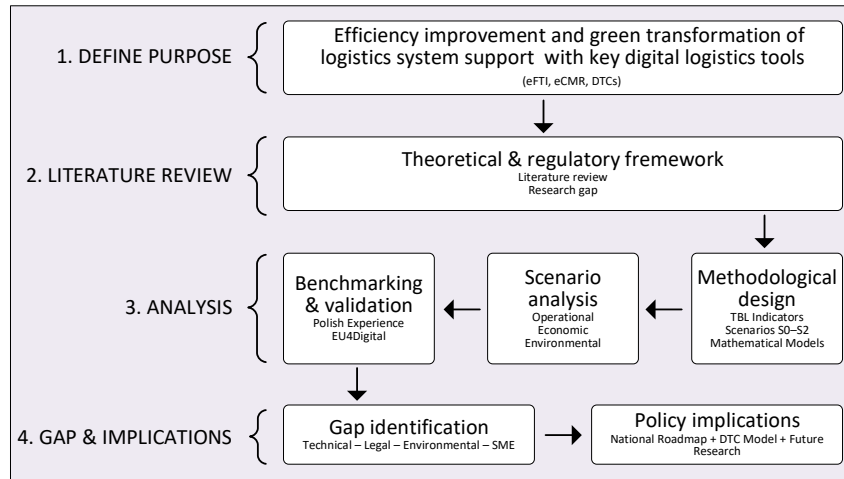


Figure 2. Research methodology structure. Own studies.

Consequently, this methodology transcends theoretical analysis, forming a practical foundation for evaluating the results of digitalization and integrating them into Ukraine’s transport policy management and infrastructure planning.

4 Results

The findings are presented through a scenario analysis that reflects varying levels of digital maturity within the transport-logistics system and benchmarks the potential effects of digitalization against a baseline (reference) state. This is achieved by contrasting the current operational state of Ukraine’s transport-logistics system (S0) with modelled scenarios that reflect a phased implementation strategy: foundational operational digitalization (S1) followed by systemic regulatory convergence (S2).

4.1 Scenario-Based Approach to Assessing Digitalization Effects

The Baseline Scenario (S0) reflects the current state of Ukraine’s transport-logistics system, characterized by paper-based documentation, fragmented digital solutions, limited interoperability, and significant border delays.

Scenario S1 (Foundational Digitalization) assumes partial digitalization through the adoption of e-CMR by individual carriers without integration into public authority systems. Electronic documents are mainly utilized for Business-to-Business (B2B) exchange, while control procedures remain partly paper-based, resulting in moderate efficiency gains.

Scenario S2 (Systemic Integration) represents full interoperability based on the implementation of e-CMR, compliance with *EU Regulation 2020/1056 (eFTI)*, and the operation of DTCs. This enables structured Business-

to-Authority (B2A) data exchange between carriers, terminals, and authorities, including pre-arrival information submission, generating the highest operational, economic, and environmental benefits.

All effects presented in subsequent sections are evaluated relative to S0. Crucially, the assessment methodology recognizes the interdependent nature of these technologies; therefore, the impacts of S2 are modelled not as simply additive to S1, but as the resulting synergies of a fully integrated data ecosystem.

4.2 Operational Effects of Freight Logistics Digitalization

Compared to the current state of freight transport organization in Ukraine, the implementation of e-CMR and eFTI-compliant solutions ensures a substantial increase in operational efficiency, primarily within the road and cross-border transport segments, which play a pivotal role in the country's foreign trade structure.

Under the baseline scenario (S0), a significant share of transit time is consumed by the processing of paper documents, data redundancy, and waiting at control points. The comparative assessment indicates that the transition to electronic freight documents reduces the average administrative processing time per shipment by 60-75%, which directly correlates to a reduction in the overall logistics cycle duration.

The most tangible operational impact is observed at the state border. With the use of structured electronic data prior to vehicle arrival, expected dwell-time reductions range from 20-30% under S1 to up to 40% under S2. This improvement is driven by reduced manual document verification and enhanced coordination among control authorities.

Furthermore, the digitalization of freight information facilitates improved route planning and more efficient vehicle utilization. Compared to S0, the share of empty runs is projected to decrease by 8-12% under the systemic integration of S2, reflecting superior synchronization between transport demand and available capacity.

4.3 Economic Effect: Cost Reduction for Small and Medium-Sized Enterprises (SMEs)

Administrative costs related to freight documentation are particularly significant for SMEs, which dominate Ukraine's road transport sector. The foundational transition from paper-based CMR to e-CMR (S1) can reduce direct administrative costs per shipment by 50-70% through the elimination of printing, storage, and manual data entry.

Additional economic benefits arise from higher fleet utilization due to shorter dwell times. Under systemic integration (S2), the compounding effects of these operational efficiencies are estimated to decrease total logistics costs for SMEs by 7-10%, while real-time access to shipment data supports faster invoicing and improved cash flow².

4.4 Environmental Effects: Emission Reduction Potential

In the baseline scenario (S0), a significant share of greenhouse gas emissions is generated due to prolonged vehicle dwell time at borders, uncoordinated route planning, and a higher frequency of empty runs. This establishes the reference point for assessing the environmental impact of digitalization (Poliak et al., 2026).

Reducing dwell times directly leads to decreased fuel consumption caused by engine idling. Under S1, CO₂ emissions per shipment are projected to decrease by 3-5%, whereas in the case of full integration within DTCs, this figure rises to 8-10%, reflecting the overlapping benefits of reduced idling and optimized regional routing.

An additional environmental effect is generated through the reduction of empty runs. Digital synchronization of loads leads to measurable environmental benefits, lowering NO_x and PM emissions. Even a moderate reduction in this metric yields a disproportionately high environmental result, confirming the systemic nature of the environmental benefits derived from the digitalization of freight information. Real-time emissions monitoring via eFTI and DTCs integration allows accurate, continuous tracking of environmental performance, aligning with EU *CountEmissionsEU* and ISO 14083 standards (Soone & Svahn, 2023³).

4.5 Digital Transport Corridors as an Integrated Result

Comparing the isolated implementation of e-CMR and eFTI against the integrated scenario of DTCs indicates that maximum effects are achieved specifically under conditions of the systemic interaction of all digital tools. Within the DTC ecosystem, the structural B2A integration links carriers, terminals, and public authorities. This allows not only for the optimization of operational processes but also for the creation of a high-quality data foundation for the strategic management of transport policy. Compared to the baseline state, this integrated approach ensures the highest aggregate indicators of operational, economic, and environmental efficiency.

Table 1 summarizes the key performance indicators (KPIs) and qualitative effects, demonstrating that the integrated scenario (S2) consistently outperforms partial digitalization (S1) across all dimensions, particularly where systemic network synergies are required.

² https://vervo.eu/en/news/vervo-news/ecmr-in-2026-hauliers-must-act-before-the-paper-era-ends?utm_source

³ [https://www.europarl.europa.eu/RegData/etudes/BRIE/2023/757562/EPRS_BRI\(2023\)757562_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/BRIE/2023/757562/EPRS_BRI(2023)757562_EN.pdf)

Table 1. Key Performance Indicators (KPIs) and Effects of Implementing DTCs

Category	KPI / indicator	Partial digitalization (S1)	Systemic integration (S2)	Qualitative effects
Operational	Reduction in border dwell time (%)	20–30	35–40	Improved logistics synchronization; reduction in manual verification; better coordination between control authorities
	Reduction in the share of empty runs (%)	8–10	10–12	Optimization of fleet utilization; more efficient route planning
Economic	Reduction in administrative costs for SMEs (%)	50–70	50–70	Reduction of printing, storage, and processing costs; reduction of errors; increased fleet turnover
	Reduction in total logistics costs (%)	–	7–10	Increased SME competitiveness; increased cost predictability
Environmental	Reduction in CO ₂ per shipment (%)	3–5	8–10	Fuel savings due to reduced dwell times and empty runs; enhanced environmental responsibility of carriers

Overall, the DTCs scenario illustrates that fully integrated digital freight systems provide the most comprehensive improvements. While foundational tools (S1) deliver immediate administrative relief, it is the synergistic ecosystem of S2 that forms a robust foundation for strategic transport policy, dynamic operational planning, and sustainable long-term logistics.

4.6 The Polish experience as a reference base for the systemic integration scenario

To ensure the empirical validity of the estimates, the results were triangulated with the experience of Poland, whose progress through systemic integration phases serves as a baseline for digital logistics solutions. (Fig. 3).



Figure 3. Roadmap of regulatory and operational milestones for eFTI and e-CMR adoption in Poland ⁴

Poland’s experience in participating in pilot projects for DTCs within the TEN-T network forms the empirical foundation for the parametrization of S2 used in this study. The empirical data was derived from the study conducted by the Polish Road Transport Institute (2023).

This benchmarking approach facilitates the coordination of regulatory alignment while identifying critical environmental and green logistics benefits as prerequisites for long-sighted strategic decision-making.

Regulatory alignment:

- Compliance with Regulation (EU) 2020/1056 (eFTI) and Official Journal L 2025/2243 ensures interoperability across the EU (EUR-Lex summary⁵; Dz. U. UE L 2025/2243⁶).

⁴ https://transport.ec.europa.eu/transport-themes/logistics-and-multimodal-transport/efti-regulation_en?utm_source=chatgpt.com

⁵ <https://eur-lex.europa.eu/PL/legal-content/summary/electronic-freight-transport-information.html>

⁶ <https://www.prawo.pl/akty/dz-u-ue-l-2025-2243,72526317.html>

- Integration with national customs systems enables seamless electronic verification while maintaining domestic workflow efficiency.

Environmental and Green Logistics Benefits

- CO₂ emissions are reduced by 8–10% per shipment due to shorter idle times and fewer empty runs.
- Real-time monitoring supports compliance with EU *CountEmissionsEU* and ISO 14083 standards.
- Digitalization acts as a driver of green logistics, reducing overall environmental footprint.

Table 2 The status of e-CMR and eFTI implementation based on the example of Polish transport companies

#	Company	Type of Transport	Public Information on e-CMR / eFTI	Status (short)	Source
1	Colian Logistic	Road / domestic & international	Pilot implementation of e-CMR (Poland ↔ UK route), described in GS1 case study and industry publications.	Pilot / practical hybrid e-CMR implementation	https://gs1pl.org/aktualnosci/pionierskie-wdrozenie-e-cmr-w-colian-logistic/
2	3CARGO	Road / freight forwarding	Participant in national e-CMR pilot programme.	e-CMR pilot participant	https://www.3cargo.com/ru/szyl-program-pilotazowy-e-cmr-3cargo-jednym-z-ogniw/
3	Raben Group (Poland)	Road / warehousing / intermodal	Mentioned in industry publications as gradually implementing e-CMR / digital consignment notes.	Digitalisation initiatives — references to e-CMR in publications (case study confirmation needed)	https://rpms.pl/elektroniczn-e-listy-przewozowe-e-cmr-korzysci-i-wyzwania/
4	DB Schenker (Poland)	Road / global operator with Polish branch	Active digitalisation of transport processes (digital platforms, EDI); referenced in the context of electronic transport documents.	EDI & digitalisation — probable group-level e-CMR usage (no specific Polish case study publicly available)	https://www.dbschenker.com/pl-pl/biznes/centrum-uslug-cyfrowych/zlecenia-przesylek
5	DSV (Poland)	Road / global carrier	Long-standing EDI capabilities and electronic document handling; references to electronic consignment documentation.	EDI & digitalisation — global experience with e-documents; Polish operations focused on automation	https://www.dsv.com/pl-pl/dlaczego-dsv/connectivity/dsv-edi
6	DACHSER (Poland)	Road / international	Partner in the development of interoperable e-CMR software (industry and open initiatives).	Active involvement in interoperable e-CMR development projects	https://lorry.pl/dachser-wspiera-rozwoj-interoperacyjnego-oprogramowania-ecmr/
7	Rhenus (Poland)	Road / multimodal	Global operator active in digital integration and electronic documentation; no specific Polish e-CMR case publicly confirmed.	Digital readiness / technology integration — no confirmed production e-CMR case in Poland	https://www.rhenus.group/pl/pl/rhenus-group/rhenus-w-polsce/
8	PKP CARGO	Rail / intermodal	Development of digital customer solutions and electronic railway consignment documentation (CIM); part of broader transport document digitalisation.	Rail digitalisation (CIM/e-documents); not directly related to e-CMR (road only)	https://www.pkpcargo.com/pkp-cargo-wdraza-cyfrowe-rozwiazania-obslugi-klientow/
9	Polish Ocean Lines (PLO)	Maritime / shipping line	No publicly available evidence of production use of eFTI or e-CMR; maritime operators typically use proprietary digital documentation systems.	No confirmed public evidence of eFTI/e-CMR usage	https://www.plo.com.pl/

Source: Authors' elaboration

Thus, the Polish experience serves as a reference empirical base. It confirms the achievability of the S2 results. This allows the obtained estimates to be viewed not as hypothetical but as consistent and suitable for shaping the policy of digital transformation in Ukrainian freight logistics. By synthesizing the experience of Poland's digital transition, the following strategic lessons are identified as critical for Ukraine's implementation:

- Pre-arrival data exchange reduces physical checks and dwell times.
- Integration with EU and national systems ensures regulatory compliance and interoperability.
- Environmental monitoring provides actionable data for sustainable logistics.
- Incremental pilot projects allow for early identification of technical and organizational challenges, facilitating broader adoption.

5 Discussion

While the results demonstrate significant potential benefits of digitalization in freight logistics, a more critical interpretation is required to distinguish between the effects of foundational digital transformation (S1) and the specific contribution of systemic eFTI integration (S2).

First, it is important to address the additionality of eFTI. A substantial share of the observed improvements – including reductions in administrative time, better fleet utilization, and lower emissions – can already be achieved through broader digitalization processes, such as the adoption of basic transport management systems or electronic data interchange (EDI). In this context, eFTI should not be interpreted as the sole driver of these baseline effects. Instead, the added value of eFTI lies primarily in its role as an enabling regulatory and interoperability framework, particularly in B2A communication and cross-border data exchange. Its main contribution is the standardization and legal recognition of electronic freight information across jurisdictions, which facilitates coordination between carriers and public authorities. Therefore, the maximum benefits attributed to eFTI in this study are conditional upon its integration within broader digital logistics systems.

Second, the additivity of the estimated benefits requires careful consideration. The impacts presented across the operational, economic, and environmental dimensions are interrelated and not fully independent. For instance, reductions in border dwell time directly influence fuel consumption and emissions, while improved route planning affects both operational efficiency and cost structures. As a result, simply aggregating these effects could lead to an overestimation of total benefits. Our scenario modelling acknowledges these interdependencies, emphasizing that S2 results are driven by systemic synergies rather than merely additive calculations. Future research should continue to apply integrated modelling approaches that explicitly account for these overlapping variables.

Third, the transferability of the Polish experience to Ukraine must be treated with caution. While Poland provides a valuable empirical reference, the institutional, economic, and infrastructural conditions differ significantly. Ukraine faces severe additional constraints related to post-war recovery, infrastructure damage, and uneven digital maturity across stakeholders. Consequently, the Polish case should be interpreted not as a direct benchmark, but rather as an indicative developmental trajectory.

In this context, the assumption that eFTI implementation is an immediate prerequisite for digitalization requires refinement. Digital transformation in Ukraine must progress through a tactically phased approach, starting with the adoption of practical, accessible commercial solutions – such as e-CMR and foundational digital platforms (S1) – before advancing toward full alignment with eFTI standards (S2). This strategy allows stakeholders, particularly SMEs, to capture early operational wins while gradually building interoperability capacity.

Furthermore, these findings highlight that the realization of benefits depends not only on regulatory frameworks but also on the market availability of digital applications that utilize logistics data. Tools such as route optimization systems, scheduling platforms, and fleet management solutions are essential for translating standardized data into tangible operational improvements. Without the deployment of these application layers, the theoretical potential of eFTI remains largely unrealized.

Against this background, to translate these research findings into operational reality, this study proposes the concept of the Interoperable DTC Ecosystem. As illustrated in Figure 3, this framework serves as a blueprint for a phased digital transition, designed to link Ukraine’s physical logistics flows with European digital interoperability standards.

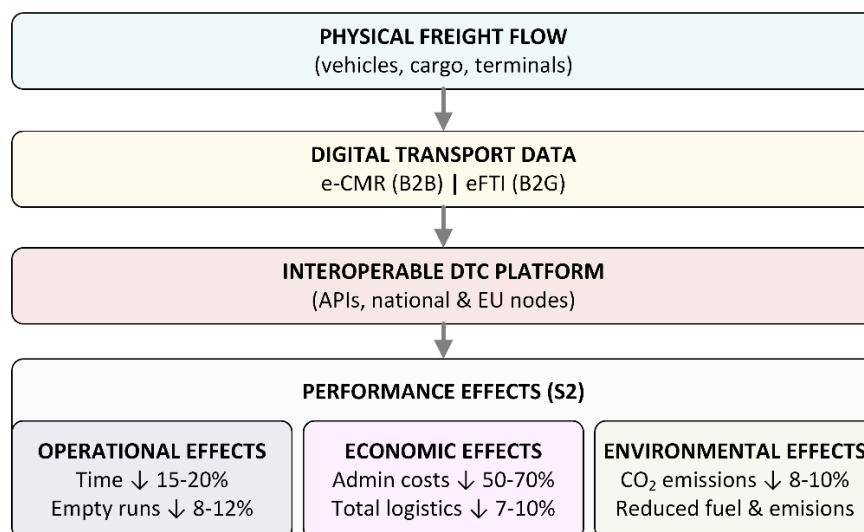


Figure 3. Conceptual Model of the Interoperable DTC Ecosystem and Projected Performance Effects (S2).

Figure 3 illustrates the proposed Interoperable DTC Ecosystem, which functions across three integrated tiers. The digital layer unifies commercial (B2B) and regulatory (B2A) data, establishing the domestic e-TTN as a single source. This data feeds into the interoperability layer, a gateway that utilizes Application Programming Interface (API) integration to bridge Ukraine's "Diiia" infrastructure with EU eFTI standards, ensuring seamless cross-border validation. Finally, the performance layer quantifies the S2 outcomes enabled by this architecture, projecting critical recovery gains: a 15-20% reduction in vehicle turnaround time, a 50-70% cut in administrative costs, and an 8-10% decrease in CO₂ emissions.

6 Conclusion

This study fulfilled its set objectives by defining a pathway for Ukraine's freight logistics digital and green transformation. First, the analysis of contemporary approaches confirmed that digitalization is a prerequisite for the twin transition advocated by the EU. Second, the parametric assessment demonstrated that full eFTI adoption could yield a 15-20% reduction in delivery times and significant decarbonisation (8-10% CO₂ reduction), validated against Polish empirical benchmarks. Third, the developed conceptual model of the Interoperable DTC Ecosystem illustrates that Ukraine is capable of completing technological convergence into the European digital transport area, effectively synchronizing its domestic infrastructure with EU eFTI standards.

However, a critical evaluation of these findings dictates that realizing this integrated scenario will face substantial practical barriers. Immediate leapfrogging to full DTC integration is practically unfeasible given the current operational constraints, including the destruction of physical infrastructure, regulatory lags, and the digital divide among SMEs. Therefore, Ukraine must adhere to a strictly phased adoption strategy, prioritizing foundational, commercially available tools (S1) to secure immediate operational efficiencies before attempting complex, cross-border B2A integration. Furthermore, as the projected outcomes of this study are derived from scenario-based modelling, future empirical research, particularly post-war pilot implementations, will be essential to validate these theoretical KPIs against real-world operational frictions.

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