ReMuNet

Pioneering resilient and adaptive multimodal transport networks

D1.5

Analysis of effects of disruptive events on the European freight transport network and resulting societal impact

Hanken School of Economics

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

FGD	Focus group discussions
RCA	Root-cause analysis
TITR	Trans-Caspian International Transport Route
TEN-T	Trans European Transport Network
TITLE	xxx

Executive Summary

The Horizon Europe project Resilient Multimodal Transport Networks (ReMuNet) aims to improve the resilience of the freight transport network in the EU in the face of disruptive events and to enhance sustainability. This is proposed to be achieved by offering network users alternate routing options and identifying disruptions and ways to mitigate their impacts.

One of the four core objectives of the ReMuNet project is to develop a standardized methodology to describe multimodal transport networks. The proposed standard is derived from existing approaches and developed together with critical stakeholders to ensure Europe-wide practicability and acceptance which can be easily transferred into appropriate regulatory frameworks ensuring more efficient communication and operational stakeholder inter-connectivity. The first task towards this core objective was to create a typology of disruptive events, which has been addressed in a prior report for Task 1.3. The subsequent report addressed Task 1.4, which conducted root cause and impact analysis of selected disruptive events**.** This report presents **T1.5: Analysis of effects of disruptive events on the European freight transport network and resulting societal impact.** Building on typologies and classifications of disruptive events in Task 1.3, and the root-cause analysis in Task 1.4, Task 1.5 presented in this report will analyze the societal impact of transport network disruptions. This analysis will be utilized in Work Packages 2 and 4.

This report analyses the impact of disruptive events on the transport network, the underlying supply chain, and the society. The impact, the response and the resilience demonstrated at each of these three levels is analysed for six case studies of disruptive events in the European transport network. Conclusions are drawn regarding the societal impact of disruptions, the resilience to disruptions, and the intersectionality of disruptive events. The team at Hanken School of Economics conducted a qualitative study that included 17 interviews and 6 focus group discussions, as well as extensive document analysis. The disruptive events analysed in this report represent different categories according to causes as specified in the typology of disruptive events developed in Deliverable 1.3 and affected the TEN-T corridors Rhine-Danube and North Sea-Baltic. Analysis is based on the previously developed typology and informed by a review of the extant literature. At the end of this report, recommendations for how to manage the impact of disruptive events in the European transport network and to enhance its resilience are given for transport network operators, supply chain managers, and policy makers.

By building on the typology for disruptive events developed in ReMuNet Task 1.3 and the root causes identified in T1.4, this report provides insights to impacts of disruptive events on different levels, the transport network, supply chains and society. This study is an important part of achieving the goal of the project: **the building of an Artificial Intelligence (AI) based collaborative platform to promote synchro-modal relay transport across European rail, road, and inland waterways to improve network resilience, reduce emissions, and boost corridor efficiency during disruptive events**. The analysis on societal impact, along with the terminology and typology developed in the previous task in this qualitative study will be a critical input to the mathematical models that follow in subsequent work packages.

1. Introduction

With increasing complexity of global supply chains and closely timed transport schedules, the vulnerability of European trade to disruptive events will continue to increase unless transport networks become more resilient. ReMuNet identifies and signals disruptive events and assesses their impact on multimodal transport networks. This report is part of WP1. It describes a qualitative study conducted by the team at Hanken **analysing the impact of disruptive events** in the European multimodal freight transport network with a focus on the impact on society. Supply chains have significant impact on the societies they operate in (Messmann et al., 2020). This has become particularly evident throughout the COVID-19 pandemic and its manifold ripple effects with disruptions to distribution networks (Magableh, 2021) and key industries like food processing (Ivanov, 2022). Throughout this period, a destabilisation of supply and demand (Kovács & Falagara Sigala, 2021), amidst wider pandemic-related changes, was evident to the general public. Thus, the impact of transport disruptions on society and measures to enhance resilience warrants further investigation.

Sudden failures and transport network disruptions may cause severe strains on the society. Research demonstrates that the most difficult to manage complexities in logistics and supply chain management arise from interactions between people. Transport is intricately linked with wider societal activity, as a provider of employment and a generator of business. Hence, it is vital that societal impact is considered as part of ReMuNet. **Societal impact in this context refers to the consequences and effects of disruptions on individuals, stakeholders, communities, and society when there are interruptions or disturbances in transportation systems.** Another feature explored in this report is societal resilience. Societal resilience is the ability of the society (not just individuals or organizations) to reach an equilibrium after a shock (conservative resilience) and to renew itself while going back to normal functioning after the disruption (transformative resilience) (Anholt et al., 2021). This report explores the response to transport disruptions beyond the transport network and supply chain levels, considering the societal level as well. The resilience showcased across these levels is analysed, which feeds into recommendations for increasing resilience to the impact of disruptive events in the European transport network.

Furthermore, this report discusses the intersectionality of disruptive events. This occurs when multiple disruptive events affect transport networks simultaneously, their impacts overlapping and converging (Steinfield et al., 2021). In some cases, as will be made evident in the analysis presented in this report, **the occurrence of a second disruption soon after the first, greatly exacerbates the challenges faced by the society and increases the time required to return to normal functioning**. This intersectionality can involve various types of disruptive events and this report follows the typology for disruptive events developed in Deliverable 1.3, which distinguishes between ten different categories of disruptive events based on their causes. The research questions this report addresses are:

1. What is the impact of disruptive events in the European transport network on the transport network, supply chains, and society?
2. How do the transport network, supply chain, and societal level respond to disruptive events and demonstrate resilience?

3. How does the intersectionality of disruptive events manifest in the European transport network?

The report is structured as follows: The Literature Review (Section 2) provides an overview of academic research on resilience, disruptions at the transport networks and supply chain level and their impact, and intersectionality and ripple effects between disruptions. The Methodology (Section 3) section sets out the research design, the criteria for selecting the six case studies, and the framework for the analysis of the case studies. Next, in the section Analysis of Past Disruptive Events (Section 4), six disruptive events in the European transport network are introduced and analysed according to their impact, the response to them, and the resilience exhibited at the transport network, supply chain, and societal level. The Discussion section (Section 5) explores the impact of climate change, the ripple effects, intersectionality, and bi-directionality of impact, societal impact, and resilience. Recommendations (Section 6) for policy makers and managers are provided ahead of the Conclusions (Section 7).

2. Literature review

This section begins by defining resilience at different levels, followed by introduction to supply chain disruptions and transport network disruptions. Additionally, the review explores the intersectionality of transport network disruptions. Finally, impacts of transport network disruptions is discussed, highlighting how various social factors intersect with transport network vulnerabilities and influence resilience strategies.

2.1 Resilience at different levels

Resilience is a multidimensional and multidisciplinary concept with roots in psychology and ecosystems before being adapted to the supply chain management field (Bhamra et al., 2011; Kamalahmadi & Parast, 2016). **Resilience can be defined as "the ability of a system to return to its original state or move to a new, more desirable state after being disturbed"** (Christopher & Peck, 2004, p. 2). The definition of resilience can be divided into two main categories (Wei et al., 2022):

1. Static resilience, that refers to the ability to maintain a high level of functionality in a system impacted by external shocks. Static economic resilience refers to the capability to use the remaining resources efficiently at a specific point in time.
2. Dynamic resilience refers to the capability and speed by which a system recovers from external shocks. Dynamic economic resilience focuses on how resources can be utilized efficiently for repair and reconstruction over the recovery time.

Further, resilience (or resiliency), includes readiness and preparedness, response and adaptation, and recovery or adjustment phases (Bhamra, et al., 2011). Resilience encompasses various levels in a "resilience onion" (Vargas-Hernández, 2022), starting with individual actors (people, or companies), their networks (social network, supply chain, infrastructure), to society at large. The highest level of societal resilience can also be seen as the "fourth age of global safety", whereby it focuses on how society including

organizations and critical infrastructure can respond to emerging systemic risks (Haavik, 2020). Ekström et al., (2023) incorporate organisations, networks (both supply chains and infrastructure), and sectors in their view on societal resilience. In ReMuNet, the focus is on disruptive events in the transport networks and how they play out through the two network elements of resilience (the supply chain, and the transport network aspect of infrastructure) on societal resilience (see Figure 1). The project defines a resilient freight transport network as one that "**minimizes disruption-induced impacts on network performance, in both intensity and duration, along with minimizing the system recovery time**" (FIR, 2024). Further, the project follows Haavik's (2020) socio-technical view on societal resilience.

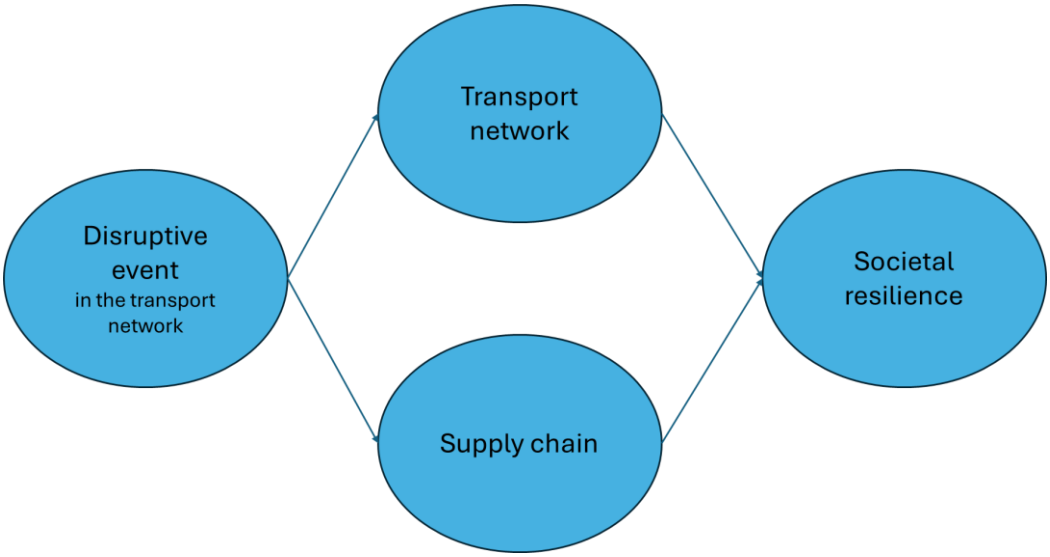

Figure 1: Disruptive events and their impact on societal resilience through transport networks and supply chains.

From the infrastructure perspective, much of resilience literature focuses on critical infrastructure (Haavik, 2020, Vargas-Hernández, 2022). This includes transport infrastructure as well as transport networks where disruptions in either can trigger crises across various sectors in society (Kachali et al., 2018). At *transport network level*, resilience refers to the **ability of a transportation system to absorb, adapt to, and recover from disruptions while maintaining its essential functions and services.** A resilient transport network can withstand various shocks and stresses, such as natural hazards, accidents, infrastructure failures, or other disruptive events, without experiencing significant downtime.

At a *company level,* Sheffi & Rice, (2005) define a resilient firm as one that mitigates vulnerability to disruptions through specific mechanisms. *Supply chain resilience* is defined as 'the capability of a supply chain to prevent disruptions and to reduce the impact of disruptions through developing required level of readiness, quick response, and recovery ability (Chowdhury & Quaddus, 2016, p. 712), and it consists of the ability to return to normal performance levels following a supply chain disruption (Behzadi et al., 2020; Zsidisin & Wagner, 2010). Interestingly, supply chain resilience is often looked at from the focal company perspective, and as an example Blackhurst et al., 2011) sees supply chain resilience as a firm's ability to recover from disruptive events from supply chain.

At a *societal level*, resilience refers to **ability of the society or social entities (not just individuals or organizations) to reach an equilibrium after a shock (conservative resilience) and to renew itself while going back to normal functioning after the disruption (transformative resilience)** (Anholt et al., 2021). These approaches emphasize the collective ability of various stakeholders, including individuals, institutions, communities, societies, and social systems to withstand, adapt to, and recover from disruptions while maintaining essential functions and services. It encompasses the capacity of various stakeholders to effectively respond and recover from disruptive events (Haavik, 2020).

2.2 Transport network disruptions

A disruptive event can be defined ‘as any interruption or change, planned or unplanned, in the operations of a transport network, creating effects, such as delays, blockages, closures, or business transformations’ (Kulkarni et al., 2023). Disruptions within the transport system can stem from various internal events, such as traffic accidents and technical failures, or external strains, often due to natural occurrences such as floods, landslides, heavy snowfall, storms, wildfires, earthquakes. While accidents and technical failures may have limited extents and impact on e.g. one transportation mode or route only, disruptions caused by natural hazards may cover larger geographical areas in the transport network (Jenelius & Mattsson, 2015). Various types of mitigation tactics can be implemented by both suppliers and customers of transportation services, offering significant potential to reduce business interruption losses. **Fehler! Verweisquelle konnte nicht gefunden werden.** provides a summary of the main tactics for mitigating transportation network disruptions.

Supplier-Side Resilience Options	Customer-Side Resilience Options
•Excess capacity*:* Bringing capacity from a network that is experiencing little or no damages •Re-routing: Redirecting vehicles to alternative routes, such as vehicles to operating ports •Cargo prioritization: Prioritizing, taking cargo values into consideration •Effective infrastructure asset management: Improvements in traffic flows •Production recapture: Working extra hours/shifts for instance unload backlogged ships after ports reopen. •Export diversion for import use: Obtaining goods originally intended for the international market as substitutes for disrupted imports or goods produced domestically. •Effective management: Improving decision-making, stakeholder coordination, information sharing •Modal substitution (deploying substitute mode of transport) (Janic 2018) and sourcing and distribution from alternate sources. •Conservation (reducing volume of transport services) (Janic 2018)	•Use of inventories: Stockpiling critical inputs •Conservation: Implementing ways to utilize lower quantities of inputs per unit of output •Input substitution: Making use of goods like the ones whose output is disrupted •Import substitution: Transporting goods in supply shortages into the region from outside of it •Production recapture: Working extra hours/shifts for instance after the ports reopen to make up lost production •Production relocation. Moving production activities to branch plants/facilities located outside of disaster-affected regions. •Effective travel demand management: implementing ways to decrease travel demand during recovery

Figure 2: Summary of resilience tactics to transportation network disruptions (Adapted from Wei et al. (2022) and Janic (2018))

Transportation network disruptions specifically *interrupt goods in transit,* leaving other supply chain operations (such as production) intact unless ripple effects occur (Wilson, 2007). Such disruptions occur when material flow between two echelons in a supply chain is interrupted, ***temporarily halting the transit of goods, regardless of the disruption's source*** (Wilson, 2007). Previous literature on transport network disruptions has examined disruptions across various transport modes, their links and nodes, and their impacts. For instance, studies have focused on disruptions in rail passenger transport networks (Janić, 2018), road transport networks (Kurth et al., 2020; Mattsson & Jenelius, 2015; Pregnolato et al., 2017), as well as disruptions in specific nodes such as ports (Verschuur et al., 2020; Wei et al., 2022). Additionally, research has explored disruptions in multimodal transportation systems (Burgholzer et al., 2013; Tympakianaki et al., 2018) and specific locations within the supply chain (Wilson, 2007). Various types of mitigation tactics can be implemented by both suppliers and customers of transportation services, offering significant potential to reduce business interruption losses. Figure 2 provides a summary of the main tactics for mitigating transportation network disruptions.

2.3 Supply chain disruptions

Commonly, a supply chain disruption is seen as an unplanned event upstream or downstream the supply chain that disrupts the flow of goods or services (Craighead et al., 2007; Manhart et al., 2020), and, therefore, affects the focal firm negatively (Bode & Macdonald, 2017). Norrman & Lindroth, (2001) distinguish between different scales of supply chain disruptions, ranging from operational matters to large-scale events such as natural hazards (e.g., flooding, earthquakes, and hurricanes) and man-made events (e.g. accidents, political instability, terrorism). They differ in their degrees of uncertainty as well their potential impact. **Supply chain disruptions may occur as the consequence of transport network disruptions, or also be unrelated to them**, e.g. in the case of quality issues in production or a fire at a manufacturing plant.

Supply chain disruptions pose multifaceted challenges to businesses that extend beyond mere operational hindrances. These disruptions can incur substantial financial costs, including increased expenses associated with expedited shipments, alternative sourcing, and the implementation of contingency plans. Furthermore, such disruptions often result in reduced revenue streams due to delays in fulfilling customer orders and subsequent sales losses. Concurrently, inventory shortages stemming from disrupted supply chains can precipitate production delays, impairing customer satisfaction and market competitiveness. Supply chain disruptions can inflict reputational damage on firms, eroding customer trust and brand equity. Operational disruptions may trigger contractual penalties, legal liabilities, and regulatory non-compliance, exacerbating the adverse impact. The complexity of supply chain networks amplifies these challenges, necessitating a strategic reassessment of supply chain design and risk management practices to enhance resilience in the face of unforeseen disruptions. Thus, mitigating the impacts of supply chain disruptions requires a comprehensive understanding of the interconnectedness and vulnerabilities inherent within global supply chains, underpinning the imperative for proactive risk mitigation strategies and resilience-building efforts. Importantly, the effects of a disruptive event can either cascade through the supply chain or be mitigated.

Mitigation strategies for supply chain disruptions can broadly be grouped into two types: (a) bridging strategies that focus on early warning and quick mitigation that create linkages between the firm and its environment, and (b) buffering strategies that establish safeguards from an internal focus, thereby minimizing the firm's exposure to risk and uncertainty in the environment (Bode et al., 2011). Increasing information sharing in the supply chain is an example of a bridging strategy, while pre-positioning stock would be an example of a buffering one.

Disaster management offers a cyclical view on approaching disruptions. *Prior to* any disruption, firms need to develop the required level of readiness to reduce the likelihood or the potential impact of disruptive events (Chowdhury and Quaddus, 2016). Preparedness strategies include a wide range of activities, from pre-positioning inventory and establishing flexible production capacity, and vetting alternative suppliers, but also training personnel, identifying alternative suppliers, routes, and transportation modes (Jahre et al., 2016). Many disruptive events send out early warning signals (Mitroff, 2000). If these accident precursors are detected and correctly interpreted, for instance by supply chain visibility (Brandon-Jones

et al., 2014), disruptions can be averted or their impact limited. Supply chain visibility can include aspects of information sharing across supply chain members, but also tracking and tracing, visibility into scheduled arrivals, or into one another's logistics information systems. However, when it comes to events outside of the supply chain, it can extend to early warning of, and related anticipatory action to hydro-meteorological hazards (Yan, 2023); or similarly, of geopolitical developments. Thus, for example, new suppliers can be activated, or new routes established before a region or e.g. a border crossing is cut off. Similarly, items can be delivered to a region prior to connections being flooded. *During disruptive events*, firms focus on a fast response to supply chain disruptions (Bode and MacDonald, 2017). It is crucial to respond to short-term disruptions quickly, and adaptability, to adjust supply chain design to meet structural shifts (Kovács & Falagara Sigala, 2021). For example, production changeover was a popular mitigation strategy that enabled companies and entire countries to reorientate their production in response to the COVID-19 pandemic, with e.g. the automotive industry producing ventilators, or distilleries producing hand sanitizers (Kovacs and Falagara Sigala, 2021). *Post disruption*, supply chains require response and recovery ability to reduce the impact and to bounce back from the disruption (Chowdhury and Quaddus 2016). This may require redesigning supply chains, and reconstructing facilities and infrastructure. The cycle is closed by learning from disruptions, for better preparedness and supply chain resilience.

Although companies and governments have been focusing on building capabilities to anticipate supply chain disruptions and mitigate their impact (Ambulkar et al., 2015), recent disruptions, such as COVID-19 and Russia's invasion of Ukraine have demonstrated that many of these entities were not sufficiently prepared for disruptions at such a scale (Craighead et al., 2020; Kovács & Falagara Sigala, 2021; Srai et al., 2023). These disruptions underscored the need for supply chains to rebuild with resilience to effectively respond to challenges posed by systemwide disruption (Browning et al., 2023). Unlike past disruptions, which were often narrow in impact and short-term in duration, these recent disruptions have shown an intersectionality of disruptive events and revealed shortcomings in responses, as discussed more in detail below.

2.4 Intersectionality and ripple effects of disruptions

The COVID-19 pandemic triggered severe disruptions globally for most supply chains and businesses, leading to uncertainties in both supply and demand, as well as capacity fluctuations, consequently causing gaps and disruptions within global supply chains. This combined with the healthcare crisis serves as a prime example of the challenges faced in maintaining societal resilience. The ongoing Russia–Ukraine conflict is further exacerbating disruptions in global supply chains, compounding the challenges imposed by the COVID-19. These disruptions have created both a ripple effect and highlighted intersectionality throughout global supply chains worldwide (Alam et al., 2024).

According to Dolgui et al., (2020, p. 1286), the ripple effect "refers to structural dynamics and describes a downstream propagation of the downscaling in demand fulfilment in the supply chain as a result of a severe disruption." The definition implies that the ripple effect refers to multi-stage networks and triggering failures in the network elements as a domino effect (Ivanov & Dolgui, 2021). Under'estimating the negative influences of the ripple effect

can lead to a misunderstanding of the repercussions that may result in significant, far-reaching, and long-lasting damages (Alam et al, 2024).

The incident evolution of a disruptive event can result in cascades within the same sector but also across sectors (Kachali et al., 2019), through simultaneous as well as sequential dynamic developments. For example, incident evolutions in the pandemic have been described in Kovács and Falagara Sigala (2021) as follows: The initial direct impact was observed in manufacturing plants, which had to cease operations when their workforce became ill or was quarantined. This led to disruptions not only at individual plants and production lines but also across entire industries. Subsequent indirect effects rippled through the supply chain, particularly in cases where alternative suppliers could not be secured or were simultaneously affected. Further indirect consequences quickly materialized due to a combination of export and travel bans, compounded later by widespread unemployment resulting from reduced consumption. Concurrently, the pandemic induced various forms of irrational consumer behavior, from panic buying to price speculation, exacerbating the bullwhip effect. A further key characteristic of the pandemic setting is the simultaneous occurrence of severe disruptions in supply, demand, and logistics infrastructure, creating a novel complex scenario with both forward and reverse ripple effects (Falagara Sigala et al., 2022).

Intersectionality of transport disruptions refers to the overlap or convergence of multiple factors or events affecting transportation systems simultaneously (Steinfield et al., 2021). This intersectionality can involve various types of disruptions, such as natural hazards, geopolitical conflicts, infrastructure failures, or technological breakdowns, occurring concurrently or sequentially within the transport network. Unlike ripple effects, which focus on the spread of disruptions within a specific system (e.g., supply chain) (c.f. Dolgui et al. 2020), the intersectionality of transport network disruptions emphasizes the multifaceted nature of disruptions affecting transportation infrastructure, services, and operations and the society at large. These disruptions may interact and compound each other, leading to complex challenges for transportation stakeholders and users. For instance, the intersectionality of the economic, climate and digital crises along with the war in Ukraine and the remnant effects of COVID-19 has significantly impacted the transport sector (Scott & Scott, 2023).

The World Economic Forum has called the current situation a “polycrisis”, where the world is facing connected risks, with the cost-of-living crisis being the most immediate and severe risk. The climate-related risks are the biggest future threat and the polycrisis could have catastrophic consequences given the rise of armed conflicts (Alam et al., 2024; *We’re on the Brink of a ‘Polycrisis’ – How Worried Should We Be?*, 2023). The WEF defines a polycrisis as: “a cluster of related global risks with compounding effects, such that the overall impact exceeds the sum of each part”, which accurately captures the intersectionality of the recent disruptive events in the EU.

2.5 Impacts of disruptions on transportation networks

This section reviews the impact of disruptions on transportation networks at different levels and approaches. Firstly, the disruptions can have an impact on individual actors within the transport ecosystem, such as operators, logistics companies, and other service providers.

The disruptions can also have an impact on *individual nodes and links*. The predominant focus of extant research lies in the examination of disruptions through isolated nodes or links. For instance, Pregnolato et al. (2017) investigated the impact of floods on the road network. The authors note that there's a common assumption that a road is either fully operational or fully blocked in the presence or absence of flooding. However, they argue for a more nuanced approach that considers factors such as vehicle speed and the depth of standing water. The work identifies the maximum threshold for safe driving, stopping, and steering without loss of control as 30cm (depth of flood water). Below 30cm, it may still be possible for the road to be operational, albeit at reduced speeds. In another study, Tympakianaki et al., (2018) analyzed the impact of tunnel closures, which are a common occurrence in Sweden, on multimodal redistribution of vehicles (Tympakianaki et al., 2018). The authors identified impacted areas, assessed the impact on network performance, demand patterns and the redistribution of vehicles onto alternate paths. Such analysis is crucial for traffic management authorities when planning to use spare capacity on alternate modes of transport.

However, the functionality of individual node of transportation system is largely dependent on the status of the entire network, which can be affected by large-scale disaster events such as earthquakes and hurricanes that result in spatially distributed impacts (Wei et al., 2022). As most of the previous academic investigations focus on isolated nodes or links, there remains a gap regarding the interdependency dynamics in *transportation networks*, including the ripple effects. From *a supply chain* perspective, disruptions in transportation networks can affect both the customers and suppliers of logistics service providers, as well as the wider supply chain, as described in the section on supply chain disruptions. The negative consequences of disruptions can have an immediate damaging impact as well as longer term effects (Blackhurst et al., 2011).

In the context of transport network disruption, *societal impact* refers to the consequences and effects of disruptions on individuals, stakeholders, communities, and society as a whole. Transport network disruptions can have severe *economic impacts.* Economic impact measurement does not focus on property damages, which typically occurs when the disruption commences, but instead highlights the loss reductions of the flow of goods and services resulting from the disruptions. The economic impacts of these disruptions can extend well beyond the event, node or link itself, for instance beyond on-site operations at the port complex, through supply chain curtailments and delays in delivering imports and exports to their destinations (Wei et al., 2022). The flow losses are typically measured as the reduction in production levels at the micro-level or as losses in gross domestic (regional) product (GDP or GRP) and are usually characterized as business interruption (Wei et al., 2023). For instance, Kurth et al. (2020) explored road transport network scenarios in different cities in USA wherein cities exhibited varying degrees of resilience. The findings unveiled substantial impacts on GDP, particularly in scenarios lacking resilience. Surprisingly, even affluent, and economically robust cities suffered considerable losses due to transport disruptions. Moreover, the recovery period for these cities extended to 1-2 years.

Transportation network disruptions, especially those affecting broader regions, can have significant impacts, particularly when considering the indirect and ripple effects through the supply chains and interconnected transportation infrastructure system (Wei et al., 2022). It

is essential to note, when analysing societal impact, that transport network disruptions do not affect all people in a region equally, and the impact can be linked to social vulnerability. The term social vulnerability specifies how societal characteristics of individuals, groups, or communities impact their ability to anticipate, cope with, and recover from disruptive events shortly (Delgado et al., 2023). Economically disadvantaged groups typically suffer a higher proportion of income losses directly and indirectly from transport network disruptions than those in middle- and upper-income brackets (Wei et al., 2022). For instance, disruptions to road networks can significantly affect the food security of communities (Delgado et al., 2023). Delgado et al. (2023) examined the impacts of disruptions in the food supply chain caused by road network issues across different counties in the mid-Atlantic region of the USA. They suggest that factors such as race and ethnicity, household composition, economic status, and household type contribute to the social vulnerability of food transportation disruptions. As critical gateways in a nation's supply networks, seaports and their associated inland transportation infrastructure are particularly vulnerable to major disruptions (Wei et al., 2022), that can affect the people in a region unequally. Wei et al (2022) observed that lower-to-middle income groups are more proportionally impacted by port distributions, while middle-to-higher income groups are more impacted by building damages. These studies underscore the importance of considering the broader societal context when analyzing the impacts of transport network disruptions (Delgado et al., 2023).

Societal resilience includes broader responses, even outside the transport sector. It is critically important to focus on ensuring the restoration of the transport system to a good workable order as soon as possible. However, Marsden et al., (2016) highlight that this should be just one part of resilience. The authors emphasize that societal resilience includes broader responses, even outside the transport sector. They encourage the consideration of why consumers are using the transport network and what activities are involved. They posit that there is significant adaptive capacity within the society which could be better harnessed to reduce the impact of disruptions. They propose so called smart resilience, which is a combination of both transport and non-transport responses, working to minimize impact of disruptions. These include better and coordinated communication with consumers, developing capacities of users and businesses to adapt to different events through greater multi-modality, flexible working practices and reassessment of the economic impacts of disruptive events beyond the obvious reduction in flows and increased delays. Although this work is targeted at passenger transport, some of the insights are also applicable to freight transport.

To conclude, freight transportation disruptions have garnered less attention compared to supply-related disruptions. The literature reviewed underscores the critical importance of understanding mitigation strategies across different modes of transport, links, and nodes. Importantly, various resilience tactics, applicable to both suppliers and customers of transportation services, hold promise in mitigating business interruption losses. Recognizing the importance of different stages in the disruption cycle—from readiness and preparedness to response and adaptation, and finally, recovery, adjustment, and learning—is vital. Furthermore, the impacts of events like COVID-19 and war in Ukraine, highlight the need to understand the intersectionality and ripple effects.

Our study takes a focused approach to study the freight transport network on two TEN-T corridors in the EU. The disruptive events affecting the Rhine-Danube corridor and the North Sea-Baltic corridor are studied in detail. The resilience and societal impact of the EU transport network to these disruptions is the mainstay of this report.

3. Methodology

3.1 Research design

The findings presented in this report draw upon a wide range of sources, including both primary and secondary data, namely 17 expert interviews, 7 focus group discussions and document analysis. The interviews were conducted to gain insight into stakeholders' perceptions of disruptions in the EU multimodal transport network. Interviewees were infrastructure managers, logistics operators, members of government agencies, and other stakeholders in the EU transport network. Appendix A presents the table of metadata, with the interviewee descriptions and codes used to represent them in this report. A total of 8 countries were represented in these interviews: Germany, Finland, Lithuania, Estonia, Switzerland, Austria, Denmark, and Belgium (see Figure 3). 7 of the interviewees were involved in intermodal transport including rail, road, inland waterways, and short sea shipping. 5 others represented combined transport operations involving rail and road. One organization managed the combined transport of road and air. There were 5 organizations who also managed terminals and/or warehouses. One organization regularly dealt with 4 modes of transport: air, rail, road, and short-sea shipping. Two organizations were focussed on single modes of transport, one on road and one on maritime shipping, and did not consider multimodal operations (see Figure 4).

Figure 3: Geographical spread of interviewees.

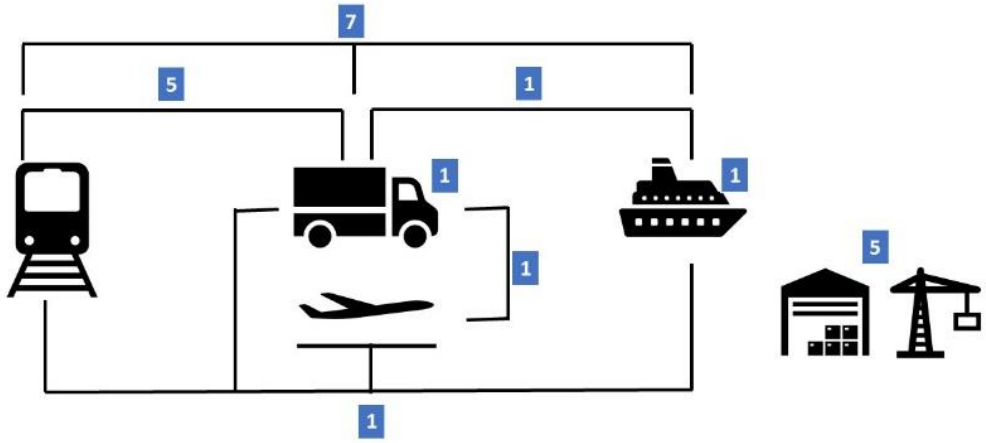

Figure 4: Transport modes and nodes and number of interviewees representing each.

60 people participated in focus group discussions in groups of 5 to 8 people. Participants were asked to choose 2 to 4 recent disruptive events in Europe in the last 5 years and analyse the following: the cause, impact, response, geographical extent, and time duration of the disruption. Focus group discussions spanned multiple disruptions and their overall analysis with respect to the European transport network. These findings were presented as flipcharts accompanied with a short presentation. Further analysis was then conducted on several disruptive events based on document analysis. Documents that formed part of the analysis are all publicly available online. They include articles from both national and international media sources as the disruptive events discussed here all received wide-spread media coverage, as well as reports for example by government agencies, transport operators, or non-governmental organizations. Appendix B contains the links to the various document used in the analysis. The qualitative data collected was analysed using thematic analysis. The analysis was guided by the previously developed typology for disruptive events (see classification of disruptive events (Kulkarni et al., 2023)).

3.2 Criteria for selecting case studies

This report builds upon previous deliverables of the ReMuNet project, particularly the typology of disruptive events (Figure 5). Typology differentiates between causes of events. These formed a criterion for selecting the disruptive events for the analysis in this report. The six cases studies selected cover various cause categories: natural hazards, regulatory changes, health emergencies, geopolitical crises, and extreme weather events. This is regarded as essential to allow for a broader assessment of societal impact as some causes have inherent socio-economic dimensions while the societal impact for others, particularly the natural events, may at first glance be more remote.

A second criterion was that the significance of the cases was emphasized during the interviews and focus groups. A third criterion for selection of events was their recency. All disruptive events covered in this report occurred in the past 5 years, 2019-2024. This is particularly important when analyzing societal impact as the interconnectedness of transport networks and associated trade and supply chains has developed considerably over recent years. Therefore, the societal impact of transport disruptions can be assumed to have changed significantly. We also sought cases in which we expected to discover

intersectionality and ripple effects. Further we also wanted to include both recurrent (such as floods) and unique cases (such as Brexit).

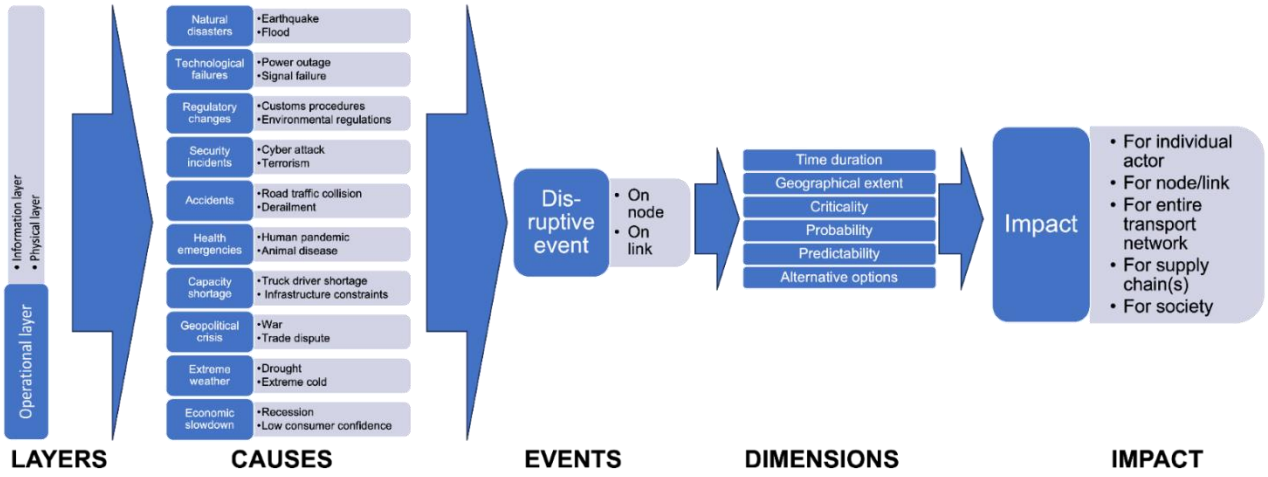

Figure 5: Typology of disruptive events.

A further criterion for the selection of events studied in this report was that they had an impact along the two corridors of the interest of ReMuNet project, the Rhine-Danube corridor, and the North-Sea Baltic corridor, as explained in section 3.2.1 below.

3.2.1 *Association with TEN-T networks of interest*

The Trans-European Transport Network (TEN-T) corridors are strategic infrastructure routes across the European Union designed to improve and facilitate the movement of goods and passengers across member states (Commission, 2024). These corridors are part of a broader initiative aimed at developing a modern, high-capacity transport network across Europe, making cross-border travel smoother, safer, and more efficient. The TEN-T network encompasses various modes of transport, including roads, railways, inland waterways, maritime shipping routes, ports, airports, and terminals, integrating them into a cohesive system and focusing on sustainability (Commission, 2024).

Primary objectives of the TEN-T corridors include enhancing connectivity between Eastern and Western Europe, reducing travel times, increasing sustainability through the promotion of cleaner transport modes, and boosting economic growth by improving access to markets. The network is divided into Core and Comprehensive networks, with the Core Network being the most significant and strategically important component, consisting of nine corridors that are intended to be fully functional by 2030 (Commission, 2020). These corridors not only serve to improve internal EU transport cohesion but also to connect the EU with neighbouring countries and regions, thereby extending the benefits of enhanced mobility and trade beyond its borders. The regions of interest are chosen along two Trans-European Transport Network (TEN-T) corridors. The first is the Rhine-Danube corridor (Ayala, 2024).) including multiple major cities in central Europe such as Vienna, Bratislava, Budapest, Frankfurt, Munich, Prague, and Zilina (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). The corridor is a crucial east-west link across continental Europe. The second is the North Sea-Baltic corridor (Trautmann, 2024)), which connects northern Europe with northwest and northeast of the EU, including Finland, Estonia, Latvia, Lithuania, parts of

Sweden, and Poland (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). In July 2022, this corridor was proposed to be extended to include Ukraine and Moldova, beginning with the introduction of solidarity lanes.

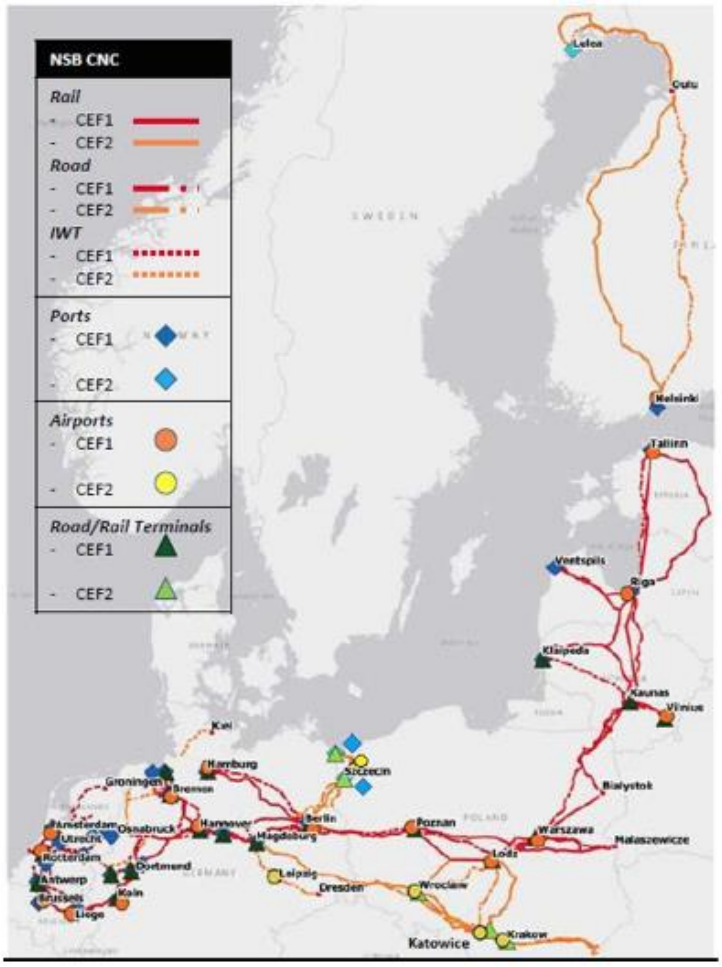

Figure 6: North Sea-Baltic corridor (Trautmann, 2024), 5th work plan

The case studies of the ReMuNet project study the impact on these corridors, as also the use cases in WP5. While selecting the historic disruptive events for analysis, the results of the searches were filtered to those that either originated in or affected the regions of interest. The Rhine-Danube Corridor is one of the nine core network corridors of the TEN-T. This corridor is particularly significant as it focuses on linking Central Europe with the southeastern region of the continent, primarily leveraging the Rhine and Danube rivers, two of Europe's major waterways, to facilitate transport in an environmentally friendly way (Peijs, 2018). While the core corridor is usually considered from Strasbourg and Frankfurt downstream, its connection to the Rhine-Alpine corridor is essential to understand its interconnectedness also in terms of inland waterways. Together, stretching from the North Sea ports in the Netherlands and Germany, through central Europe, and extending to the Black Sea, the Rhine-Danube Corridor encompasses a comprehensive multimodal transport route that includes waterways, railways, roads, and airports. Its strategic focus on inland waterways highlights the EU's commitment to promoting sustainable modes of transport, aiming to shift a substantial portion of cargo traffic from roads to less environmentally damaging modes (Commission, 2024). The corridor serves not just as a vital trade route enhancing economic interactions between regions but also as a key facilitator for cultural

and social exchange. By improving the infrastructure and operations along this route, the Rhine-Danube Corridor aims to reduce travel times, increase safety and reliability, and support the European Union's broader objectives of cohesion, sustainability, and economic growth. The development of this corridor is essential for unlocking the full potential of the internal market, ensuring smooth and efficient transport links that are crucial for businesses, travellers, and the overall economy of the region.

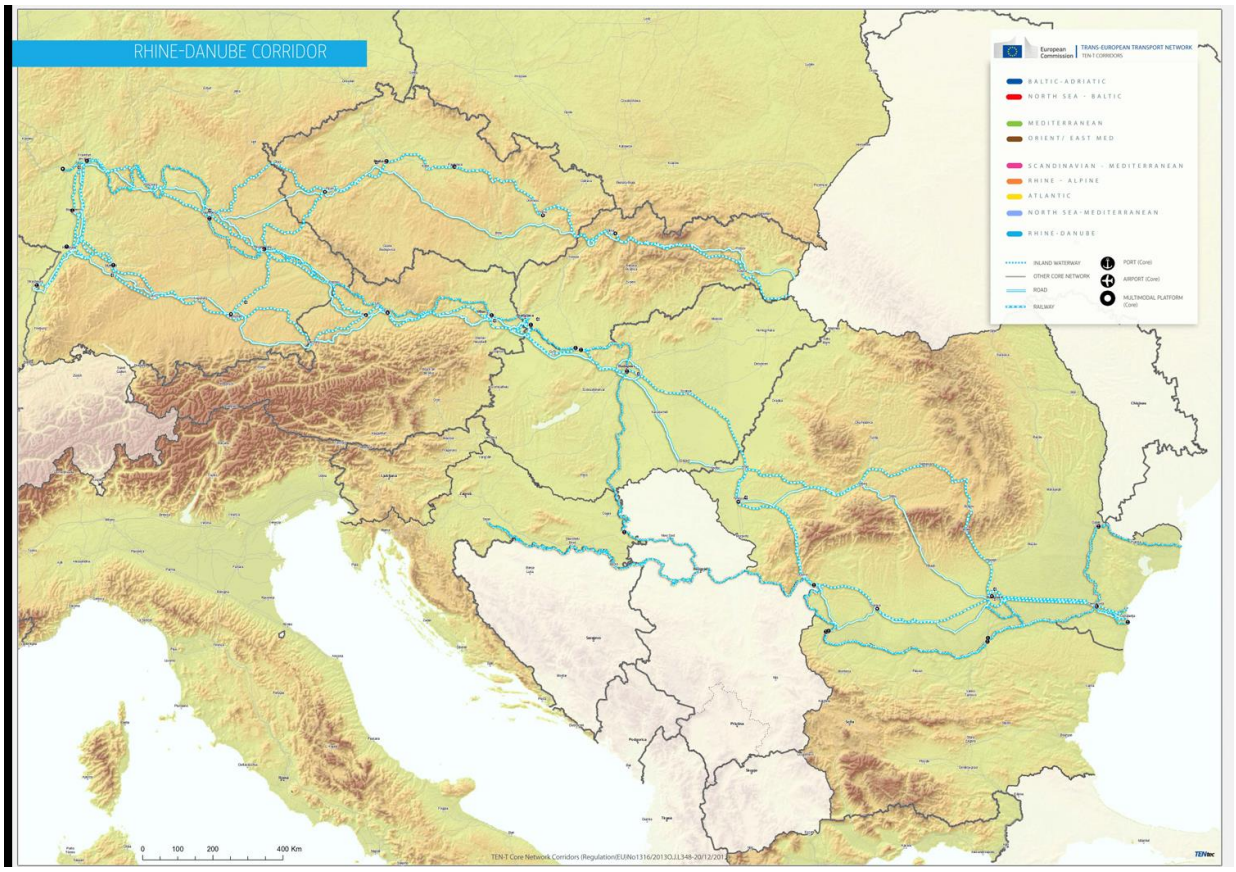

Figure 7: Rhine-Danube corridor (Ayala, 2024)

The North Sea-Baltic Corridor is envisaged to forge stronger and more efficient transportation links between the North Sea region and the Baltic states. It is the only TEN-T corridor situated exclusively in the North of Europe (Panteia & Stratec, 2017). This corridor connects the dynamic economic area of the North Sea, including key ports in Belgium, the Netherlands, and Germany, with the rapidly growing markets and ports of the more recent EU members in the Baltic Sea area, such as Poland, Lithuania, Latvia, and Estonia (Öberg & Szydarowski, 2019). Unlike other corridors that might prioritize inland waterways, the North Sea-Baltic Corridor places a significant emphasis on developing a multimodal network that integrates sea routes, rail, road, and air transport (Consortium, 2014). This includes major projects to upgrade rail infrastructure, enhance road connections, and improve port facilities, thereby ensuring smoother, more sustainable, and efficient freight and passenger movements across these regions. A key objective of the North Sea-Baltic Corridor is to overcome geographical barriers and historical infrastructure gaps, facilitating a seamless flow of trade and travel that supports economic growth and cohesion within the EU (Panteia & Stratec, 2017). It aims to boost the accessibility and competitiveness of the regions it connects, while also contributing to the EU's environmental goals by enhancing the

sustainability of transport operations along its route. The North Sea-Baltic Corridor embodies the EU's vision for a connected, competitive, and sustainable future for transport.

3.2.2 *Causes of disruptive events*

As Deliverable 1.3 demonstrated, categorizing disruptive events based on their causes was the most intuitive approach for most of the participants in the primary research. Combining the inputs from all participants, the exhaustive list of categories contained ten entries, as shown in Table 1. Some of the examples in each of the categories are also shown.

Table 1: Classification of disruptive events based on causes.

Classification	Explanation	Example
Natural hazards	Floods, earthquakes, or landslides often cause physical damage to infrastructure, leading to a significant recovery and repair period adversely affecting logistics performance (Vaillancourt & Haavisto, 2016)	Rockslides closing routes in the alps summer 2023
Technological failures	Malfunctioning transport management systems or breakdowns in communication technologies, can lead to significant inefficiencies to both the physical and information layer (Klumpp & Loske, 2021)	Signalling failure, internet outage
Regulatory changes	New customs procedures or environmental restrictions, can require adjustments in operational processes, leading to temporary slowdowns, increased compliance costs, and potential bottlenecks (Xu & Xu, 2022)	Customs changes due to Brexit
Security incidents	Cyber-attacks or terrorism, pose significant risks on both the physical and the information layer, potentially closing parts of the transport network or causing delays (Yang & Hsu, 2018)	Cyberattack, border closures
Accidents	Collisions or derailments can cause immediate and localized disruptions, but often lead to temporary closure of transport routes, diversion of freight traffic, and can sometimes have cascading effects on the broader network (Büchel et al., 2020)	Rastatt tunnel collapse, Gotthard base tunnel derailment
Health emergencies	Pandemics impact freight transport by causing labor shortages, altering supply and demand patterns, and necessitating new health and safety protocols, resulting in a wide-spread impact on logistics and supply chains (Singh et al., 2021)	COVID-19
Capacity shortage	Shortage in transportation vehicles, infrastructure, or human resources can lead to bottlenecks and increased transit times (Ji-Hyland & Allen, 2022)	Driver shortages due to Brexit
Geopolitical crisis	Armed conflicts or trade disputes, can lead to border closures, restricted access to certain routes, and increased scrutiny of goods (Caramuta et al., 2023)	Russia-Ukraine crisis, Brexit
Extreme weather	Heavy snowfall, rain, storms, or heatwaves, can disrupt all modes of freight transport. They can cause physical damage to infrastructure, reduce operational safety, and lead to closures or reduced capacity on certain routes (Doll et al., 2014)	Drought-induced low water on the Rhine 2022
Economic slowdown	As transport is a derived demand, an *economic slowdown* can lead to a decrease in demand for freight transport services, which can lead to overcapacity issues, financial strain on transport providers, and a reduction in investment in the transport infrastructure (Loske, 2020).	US-2008, EU-2022

3.2.3 *Dimensions and impact of disruptive events*

The typology developed in Deliverable 1.3 also includes multiple dimensions of events that will ultimately determine the disruptive event's impact as shown in Table 2 below. In the analysis of effects of disruptive events and their resulting societal impact presented in this report, all these dimensions will be considered as the selected case studies are discussed. The typology developed in deliverable 1.3 also highlights different levels of impact of disruptive events in the European transport network as detailed in **Fehler! Verweisquelle konnte nicht gefunden werden.**.

Table 2: Dimensions of disruptive events

Dimension	Explanation
Time Duration	Refers to how long a disruptive event affects the transport network, varying from short-term (hours or days) to long-term (weeks, months, or longer). Impacts the severity of disruption on transport, supply chains, and society.
Geographical Extent	Measures the spatial range affected, from localized areas like a single node to widespread impacts across countries or regions. Influences the scope of response, recovery, and logistical challenges.
Criticality	Evaluates the importance of affected transport components, focusing on their role in the network. High-criticality disruptions can cause significant economic losses and operational challenges.
Probability	Considers the likelihood of a disruptive event occurring, aiding in risk management and preparation for more likely scenarios.
Predictability	Assesses the ability to anticipate an event, influencing planning and mitigation efforts. Varies from predictable events allowing pre-emptive action to unpredictable events requiring rapid response.
Alternative Options	Measures the availability of alternative routes or modes to mitigate the impact, crucial for resilience planning and operational continuity during disruptions.

These levels of impact consider the highly interconnected nature of transport networks within the European economic area and society and resultant ripple effects of any disruption.

Table 3: Levels of impact of disruptive events

Level	Explanation
Individual Actor	The immediate effects on individual entities within the transport ecosystem, like operators and logistics companies. Includes operational delays, increased costs, and reduced service quality.
Transport Node or Link	The specific elements like airports, ports, and bridges. Disruptions can lead to bottlenecks, rerouting challenges, and congestion, affecting broader operational efficiencies.
Transport Network	The issues affecting multiple modes and routes. Caused by large-scale disasters or failures, leading to widespread delays and significant economic losses.
Supply Chains	The repercussions on supply chains, including production delays, inventory shortages, and increased costs, impacting businesses beyond the disruption area.
Society	The effects on the public, communities, and economy at large. Can lead to reduced access to goods, increased prices, economic downturn, and social/health consequences.

3.3 Framework for analysis

The focus of the analysis in this report lies on the last three levels of impact—transport network, supply chains, and society—underscores the compounding nature of transport disruptions in a highly interconnected world. These levels capture the ripple effects that can amplify initial disruptions, spreading impacts far beyond the point of origin to affect economic stability, societal well-being, and global supply chain operations. Understanding these broader implications is essential for developing comprehensive risk management and response strategies that safeguard not just the transport infrastructure but the European economy and society. This approach highlights the necessity of resilience and adaptability in mitigating the far-reaching consequences of disruptions in the European transport network. In each of these levels of impact, the analysis of each case will consider the impact of the disruptive event, the response to the disruptive event, and the resilience exhibited at

that level. The framework for analysis used for the subsequent section of this report is summarised in Table 4.

Impact: The impact of a disruptive event is the immediate and direct effect it has on the transportation system, economy, and society. At various levels, impact can range from operational disruptions for individual transport operators, causing delays and financial losses, to broader economic and societal repercussions. The severity of the impact depends on the scale and nature of the event.

Response: The response to a disruptive event involves the actions taken by transport operators, authorities, companies, and other stakeholders to manage and mitigate the effects of the disruption. This can include deploying alternative transportation modes, rerouting traffic, implementing emergency logistics strategies, and providing timely information to the public. Effective response strategies are crucial for minimizing the duration and extent of the impact, ensuring safety, and maintaining as much operational continuity as possible.

Resilience: Resilience refers to the ability of the transport network, its operators, and the broader economic and social systems to withstand, adapt to, and recover from the effects of a disruptive event. This includes pre-event planning and investment in infrastructure, systems, and policies that enhance flexibility, as well as post-event recovery efforts to restore services and support affected entities and individuals. Resilience is a critical aspect of managing transport disruptions, as it determines the speed and effectiveness of recovery and the long-term sustainability of the transport ecosystem.

Analysing the impact, response, and resilience at each level of a transport disruption offers a comprehensive view of how such events affect Europe. Transport networks do not exist in isolation and transport is a derived demand based on economic activity, supply chain operations, and ultimately consumer demand. Understanding the nature and extent of the impact provides insight into the immediate challenges posed by disruptions. Examining the response reveals the effectiveness of mitigation strategies and the capacity for operational continuity under stress. Assessing resilience highlights the long-term preparedness and adaptability of the transport system and its stakeholders. This three-pronged approach is essential for developing robust strategies that enhance the resilience of the transport network, minimize the adverse effects of future disruptions, and ensure the rapid recovery of affected systems and communities.

Table 4: Framework for analysis

	Transport Network	Supply Chain	Society
Impact	Impact on transport network	Impact on supply chain	Impact on society
Response	Response by transport network	Response by supply chain	Response by society
Resilience	Resilience of transport network	Resilience of supply chain	Resilience of society

4. Analysis of past disruptive events

In this section, six disruptive events chosen based on the criteria described in the previous section are analyzed in accordance with the framework presented above, considering impact, response and resilience across the transport network, supply chain, and society levels. Given the ten categories of causes of disruptive events developed in the typology in ReMuNet Deliverable 1.3, the six case studies presented here include natural hazards, regulatory changes, health emergencies, geopolitical crises, and extreme weather events. Disruptive events that occurred in the last five years along the TEN-T corridors Rhine - Danube and North Sea – Baltic were selected. Table 5 describes the disruptive events according to the dimensions of disruptive events identified in the typology.

4.1 Rhine droughts

The Rhine River is a critical waterway connecting multiple European countries, including Switzerland, Germany, France, the Netherlands, and Belgium, moving over 300 million tonnes of goods in a year. It is therefore also referred to as the primary artery of the region (Droughts Are Creating New Supply Chain Problems. This Is What You Need to Know, 2023; Leuven et al., 2009). In the last 5 years, declining water levels leading to transport disruptions have been experienced in 2018, 2022 and more recently 2023. The severity of the reduced water levels resulted in limitations on cargo loaded in the vessels (Steitz & Flasseur, 2023). For example, when the water level in the river drops below 135 cm, cargo must be reduced, sometimes by half, to ensure safe navigation (Spiegel, 2023).

Historically, the Rhine has been significant, not just as a political border, but also a crucial economic lifeline, as highlighted by Levainville, (1924), as early as 1924. German inland shipping currently accounts for nearly 7% of the total national transport, although there is a trend of steadily decline from the previous years (Nicolai, 2022). There are several big corporates and industries strategically situated along the Rhine to reduce transport costs, such as BASF and Covestro. Since the transport networks depending on the Rhine are so close-knit, the effects of disruptions percolate both downstream and upstream in the related supply chains (Meuchelböck & Jannsen, 2023). There are industries which rely on the river for their raw materials as well as finished goods. A disruption in supply of raw materials leads to delays and increased costs (Schattenberg, 2023). Reduced water levels can result in higher shipping costs since ships that are operational are required to operate with reduced capacities. The cargo then needs to be distributed across several ships. Companies such as the BASF receive nearly 40% of their raw materials from the river and use the water from the river for their cooling systems. The river is still the primary shipping route for grains, chemicals, minerals, coal, and oil products (Spiegel, 2023). In 2022, 182 metric tons of material were transported on the Rhine, which is significant, even though these were the lowest numbers since the Reunification and 6.4 percent less than in 2021.

Table 5: Dimensions of disruptive events across case studies

Case	Dimensions					
	Time Duration	Geographical Extent	Criticality	Probability	Predictability	Alternative Options
Rhine droughts	July-August 2022	Rhine river from Switzerland to the Netherlands, but most affected were stretches of the river in Germany	Major EU inland waterway that serves significant industrial areas and is critical for transport of fossil fuels	Water levels get low enough to affect shipping every few years, most recently 2018, 2022, and 2023	Depends on snow and rain levels along Rhine and tributaries so monitoring gives an indication; water levels fall over days /weeks	Mostly no waterway alternative, modal switch to railways running in parallel to the river or road transport
Floods along the Rhine-Danube corridor	May 2019, July 2021, August 2023, Dec 2023	Germany, Slovenia, Austria, Croatia, Hungary, Netherlands and effects on Italy, Lithuania, Poland	Major TEN-T corridors involved with critical transport lanes across transport modes	Heavy rainfall over short duration causing floods is now recurring, with two incidents in 2023 alone	Systems are better at predicting and evacuations are often planned	Longer routes avoiding areas of flooding, as several or all transport modes are affected, rerouting can be extensive
Brexit	Jan - Dec 2020 (transition period)	UK, Ireland, Northern Ireland, and trade with continental EU	Major changes to EU trade policies affecting supply chains across many areas	One time event, similar repercussions could repeat if further members decide to leave the EU	Most actions are planned policies. However, their impact needs to be considered thoroughly	Transport between EU and UK is affected regardless of transport route or transport mode
War in Ukraine	Feb 2022 - ongoing	Across Ukraine, effects on transport in Belarus and Russia	Major changes to energy, transport and critical supply chains (food)	First large-scale war in Europe in decades	Russian military buildup at the Ukrainian border was observed prior to the invasion	Reduced reliance on Russian energy, alternate transport routes avoiding Belarus and Russia
COVID-19 Pandemic	18 March 2020 - Dec 2021	Global, affecting countries to different degrees, at different times	Extreme disruptions across all transport modes and routes	First large-scale pandemic in a century	Started months earlier in China, difficult to predict exact progress	Complete transformation of practices and increased digital reliance
Strikes in Finland	March - April 2024	All main ports in Finland and railways	In practical terms, Finland is an island from logistics point of view, so closing ports paralyzes both export and import transportation	Medium, however, this long political strikes are quite rare	Medium, as the labour union warned about the strikes. The official announcement came 4 days before the strikes	Some containers were switched to track traffic, but no real alternatives

4.1.1 *Impact*

Transport Network

The 2022 Rhine drought presented a significant challenge to the European transport network, particularly highlighting the vulnerabilities of inland waterway transport systems. After a winter characterized by scarce snowfall, which failed to replenish the river basins, the situation was exacerbated by a summer marked by unusually dry conditions. The Rhine, which is a crucial artery for the movement of goods in Europe, experienced alarmingly low water levels, especially in areas with naturally shallow points, like Kaub in the German Middle Rhine valley. In some sectors of the river, the conditions remained navigable, allowing for transport operations to continue with adjustments. However, in the more severely affected areas, the diminished water levels drastically reduced the carrying capacity of vessels. Ships, typically a highly efficient means of moving bulk goods, had to operate with a fraction of their full capacity—some carrying as little as 25% of their typical load. This drastic measure was essential to ensure vessels could traverse the shallowest sections without running aground.

Yet, even with such reductions in cargo, certain stretches of the Rhine became virtually impassable for some vessels. This predicament was twofold: there were heightened safety risks associated with navigating these precarious conditions, and for many, the limited payload did not justify the costs of operation, leading to a suspension of services for some transport operators. Consequently, this not only interrupted the supply chain continuity for various commodities but also prompted a re-evaluation of transport and logistics strategies for stakeholders reliant on this crucial waterway. The repercussions of these disruptions rippled through the transport network, signalling a need for a diversified and more resilient approach to managing Europe's critical transport arteries.

Supply Chain

The low water levels on the Rhine affected supply chains dependent the river's transport capacities. Industrial plants, many of which had been strategically positioned along the Rhine to take advantage of the river's transport efficiency, found themselves facing significant logistical hurdles. Chemical companies, for example, were heavily impacted. Firms like BASF, which rely on the river for the movement of large volumes of hazardous materials, faced an acute challenge. These materials could not easily be transferred to other modes of transport such as road or rail, not only because of the sheer volume but also due to the specialized handling required for dangerous goods. The energy sector was also hard-hit, particularly coal power plants, which experienced supply shortages. These plants had become increasingly crucial in the European energy grid as a supplement to the reduced Russian gas supplies amidst geopolitical tensions. However, the transport constraints on the Rhine meant that coal stocks were not replenished in a timely manner, leading to concerns over energy security and potential power outages.

While it is complex to disentangle the economic effects of the drought from other simultaneous adverse factors, the consensus among experts is that the transport disruptions played a role in Germany's economic downturn during the period. The logistical bottlenecks

contributed to production slowdowns, increased costs for alternative logistics solutions, and ultimately, a strain on the economic output.

Society

The impact of the Rhine drought on society was complex, touching upon environmental, safety, economic, and social dimensions. The environmental consequences were pronounced, particularly for the river's natural habitats. Fish populations and bird species dependent on the river's ecosystem faced dire conditions as the lower water levels affected their breeding grounds and food sources, upsetting the delicate ecological balance. As the drought coincided with a heatwave, the riverbanks attracted more visitors seeking respite from the heat. However, the lower water levels led to unexpected hazards. Normally submerged dangers, including remnants of World War II ordnance, were exposed, posing new risks to the public engaging in recreational activities. Additionally, the altered flow dynamics resulted in unpredictable and potentially dangerous currents, further endangering those swimming or wading in the waters.

Transport-related concerns were amplified during this time due to the concurrent energy crisis. The restricted capability to transport fossil fuels via the river incited widespread worry. This was especially pressing considering the increased reliance on coal power plants due to the reduced supply of Russian gas. The stress on the energy supply chain was palpable, leading to fears of energy shortages and discussions about the need for more diverse and sustainable energy sources. Consumers quickly felt the economic repercussions as the transportation woes translated into higher prices for goods typically shipped via the Rhine. Notably, in the south of Germany, the cost of petrol surged, adding to the financial strain on households already grappling with the broader impacts of the energy crisis. These price hikes served as a tangible reminder of how intimately connected society is to the health and functionality of its transport networks.

Considering these challenges, the societal impact of the Rhine drought was a clear signal of the ripple effects that disruptions in natural systems can have on society.

4.1.2 *Response*

Transport Network

The response of the transport network to the Rhine drought in 2022 demonstrated the adaptability and preparedness of the system, drawing on years of established practices and infrastructure management. The backbone of the response was the robust monitoring and forecasting system that tracks water levels along the Rhine. This continuous monitoring proved provided necessary data that informed transport companies and vessel crews about the changing conditions of the waterway and enabling them to make timely decisions about their operations. Given the severity of the water level drops, the transport network had to be highly responsive. One of the immediate actions taken was the implementation of a modal shift strategy. Cargo that was traditionally moved via the river was rerouted to road and rail alternatives. This transition was not simple; it required significant coordination across different transportation modes and entities. In instances where waterway transport remained the most viable option, operational adjustments were made. This included the utilisation of shallower vessels that could navigate the low water more safely. Additionally, cargo loads

were distributed across several barges in push tow formations, maximizing the amount that could be moved without compromising safety. This required the offloading and redistribution of cargo, demanding additional labour and logistical planning.

The response highlighted the importance of having diversified transportation options and the ability to quickly adapt operations in the face of environmental disruptions. By leveraging established safety protocols and embracing flexibility in operational tactics, the transport network managed to maintain functionality despite the challenging conditions imposed by the drought.

Supply Chain

The supply chain response to the Rhine drought involved a complex set of adjustments as businesses grappled with the constraints imposed by reduced waterway transport capacities. Freight rates for water transport surged, as the limited cargo space had to be allocated across more vessels to navigate the low water levels, indirectly contributing to the inflationary pressures on consumer prices. These cost increases came during a particularly vulnerable period for global supply chains, already strained by the repercussions of the COVID-19 pandemic and the war in Ukraine.

Historical patterns have shown that a month-long spell of low water levels on the Rhine can lead to a 1% drop in German industrial production, a stark indication of the river's significance to the nation's economy. The 2022 drought necessitated a rapid adaptation of supply chains, with companies seeking alternative logistics solutions. However, the sheer volume of goods usually transported via the Rhine presented a substantial challenge, particularly for those industries and companies that were strategically situated along the river to capitalize on its transport advantages. For many of these companies, the difficulty lay in quickly securing alternative modes of transport that could handle the volume and specific requirements of their goods. The switch to road or rail transport was not always feasible, given existing contracts, availability issues, and the infrastructure required to handle heavy or hazardous materials. Additionally, there were already capacity issues on these alternative transport modes, which were dealing with their own pandemic and geopolitical crisis-induced challenges.

The response by supply chains, thus, was a mix of strategic re-routing, mode-shifting, and urgent negotiations with transport providers to secure necessary capacities. While some supply chains demonstrated flexibility, the drought underscored the need for more robust contingency plans capable of managing such drastic reductions in critical transport capacities.

Society

The societal response to the Rhine drought encompassed both strategic measures and community adaptations. Switzerland’s decision to tap into its national oil reserves was an example of proactive steps taken by governments to mitigate the immediate supply disruptions. This intervention was crucial in ensuring that essential energy needs of the population were met, in a time when alternative sources were under pressure due to geopolitical dynamics. In Germany, where there had been a deliberate pivot back to coal-fired power stations amid the energy crisis, the drought introduced a new layer of complexity

to the country's energy security. With coal deliveries by the river impeded, the nation faced an urgent challenge in fuelling its power plants—a situation that prompted broader discussions about energy policy and the need for a diverse and sustainable energy mix.

The Rhine drought occurred at a time when supply chain resilience was already a subject of public discourse due to recent high-profile disruptions. Consequently, there was a heightened public awareness about the drought's implications. This awareness further fuelled policy debates centred on enhancing the resilience of transport infrastructure and diversifying supply chains to prepare for future disruptions. Communities living along the Rhine felt the drought's impact in more personal terms. With the river serving as a lifeline for local economies, the reduced transport activities affected employment in sectors directly and indirectly linked to the riverine trade. Passenger transport services that rely on the river also experienced changes, altering daily commutes and travel plans.

Collectively, these responses underscored the importance of comprehensive planning and the need for a robust framework to address the multifaceted challenges posed by natural disruptions. They highlighted the interconnectedness of environmental stewardship, energy policy, economic strategy, and community resilience, emphasizing that a coordinated approach is essential in balancing of societal responses to environmental events like the Rhine drought.

4.1.3 *Resilience*

Transport Network

The transport network's resilience in the face of the 2022 Rhine drought showed a multifaceted approach that balanced immediate adaptive strategies with long-term planning. The static resilience was evident through the network's ability to continue shipping operations despite severely restricted conditions. This was made possible by an established system of monitoring and forecasting, which allowed for real-time adjustments to transport strategies. Vessels were operated with significantly reduced cargo loads, and where necessary, cargo was redirected through alternative transport modes such as rail and road, ensuring the maintenance of goods flow even under constrained circumstances.

As the situation evolved, the dynamic resilience of the transport network became increasingly apparent. The sector swiftly adapted by reallocating cargo to available rail and road options, demonstrating a capacity for immediate response. Moreover, the drought prompted the initiation of long-term infrastructural and operational planning aimed at mitigating the effects of similar future disruptions. This also encompassed a broader ambition to enhance the overall resilience of the transport network.

To strengthen the network against recurring droughts, several measures have been identified as critical. The development and acquisition of drought-resistant vessel types, along with modern push tow systems, are pivotal in maintaining operational capabilities during low water levels. The digitalisation of waterway traffic is another essential component, enhancing the efficiency and reliability of information sharing among the stakeholders. The expansion of offloading infrastructure is necessary to significantly increase the transport network's resilience by facilitating the rapid redistribution of cargo under varying conditions. In the long term, a comprehensive evaluation and implementation of waterway construction

measures are essential. This includes excavating deeper channels at critical points to ensure navigability during drought conditions and implementing integrated water management solutions, such as dams, locks, and reservoirs, to regulate water flow and storage. These initiatives underscore a commitment to not only responding to immediate challenges but also to proactively increasing the resiliency European transport network.

Supply Chain

The resilience of supply chains during the Rhine drought of 2022 was a crucial factor in mitigating the adverse impacts of this disruptive event. The immediate, static resilience was evident as logistics companies leveraged existing partnerships and infrastructure to maintain the flow of goods despite significant transport limitations. Those with established relationships with rail operators were particularly well-positioned, as they could swiftly transition cargo from water to rail, benefiting from the willingness of rail providers to accommodate additional loads. This seamless shift underscored the value of cross-modal cooperation in enhancing supply chain resilience, allowing for a relatively smooth continuation of operations where possible.

However, not all companies had the luxury of an easy switch to rail, and many resorted to road freight as an alternative. While road transport offered a viable solution to immediate transport needs, it was less desirable from an environmental perspective, given its higher carbon footprint compared to rail or waterway transport. This situation highlighted a critical resilience challenge: balancing operational continuity with sustainability goals in the face of unforeseen disruptions.

In terms of dynamic resilience, the rapidity and efficiency with which companies engaged in rerouting logistics and forging new partnerships were remarkable. This proactive approach to overcoming transport constraints showcased a high level of adaptability and resourcefulness. For example, major companies dependent on the Rhine for transport, such as the chemical giant BASF, began exploring the development of vessels capable of operating in shallower waters. This initiative represents a strategic response aimed at reducing future vulnerability to similar disruptions, demonstrating an investment in long-term supply chain resilience.

Overall, the supply chains' response to the Rhine drought highlighted a multifaceted resilience strategy. By efficiently utilizing the available transport resources and quickly adapting to changing circumstances, supply chains managed to maintain operational continuity amidst challenging conditions. Furthermore, the commitment to developing long-term solutions, such as partnerships with rail operators and investment in specialized shipping capabilities, indicates a forward-thinking approach to building resilience. These efforts not only address immediate logistical challenges but also contribute to the strategic realignment and strengthening of supply chains against future disruptions.

Society

Societal resilience to the 2022 Rhine drought reflects a broad and inclusive approach to managing and mitigating the impacts of such disruptions. At the core of societal resilience is the recognition of the Rhine not just as a transport route but as an integral part of community life, nature, recreation, agriculture, and the tourism industry. This multifaceted

perspective necessitates that any construction or logistical adaptations designed to enhance the transport network's resilience also consider the broader implications for communities along the river. As such, efforts to facilitate modal shifts in transport or to modify the river's infrastructure must engage with and incorporate the needs and opinions of these communities, ensuring that resilience-building measures do not come at the expense of the river's other vital roles.

Static resilience within society was swiftly demonstrated through government actions to address energy supply gaps, showcasing an effective initial response to the crisis. Similarly, the public's adaptability, seen in their pragmatic responses to supply disruptions and heightened awareness of the intricacies of logistical systems, underscores a fundamental resilience in facing immediate challenges. This collective response highlights a societal capability to maintain functionality and coherence in the face of external shocks, supported by strong governance and an informed and engaged citizenry.

The dynamic aspect of societal resilience emerged in the period following the drought's peak, as both policymakers and the wider community engaged in deep reflections and dialogues about the future of transportation infrastructure and energy policy. These discussions aimed not only at addressing the immediate aftermath of the drought but at reimagining a future where the transport network and energy systems are more adaptable, sustainable, and resilient to climate change impacts. The commitment to leveraging the lessons learned from the drought to foster a more robust societal structure is evident in these forward-looking initiatives. They represent a collective aspiration to not merely recover to previous conditions but to advance towards a more resilient and sustainable societal model, better equipped to navigate and withstand future environmental challenges.

This holistic approach to resilience acknowledges the interconnectedness of environmental, economic, and social systems and emphasizes the importance of inclusive and participatory policymaking. By integrating the diverse needs and voices of the communities it aims to serve, society strengthens its collective ability to adapt to and recover from disruptions, setting a course towards sustainability and resilience in the face of escalating climate change challenges.

4.2 Floods along the Rhine-Danube corridor

As confirmed by one of the experts (013-021123) in that were interviewed: “..you suddenly also have a lot more disruptions from climate now impacting, that we have not seen before, and this will only increase as the climate crisis or the consequences of the changing climate evolves and unfolds. So, here we see also that areas that were not before prone to disasters suddenly have disasters or disruptions, like Germany last year when you had the floodings of the river being overflooded”.

Northern and central Europe grappled with heavy rainfall in December 2023, with three major rivers, the Elbe, the Rhine, and the Danube swelling with high water levels (‘Parts of Northern and Central Europe Continues to Struggle with Floods’, 2023). While evacuations were required in Germany, Hungary, and the Netherlands, major damage was avoided due to prior planning. The Pretziener Wehr, a flood barrier from the 1870s located downstream of the Elbe River, was renovated in 2010 and opened, diverting a third of the river’s water to

a 21 km channel bypassing Schoenebeck and Magdeburg towns. These floods saw the Danube reaching its highest level since 2013 (*Floods in Europe*, 2023) sparking concerns about climate change. Flooding was also experienced in Lithuania. In August 2023, heavy rains caused major flooding in Slovenia, which also affected the neighbouring countries of Austria and Croatia (Al Jazeera, 2023; Kučić, 2023). Along with flooding, landslides were also observed due to severe weather (Reuters, 2023).

Hydro-meteorological hazards such as (especially snowmelt) floods are recurrent events in the joint Rhine-Danube and Rhine-Alpine corridor. In May 2023, flooding in northern Italy, Austria, Bosnia and Herzegovina, Croatia and Slovenia caused loss of life, evacuation of 1000s of people, landslides and damage to roads (WHO, 2023). Thus, the World Health Organization (WHO) reported the mounting climate crisis and urged member states to prioritize measures for countering it. In July 2021, Germany witnessed extreme flooding which had the highest death toll for any natural hazard in Germany since 1962 (Strategic Risk, 2021). Several dams burst and infrastructure was destroyed. The impact was also experienced in Belgium and Netherlands. However, due to some measures being in place, the damage was fairly contained to a narrow area. This extreme event was one of the most expensive hazards since 1980, resulting in losses of EUR 44 billion (European Environment Agency, 2023). In May 2019, floods were reported in Germany, parts of Switzerland, and Austria (FloodList, 2019a).The disruption caused evacuations, including a hospital, damage to roads and a fatality as well. In the same year in June, Poland also experienced floods, leaving communities cut off (FloodList, 2019b) and causing damage to roads, homes, electricity and water supplies.

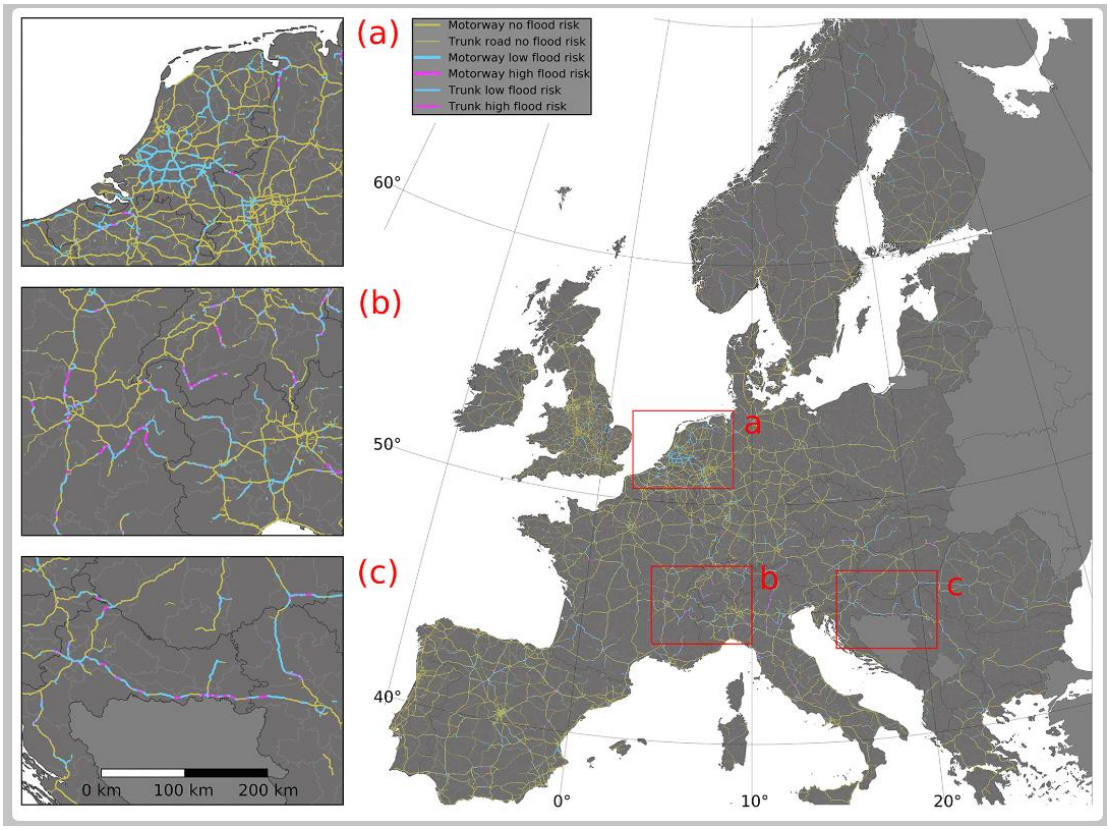

Figure 8: Flood risk of motorways and trunk roads in European main road network. (a) Netherlands, (b) Western Alps in France, Switzerland, and Italy, (c) North-western Balkans in Croatia and Serbia. (van Ginkel et al., 2021)

The river flood hazard maps as of 2021 are made available as part of the EU joint research data catalogue (Dottori et al., 2021) which are expected to provide aid to the transport network authorities in planning resilience in the transport network. Figure 8 shows the flood risk of motorways and trunk roads in European main road network (van Ginkel et al., 2021). Three areas are especially highlighted for this corridor: the Netherlands, the Western Alps in France and Switzerland, and the North-western Balkans in Croatia and Serbia. Although the Netherlands are at high flood risk, they have very high river flood protection standards, which make the overall likelihood of flood-related collapse of the road network very small. France has also recognized its vulnerabilities to flood in local flood risk studies.

4.2.1 *Impact*

Transport Network

The recurrent floods along the Rhine-Danube corridor have a profound impact on the region's transport network, exposing vulnerabilities and challenging the resilience of critical infrastructure repeatedly; and interestingly, not only that of transportation across inland waterways. Rail transport, a backbone for both cargo and passenger movement across Europe, faced severe disruptions. Waterlogging from the floods brought rail operations to a near standstill in affected areas, with tracks submerged and vital signalling equipment damaged. This paralysis of rail networks not only delayed freight deliveries but also stranded passengers and disrupted commuting patterns, underscoring the rail system's vulnerability to extreme weather events. Railway tracks in the mountainous regions are susceptible to landslides. It has been reported that in 2023, in Austria alone, the trains were forced to a standstill 1900 times due to weather conditions (*Europe's Rail Industry Needs Urgent Adaptations to Climate Change*, 2024).

Road transport was similarly afflicted. Floodwaters eroded road surfaces, washed away sections of highways, and rendered many routes impassable. The increased risk of landslides, triggered by the saturation of soil, further exacerbated the situation, making certain roadways hazardous and, in some cases, completely unusable. This loss of road access compounded the logistical challenges faced by emergency services, relief operations, and everyday traffic, leading to significant economic and societal impacts. The structural damage inflicted by the floods was considerable. Bridges, critical links in the transport network, were destroyed or severely damaged, cutting off communities and disrupting trade routes. In Belgium, the impact on intermodal services, which rely on the seamless integration of different transport modes, was particularly stark. The extreme weather conditions led to significant damage to rail tracks between key logistics hubs like Antwerp and Athus. This disruption of intermodal services highlights the interconnectedness of the European transport network and the ripple effects that damage in one area can have on the wider system.

Overall, floods across the Rhine-Danube corridor laid bare the extensive implications of such natural hazards on transport networks. The immediate effects—halted rail services, damaged roads, and lost infrastructure—are just one part. The deeper challenge lies in

rebuilding these networks to withstand future events, a task that will require investment, innovation, and international cooperation.

Supply Chain

The floods across the Rhine-Danube corridor repeatedly cause chaos on the region's supply chains, demonstrating the intricate and interconnected nature of manufacturing and logistics networks. The disruption was particularly acute in the manufacturing sector, with facilities across the region, including operations in Slovenia and Germany, severely affected. Slovenia, for instance, plays a critical role in the European automotive industry; not a single car produced in the continent is without at least one component manufactured in this country. The floods, therefore, had a ripple effect, impacting automotive production lines far beyond the immediate areas of inundation. In Germany, the floods caused significant logistical disruptions, leading to increased delays, waiting times, and a spike in late shipments. The automotive and domestic appliance industries, heavily reliant on precise and timely deliveries of components, faced acute challenges due to damaged railways and disrupted transport routes. Several industrial areas and companies located along the banks of rivers had to evacuate and halt operations as floodwaters breached their defences, entering premises and causing direct damage to machinery, inventory, and infrastructure.

Beyond the immediate physical damage, the floods also imposed logistical constraints on supply chains. The inundation of critical infrastructure and the consequent need for rerouting and other logistical adjustments led to inefficiencies, increased costs, and strained resources. The textile and garment manufacturing industry in Italy's Prato region serves as another example, where the floods damaged production facilities and disrupted the supply of materials, affecting downstream manufacturers and retailers across Europe and globally.

The ripple effects of these disruptions underscore the fragility of supply chains to natural hazards. Businesses are faced with the dual challenge of recovering from the immediate impacts of the floods and reevaluating their supply chain strategies to mitigate the risks. This may involve diversifying production locations, investing in more robust logistics solutions, or increasing inventory buffers to guard against future disruptions.

Society

The floods across the Rhine-Danube corridor had profound and far-reaching impacts on society in the affected areas. The immediate effect was the evacuation of thousands from their homes, a traumatic experience that resulted in the loss of material possessions and, more significantly, a sense of security and normalcy. The floods submerged homes and severed communities from each other and from essential services, leaving many isolated amid rising waters. Several regions reported loss of life, highlighting the deadly potential of such natural hazards. The risk increased due to intense rainfall and flooding, which disrupted vital services like electricity and heating supply, making affected populations even more vulnerable. The damaged roads, bridges, and railways often hamper rescue services and greatly slow down the economic recovery of the region. The challenging situation made it difficult for humanitarian agencies to help.

The economic impact of the floods on society was significant. The necessity to rebuild damaged infrastructure placed a considerable strain on economies, diverting resources from

other areas of need, especially in a time when other crises such as the COVID-19 pandemic made demands on public finances. The destruction of roads, bridges, and public utilities required substantial financial investment to repair but also disrupted business operations, leading to economic losses and affecting the livelihoods of many. In regions where industries were forced to halt operations due to the flooding, workers faced uncertainties about their employment and income, adding to the economic and psychological toll on the communities.

The societal impact of the floods across the Rhine-Danube corridor underscores the interconnectedness of natural hazards with human and economic systems. It highlights the need for comprehensive disaster preparedness and response strategies that go beyond immediate relief to address the medium and long-term recovery and resilience of affected communities.

4.2.2 *Response*

Transport Network

In response to the floods, the transport network faced significant challenges that necessitated immediate action. The primary focus was on rebuilding of the damaged infrastructure, including roads, bridges, rail links, and other vital components of the transport system. This reconstruction effort was critical for restoring mobility and connectivity and for facilitating the recovery processes across the affected regions. The response strategy was multi-faceted, aiming to quickly re-establish the most critical routes to ensure the flow of emergency services, relief supplies, and to gradually restore normalcy for the public and the economy. Repairing bridges was a particularly urgent task given their critical role in connecting communities and enabling the movement of goods and people. The damage to rail links also required immediate action, as these are crucial for both national and international freight and passenger services and for supply chains.

The road reconstruction included fixing damaged surfaces and addressing underlying weaknesses to prevent future damage from heavy rains. This often meant enhancing drainage systems, reinforcing roadbeds, and, in some cases, rerouting roads to safer areas. The response also considered the long-term resilience of the transport network, incorporating more robust construction standards and adopting new technologies to better withstand future flood events. Collaboration among local, national, and international agencies, along with private sector partners, was key to the effective response. Funding mechanisms were mobilised swiftly, drawing on emergency funds, insurance payouts, and, where applicable, international assistance to support the costly reconstruction efforts. Public communication was also a critical aspect of the response, keeping communities informed of progress, temporary routes, and safety advisories. *The reconstruction* efforts aimed beyond mere restoration, striving to establish a more resilient transport network capable of enduring the rising frequency and severity of extreme weather events.

Supply Chain

The response at the supply chain level was immediate and multifaceted, focusing on addressing the urgent needs of affected actors and re-establishing critical logistics connections. The foremost priority was to ensure the continuation of food supplies and other essentials to areas cut off by the floods. This task required a coordinated effort among supply

chain actors, emergency services, and local governments to identify alternative routes and methods for delivering essential goods, sometimes involving air transport or temporary bridges or pontoons to reach those in dire need.

Re-establishing connections with the rest of the country and beyond was crucial for restoring the flow of goods and services and for kickstarting the economic recovery of the affected regions. This involved a rapid assessment of the damage to transport infrastructure and logistics hubs, followed by the prioritization of repairs based on their importance to the supply chain network. Logistics companies, in collaboration with government agencies, worked to reroute shipments, find alternative storage solutions, and manage inventory in a way that minimized disruption to supply chains. The response also included leveraging technology and data analytics to improve visibility across the supply chain. This allowed for better prediction of bottlenecks, more efficient allocation of resources, and the identification of critical needs in real-time. Supply chain operators utilized digital platforms to coordinate efforts, share information on alternative routes, and update customers and partners on changes to delivery schedules.

Another critical aspect of the response was the emphasis on flexibility and adaptability. Companies temporarily adjusted their operations, accepting longer transit times, utilizing different modes of transport, and even altering production schedules to mitigate the impact of the floods on supply and demand. This adaptability was instrumental in maintaining the continuity of operations under challenging conditions and in building resilience against future disruptions. Collaboration emerged as a key theme in the supply chain response, with competitors working together to pool resources and information. Further, public-private partnerships played a pivotal role in the recovery efforts.

Society

The EU, recognizing the increasing frequency and severity of flooding events because of climate change, has invested significantly in improving its predictive capabilities. Advanced meteorological technologies and data analytics are now being utilized to forecast floods with greater accuracy and lead time, allowing for more effective planning and response. Countries particularly vulnerable to flooding have ramped up their investment in comprehensive flood risk studies. These studies are crucial for understanding the specific risks faced by different regions, informing the development of targeted strategies for flood prevention, mitigation, and response. This proactive approach to managing flood risk encompasses a range of measures, from enhancing physical infrastructure such as dams and levees to implementing land use planning strategies that reduce exposure and vulnerability.

One of the most critical components of the societal response to floods is the planning and execution of evacuations. With improved meteorological and hydrological prediction capabilities, authorities are now able to plan evacuations well in advance of the expected flooding, significantly reducing the risk to human life. These evacuations are meticulously organized to ensure that residents are moved to safety in an orderly and efficient manner, with particular attention paid to vulnerable populations such as the elderly, disabled, and those without means of transportation.

The success of these evacuations highlights the close coordination among meteorological services, emergency response agencies, local governments, and communities. Public awareness campaigns play a vital role in educating residents about flood risks and the importance of heeding evacuation orders. Community engagement initiatives are also critical for building local resilience, as they empower communities to take an active role in their own preparedness and response efforts. Overall, the societal response to the floods across the Rhine-Danube corridor highlights a shift towards a more proactive and preventive approach to disaster management.

4.2.3 *Resilience*

Transport Network

In the aftermath of the floods across the Rhine-Danube corridor, the resilience demonstrated by the transport network highlights a strategic approach to disaster preparedness and recovery. The availability of river flood hazard maps as part of the EU's joint research data catalogue represents a significant resource for transport network authorities. These maps, as detailed in research by Dottori et al. (2021), serve as a critical tool for planning and enhancing the resilience of the transport infrastructure against flood risks. By integrating these data into planning processes, authorities can identify vulnerable points within the network, prioritize investments in flood defences, and design more resilient routes and structures.

Along the Rhine-Alpine corridor, the Netherlands with its low-lying geography exemplifies static resilience in the context of flood management. With its advanced river flood protection standards, the Netherlands has developed a robust system of levees, storm surge barriers, and water management practices that significantly reduce the likelihood of flood-related disruptions to its road network. This pre-emptive approach to flood defence underscores the importance of investment in infrastructure that can maintain functionality even when faced with significant external shocks. France's response to its vulnerabilities to flooding, identified through local flood risk studies, reflects a commitment to enhancing both static and dynamic resilience within its transport network. By acknowledging these vulnerabilities, France has taken steps to not only fortify its existing infrastructure but also to ensure that resources are allocated efficiently for the repair and reconstruction of affected transport links. This includes developing contingency plans that enable a swift and effective response to flooding events, minimizing downtime, and facilitating quicker recovery.

The actions taken by countries like the Netherlands and France, informed by comprehensive risk assessments and the utilization of detailed flood hazard data, exemplify a proactive approach to building resilience within the transport network. Static resilience is achieved through the maintenance of high functionality levels of the transport infrastructure, even in the face of floods, by leveraging advanced engineering and planning. Dynamic resilience is demonstrated in the capacity and speed of the network to recover from such shocks, ensuring that resources are efficiently used both in immediate responses and in longer-term reconstruction efforts.

Supply Chain

While it is understood that floods themselves cannot be entirely prevented, the focus has shifted towards preparing for such events well in advance. This preparation includes the development of evacuation plans for critical logistics hubs and the establishment of alternative routing strategies to maintain the continuity of supply chain operations. Such measures are indicative of a move towards dynamic resilience, where the ability to quickly adapt and recover from disruptions is prioritized.

Preparation for floods also involves a broad spectrum of stakeholders within the supply chain, from suppliers and manufacturers to logistics providers and retailers. Collaboration across these parties ensures that evacuation and rerouting plans are comprehensive and that all potential bottlenecks or vulnerabilities are addressed. This collaborative approach enhances the static economic resilience of the supply chain, maximizing the efficient use of remaining resources and capabilities during times of crisis.

Furthermore, supply chains are investing in technology and infrastructure that enable more robust responses to flooding events. This includes the use of real-time tracking systems for shipments, which can be quickly rerouted in response to changing conditions, and the development of more resilient logistics infrastructure capable of withstanding flood conditions. The resilience demonstrated by supply chains in the recent floods across central Europe reflects an understanding of the challenges posed by climate change and extreme weather events. By studying vulnerabilities, identifying safe thresholds, and preparing in advance through strategic evacuations and rerouting, supply chains are not only able to withstand the immediate impacts of floods but are also positioning themselves to recover more quickly and efficiently, ensuring minimal disruption to operations and services.

Society

For centuries, even major cities along the Rhine-Danube corridor have either worked with levees (e.g. Budapest) or designated inundation zones (e.g. Vienna). Interestingly, both take it into account that floods will occur *and impact on the transport network but* are designated to protect housing while considering that some transport routes will be flooded. Thus, the way the transport network is constructed can expose it to disruptions while contributing to societal resilience.

The resilience demonstrated by society in the wake of transport disruptions caused by the floods across the Rhine-Danube corridor is a testament to the effectiveness of awareness, preparedness, and communication. Recognizing the increasing threat posed by extreme weather events, efforts have been made to ensure citizens are well-informed about the risks associated with flooding. This awareness is crucial for fostering a culture of preparedness that can significantly mitigate the impact of such events on communities. Training on evacuation practices forms a critical component of societal resilience. By equipping citizens with the knowledge and skills necessary to respond effectively in the event of a flood, local authorities and disaster response organizations can enhance the safety and well-being of communities. These training programs often cover a range of topics, from understanding flood warnings and identifying safe evacuation routes to basic survival skills and the importance of maintaining a personal emergency kit. This preparation is key to ensuring

that, when faced with the reality of an impending flood, residents can act swiftly and confidently, reducing the risk to life and minimizing panic.

Improved communication channels have also played a vital role in reducing the societal impact of transport disruptions due to flooding. Advances in technology have enabled the dissemination of real-time information regarding flood risks, evacuation orders, and safe routes out of affected areas. Social media platforms, emergency alert systems, and community networks facilitate rapid communication, ensuring that vital information reaches those who need it most, quickly, and efficiently. Community solidarity and support mechanisms activate in times of crisis and demonstrate societal resilience. Neighbours helping neighbours, local businesses providing resources, and volunteers supporting emergency services illustrate the collective response to adversity that characterizes resilient societies.

The demonstrated resilience at the societal level, characterized by informed awareness, proactive preparedness, and effective communication, underscores the importance of a comprehensive approach to managing the challenges posed by floods and their associated transport disruptions. It highlights the collective strength of communities in facing such disruptions, not merely as passive recipients of aid but as active participants in their own protection and recovery. This societal resilience, built on the pillars of knowledge, preparedness, and communication, forms a crucial defence against the increasing frequency and intensity of flooding events, ensuring that societies can withstand and recover from these challenges with greater efficiency and less overall impact.

4.3 Brexit

On 31st January 2020, the United Kingdon left the European Union (Walker, 2024). While this turn of events vastly affected the UK (Cecil, 2024; Forrest, 2024), there has been significant impact on the EU transport network, necessitating change of policies and regulations. While there were the initial changes required to adjust to the separation of the UK from the single market, 3 years later, even more uncertainty is experienced on both sides, often referred to as Brexit 2.0 (The National, 2023).

A recent example of a complicated side-effect of the Brexit is the 10% Brexit tariff rule, which is set to negatively affect electric vehicles exported from EU to UK and vice versa (O'Carroll, 2023). According to the regulation, any EV exported between EU and UK must be at least 45% made in either EU or UK or else be subjected to a 10% tariff. Since the batteries of EVs are made in China, the EVs are liable for tariff, starting from January 1st, 2024. The manufacturers are speeding up the setup of EV battery factories and the required supply chain to avoid taxes, meanwhile asking the commission for a suspension of tariff for at least 3 years. This policy related disruption shows how the Brexit not only impacts the manufacturing and overall supply chain of EVs, but also threatens the sustainability goals of the EU, which are pushing for transition to EV.

Another recent example is the regulations between Ireland (EU) and Northern Ireland (UK), requiring certain products to be labelled specifically as "not for the EU" (Kriege, 2023). This requirement has significantly affected retailers, adding logistical hurdles. While several

sectors in transportation have suffered due to reduced workforce as a result of stricter immigration, the numbers indicate a shortage of 76,000 drivers (Kriege, 2023).

Although the UK may no longer be a part of the EU, it is very much a part of the European logistics puzzle. Earlier estimates from 2021 indicated that over 4.4 million freight vehicles move between the EU and the UK annually (Beresnevičius, 2021). The intersectionality of the longer than expected pandemic and the Brexit further accentuated the driver shortage problem, when many of the drivers close to retirement suddenly opted for early retirements. Further, this compounded with additional regulations such as requirements of veterinary certificate for certain meat and dairy products, prenotification of Sanitary and Phytosanitary (SPS) goods and other customs clearances (Beresnevičius, 2021). The supply chains experienced large periods of loss, uncertainty, and multiple disruptions in tandem.

Along with the initial confusion and long waiting times of the transition period, Brexit has increased the cost of goods transport (BERTHELOT, 2021). A Europe-wide decline in capacity was recorded on routes to and from UK, increasing the road freight costs, with the France-UK route seeing a price increase by 51% year-on-year in 2021. The EU has been taking strong measures to recover from Brexit. The new routes planned to improve Europe-wide connectivity, the TEN-T framework, has omitted routes involving the UK from the planning (reporter, 2023).

4.3.1 *Impact*

Transport Network

The impact of Brexit on the European transport network has been profound and multifaceted, fundamentally altering the landscape of freight transport across borders previously seamless under EU membership. The reintroduction of border controls between the UK and EU member states significantly increased waiting times for freight carriers, with long queues evident at several points in time in the Southeast of England, around the key port of Dover. This surge in delays can be attributed to the additional paperwork and customs checks now required, a stark departure from the pre-Brexit era of free movement of goods. The complexity and volume of this new bureaucratic process have not only slowed down operations but also introduced a higher degree of unpredictability into transport schedules. Compounding the issue of increased waiting times are labour shortages within the transport sector. Drivers, who once moved freely across the UK and EU regions, now face significant barriers to work due to new immigration rules and work permit requirements. This reduction in available labour has directly contributed to increased lead times and costs for freight transport, placing additional strain on supply chains already navigating the complexities of post-Brexit trade.

Transport bottlenecks resulted in substantial delays and escalated transportation costs, impacting businesses and consumers alike. The logistical challenges were not limited to physical delays; they also encompassed the financial burden of the increased cost of goods transport, further complicating the economic landscape post-Brexit. Furthermore, the strategic development plans for the Trans-European Transport Network (TEN-T) have adapted to the new reality, with connectivity plans no longer including the UK. This exclusion from the TEN-T development plans signifies a pivotal shift in the approach to Europe-wide

connectivity, underscoring the broader implications of Brexit on the transport infrastructure and network development within the continent.

In summary, the transport disruptions resulting from Brexit have led to increased operational complexities, higher costs, and a reshaping of the European transport network's strategic future. These challenges reflect a new era of transport, marked by heightened border controls, labour shortages, and the need for revised connectivity strategies that accommodate the geopolitical shifts brought about by the UK's departure from the EU.

Supply Chain

The ramifications of Brexit on supply chains at both the EU and UK levels have been significant, primarily driven by the shift in legislative frameworks and regulatory environments. With the UK's departure from the EU, it was no longer mandated to adhere to EU regulations, instigating a cascade of adjustments for businesses engaged in trade between these two entities. One of the immediate implications was the requirement for businesses to differentiate product labelling for items destined for the UK versus those for the EU market. This regulatory divergence placed an additional burden on businesses, complicating logistics and marketing strategies and, in some cases, necessitating a complete overhaul of packaging processes. Especially small and medium sized businesses have struggled to adapt their supply chains and processes and have in some cases had to decide to stop doing business between the EU and the UK. As highlighted by an intermodal operator (010-271023) during our interviews: "*Well, take the example of the Brexit. So, it's becoming more difficult now due to customs issues if you want to organize a transport from or towards UK*", businesses are looking at alternatives to the UK within EU.

The introduction of new tariffs further complicated the post-Brexit trade landscape. Notably, electric vehicle (EV) manufacturers found themselves at the nexus of these complications, with the implementation of a 10% Brexit tariff on EVs not meeting specific manufacturing origin criteria. This legislative nuance, primarily affecting EVs due to the international sourcing of their batteries, required manufacturers to rapidly accelerate the establishment of battery factories within the EU or UK to circumvent these tariffs, while simultaneously petitioning for their suspension. This situation underscores the broader supply chain challenges faced by manufacturers, who now must navigate an intricate web of tariffs and origin rules that directly impact cost structures and operational viability.

The requirement for additional clearances and checks for products imported into the UK from the EU has further strained EU supply chains. This increase in administrative and logistical burdens has led to delays, inflated costs, and diminished profit margins, threatening the efficiency and profitability of cross-border trade. Businesses have been forced to reassess their supply chain configurations, seeking ways to mitigate these new inefficiencies and protect their bottom line. The establishment of the Ireland-Northern Ireland border as the sole land border between the UK and the EU has introduced unique challenges for trade and customs. This geopolitical shift has created a complex scenario for local businesses and communities, who must now navigate a labyrinth of new regulatory and logistical hurdles that affect daily operations and long-term strategic planning.

The transport disruptions induced by Brexit have had a profound impact on supply chains, necessitating a recalibration of operational strategies to adapt to the new regulatory and

trade environment. From product labelling and tariff navigation to the adaptation to new customs procedures and the reconfiguration of supply routes, businesses have been compelled to undertake comprehensive reviews and adjustments of their supply chain practices maintaining continuity and competitiveness in the post-Brexit landscape.

Society

The transport disruptions following Brexit have had significant societal impacts, reverberating through the lives of individuals and communities across the EU and the UK. One of the immediate consequences was the loss of employment for many workers, including drivers, who found themselves caught in the crosshairs of new regulatory and immigration frameworks. The necessity for updated paperwork and qualifications to meet post-Brexit job requirements posed additional challenges, leading to job insecurity and uncertainty for many. Perhaps nowhere were the societal impacts of Brexit more acutely felt than in the regions of Ireland and Northern Ireland. The introduction of a land border between the EU and the UK marked a profound change for local communities accustomed to free movement for trade, work, and daily life. This new border complicated local trade, affecting everything from the flow of goods to the rhythm of daily commutes, and instigated a host of logistical and bureaucratic challenges that impacted the local economy and quality of life.

Businesses, particularly small enterprises, faced heightened difficulties due to additional testing, clearances, or labelling for the import-export of essential goods, such as food items. The added administrative burden and delays not only frustrated businesses and consumers alike but also placed financial strains on operations, with some small businesses struggling to bear the costs or navigate the complexities, leading to closures or reduced services. Additional delays and confusion at borders contributed to widespread frustration among businesses and consumers. The uncertainty and inconsistency in the application of new rules often led to missing paperwork and further delays, exacerbating tensions and undermining trust in systems that were once taken for granted.

The societal impacts of the transport disruptions due to Brexit extend far beyond the immediate logistical challenges, affecting the very way of life for many individuals and communities. From employment losses and forced relocations to the disruption of local trade and the daily inconveniences of added bureaucratic hurdles, the consequences of Brexit have deeply affected societal cohesion, economic stability, and the personal lives of citizens across the EU and UK. However, it can be difficult to differentiate between the impact of the transport disruption from other consequences of Brexit.

4.3.2 Response

Transport Network

In response to the transport disruptions caused by Brexit, the transport network has had to undergo significant adjustments to adapt to the new reality of UK-EU relations. The fundamental shift in treating transports between the UK and the EU not as intra-Community supplies but as exports to a third country has necessitated a comprehensive re-evaluation of logistics strategies and operational frameworks. This reclassification has introduced a layer of complexity previously absent, with goods now subject to customs checks, tariffs, and regulatory scrutiny that were not required when the UK was part of the EU.

One of the most tangible outcomes of this shift has been the increase in transit lead times for goods moving between the UK and the EU. The additional procedures for customs declarations, safety and security requirements, and potential tariffs have inevitably extended the duration of goods in transit, affecting the efficiency and predictability of supply chains. This increase in lead times not only impacts the transport network's ability to meet delivery schedules but also influences the broader economic landscape by affecting inventory management, production schedules, and ultimately, the end consumer experience. In response to these challenges, transport and logistics providers have adapted by enhancing their customs brokerage services, investing in technology to streamline the documentation process, and training staff to navigate the new regulatory environment. There has been a concerted effort to improve communication and coordination with customs authorities to minimize delays and ensure the smooth passage of goods across borders.

Furthermore, to mitigate the impact of increased transit times, some companies have explored alternative routes and modes of transport. This includes increasing the use of sea freight as an alternative to road transport, thereby bypassing some of the congestion and delays experienced at key border crossings. Additionally, there has been an emphasis on developing more robust contingency planning, with businesses building greater flexibility into their logistics operations to better withstand the uncertainties and fluctuations in transit times. By reevaluating logistics strategies and embracing new operational frameworks, the transport sector aims to navigate the complexities introduced by Brexit, ensuring the continued flow of goods between the UK and the EU despite the challenges posed.

Supply Chain

In response to Brexit, supply chains across the UK and EU have undergone substantial reconfigurations. The intricate nature of trade between the UK and EU, now governed by a new framework including the Withdrawal Agreement, the EU-UK Trade and Cooperation Agreement, and the Northern Ireland Protocol, has prompted some companies on both sides to seek alternative trading partners. This strategic pivot aims to mitigate the impact of disrupted supply chains by diversifying sources of imports and reducing dependency on cross-Channel trade routes that have become more complex and costly post-Brexit.

The Protocol, particularly, introduces a unique arrangement for Northern Ireland, allowing it to remain within the UK customs territory while still having access to the EU's Single Market for goods. This dual status, designed to avoid a hard border on the island of Ireland, has introduced a new level of complexity to supply chains, affecting the movement of goods and necessitating innovative logistical solutions. Companies have had to navigate a labyrinth of regulatory requirements to ensure compliance, adding administrative burdens and costs. UK exporters have faced significant challenges, including absorbing additional freight costs that have arisen from the need to reroute goods to comply with the new trading terms. These increased operational expenses, combined with the administrative costs associated with compliance to the new trade agreements, have put pressure on profit margins and competitive positioning in the market.

In response to these challenges, businesses on both sides have been proactive in adapting their supply chain strategies. This has included investing in technology to streamline customs processes, engaging in direct dialogue with customs authorities to clarify new

procedures, and enhancing logistics planning to account for longer lead times and potential bottlenecks at border crossings. Companies have also explored the establishment of new supply routes and logistics hubs to optimize the flow of goods under the new regulatory landscape. There have been strategic shifts in sourcing, with companies looking to other parts of the world to replace or supplement imports previously sourced from each other. This global diversification is not only a response to the immediate disruptions caused by Brexit but also a strategic positioning to build more resilient and flexible supply chains capable of withstanding future geopolitical shifts or disruptions and can also be attributed to other recent transport disruptions due to COVID-19 or geopolitical shifts due to the war in Ukraine.

Society

The societal response to the transport disruptions and broader impacts of Brexit has been a critical area of focus, particularly in terms of protecting the rights and livelihoods of citizens who have built their lives across the fabric of the UK's membership in the EU. Recognizing the profound implications that Brexit would have on individuals—ranging from residency rights to employment and beyond—the protection of these rights became a top priority in the negotiations between the EU and the UK. This priority was encapsulated in the negotiations leading to the Withdrawal Agreement, which aimed to secure the status and rights of EU citizens residing in the UK, and vice versa, UK citizens living in the EU. The agreement sought to ensure that those who had moved across borders under the free movement principle were not unduly penalized by the UK's departure from the EU. This included provisions to protect their residency rights, access to healthcare, employment rights, and other social benefits that were predicated on EU membership.

The societal response also involved significant efforts from both governmental and non-governmental organizations to provide support and guidance to affected citizens. Information campaigns were launched to help individuals understand their rights and the steps they needed to take to secure their status post-Brexit. Legal aid services were offered to those navigating the often-complex application processes for residency or citizenship status in their host countries. Communities themselves played a crucial role in the societal response, with grassroots initiatives emerging to offer support, advice, and solidarity to those impacted by the changes. These community-led efforts not only provided practical assistance but also fostered a sense of belonging and resilience among citizens facing uncertainty due to the geopolitical shifts.

Businesses and consumers alike had to navigate the realities of increased waiting times, additional paperwork, and the overall impact on the availability and cost of goods and services. This situation called for a collective adaptation to the new norms of cross-border trade and movement, underscoring the interconnectedness of societal well-being and the efficiency of transport networks and supply chains. Consequences of Brexit were apparent slowly to many consumers and have resulted in a shift of attitudes towards Brexit in the UK.

4.3.3 *Resilience*

Transport Network

In the face of transport disruptions due to Brexit, the resilience of the transport network, both within the UK and across the EU, has been tested and demonstrated through strategic

adaptations and innovative solutions. The reconfiguration of Europe-wide connectivity, particularly through the Trans-European Transport Network (TEN-T) framework, reflects a form of static resilience. By omitting routes involving the UK, the TEN-T framework has adapted to the new geopolitical reality, focusing on enhancing the efficiency and functionality of routes within the remaining EU member states. This adjustment ensures that the integrity and operational capacity of the EU's transport network are maintained, even as the landscape of cross-border transport changes.

Dynamic resilience is evident in the introduction of the Windsor Framework, which aims to mitigate the specific challenges faced at the Northern Ireland border. The Framework's introduction of "green" and "red" lanes represents a significant innovation aimed at streamlining the movement of goods. By reducing the number of checks required on goods arriving from Great Britain into Northern Ireland ports, the Windsor Framework alleviates some of the bottlenecks and delays that have characterized post-Brexit trade. Goods traveling through the "green lanes" face fewer inspections based on pre-established criteria of low risk, significantly speeding up the process and reducing the administrative burden on transport operators. This approach not only demonstrates dynamic resilience by enabling the transport network to recover from the initial shocks of Brexit-induced disruptions but also showcases a commitment to utilizing resources efficiently for repair and reconstruction over the recovery period. The strategic planning behind the Windsor Framework, and the adjustments to the TEN-T framework, underscore an adaptive, forward-thinking approach to maintaining and enhancing transport connectivity in the post-Brexit era.

Both the static and dynamic resilience measures adopted at the transport network level highlight the ability of transport authorities and policymakers to navigate the complexities introduced by Brexit. By reimagining and restructuring routes, and by introducing new customs facilitation measures, the transport network is evolving to meet the challenges of this new context, ensuring the continued flow of goods across borders, and maintaining the level of functionality essential for economic stability and growth.

Supply Chain

The resilience of supply chains in the wake of Brexit-induced transport disruptions has necessitated a strategic and multifaceted approach to maintain and strengthen the bi-directional flow of goods between the EU and the UK. Recognizing the importance of EU-UK trade, efforts have been made to smoothen policies and create frameworks that accommodate the new realities of post-Brexit commerce. This is crucial not only for preserving trade volumes but also for ensuring the stability of supply chains, particularly for UK manufacturers reliant on the "just-in-time" delivery model, which is highly sensitive to delays and disruptions.

One of the key manifestations of dynamic resilience in this context has been the implementation of the Brexit Adjustment Reserve by the EU. With a funding source of €5.37 billion, this initiative aims to mitigate the financial consequences of Brexit for Member States, regions, and sectors that are most adversely affected. By providing targeted financial support, the Reserve helps to cushion the immediate impacts on supply chains, allowing for adjustments and adaptations to new trade conditions. This support is instrumental in maintaining the continuity of supply chains during the transition period, ensuring that

businesses can adjust to new customs regulations, tariffs, and border checks without severe disruption to their operations. Additionally, the establishment of a new framework for the joint management of fish stocks in EU and UK waters represents another strategic response aimed at preserving economic interests and environmental sustainability. This agreement, alongside provisions for continued and sustainable air, road, rail, and maritime connectivity, demonstrates a commitment to collaborative management of shared resources and infrastructure, essential for the resilience of supply chains reliant on these modes of transport.

Static economic resilience is reflected in the ongoing efforts to streamline policies and regulations governing EU-UK trade. By working towards more efficient customs procedures and reducing bureaucratic hurdles, both the EU and the UK are striving to maintain a high level of supply chain functionality amidst the external shock of Brexit. This includes initiatives aimed at simplifying paperwork, enhancing digital customs processes, and facilitating smoother border crossings for goods. An expert from multi-modal transportation (04-181023) summarized the learnings from the Brexit and how resilience built from it has also increased customer expectations: "*Three years ago, when the Brexit came, three years ago or two years ago, it was like, "Okay, guys, yes, there are some new regulations, some papers, whatever. Take your time. If you have stabilized in four weeks, all is good, more or less". Now, I would say, they expect that in two-three days, we solve the issue. Because we are now used to it; we have learned; we have experience; we have seen that, done that. So, this is the main, or that's also one major point, to find a solution on the disruption, it's also increased expectations from the customer*."

Society

The societal resilience in response to the transport disruptions and broader implications of Brexit underscores the adaptability and flexibility of both the European Union and the United Kingdom. The departure of the UK, formerly the EU's third most populous state and a significant contributor to the ideological balance within EU institutions, has necessitated a recalibration of social and political dynamics within the Union. This shift has far-reaching implications, not just in terms of transport and trade, but also in the cultural and linguistic landscape of the EU. In response to these societal shifts, there has been a concerted effort within EU institutions to ensure continuity and maintain the effectiveness of communication and legislative processes. This has involved enhancing language training programs for staff and increasing the use of multilingual documentation to ensure inclusivity and accessibility for all member states. Moreover, the EU has strived to uphold its principles of diversity and multilingualism, reinforcing its commitment to these values in the face of changing demographics.

On a broader societal level, the resilience to Brexit-induced disruptions has also manifested in the strengthening of EU unity and solidarity. The departure of a major member state has spurred conversations around the future direction of the Union, its policies, and its global positioning. This period of reflection and adjustment has been an opportunity for the EU to reaffirm its commitment to its founding principles, including the promotion of peace, security, and sustainable development. At the grassroots level, civil society organizations, advocacy groups, and citizens have engaged in dialogues and initiatives aimed at bridging gaps and fostering understanding between the UK and the EU post-Brexit. These efforts reflect a

dynamic resilience, showcasing the capacity of societies to adapt to new realities, foster connections, and work towards mutual understanding and cooperation despite the challenges posed by political and economic shifts.

4.4 War in Ukraine

The Russian war on Ukraine escalated in February 2022 with Russia's invasion. The war impacted not just on Ukraine, but brought about several changes in which EU trade was conducted (*Economic Implications of Trade Rerouting since Russia–Ukraine War*, 2024), such as diversion of EU exports to Russia and Belarus to Eastern Europe and Central Asia. By August 2023, Europe's biggest businesses had already reported a hit of more than EUR 100 billion in profits as a result of scaling back or cutting Russian operations (Hollinger, 2023). There was hardly a corner left untouched, for many businesses, since the war affected the entire value chain- from delays, labour shortages to energy prices, and customers. The several waves of sanctions against Russia and its withdrawal from the market has forced businesses to adopt a flexible and agile approach, to counter the uncertainty and volatility.

The war severely disrupted the European gas markets causing a huge surge in energy prices (Emiliozzi et al., 2024). Russia was the primary provider for natural gas and crude oil imports, accounting for 44% and 22% of the total EU imports respectively. EU scrambled to compensate the shortage with Liquefied Natural Gas (LNG) to ensure energy security. To mitigate the impact of rising energy prices on households and businesses, governments in the EU adopted several measures such as energy tax abetments and price ceilings which burdened the government's finances. It is estimated that European governments allocated over EUR 650 billion between until January 2023 to address the energy crisis (Emiliozzi et al., 2024), with Germany allotting EUR 158 billion and France and Italy each allotting EUR 90 billion. This crisis has thrown a spotlight on addressing a long-term strategy, including renewables, LNG, and critical minerals necessary for the transition to clean energy, while identifying potential vulnerabilities. As described by an expert in supply chain and societal impact (015-101123) in the interviews conducted as part of the qualitative study, "*And this disruption that we had on the Russian war, of course it helped us with this thing [transition away from fossil fuels]. And that all the time companies are looking for other alternatives than dependence on oil*."

On a different note, any association with Russia, is affecting the brand value of products. Companies are now treading carefully to ensure that their products are seen associated with Russian politicians or military personnel (Hollinger, 2023). Also, the Russia-Ukraine war has affected food prices globally, and not just in the EU. Ukraine was a major supplier of agricultural products to many developing economies, which have since experienced a price rise by more than 50% (in some countries) of basic food commodities (EMEDIEGWU, 2024). Another consequence that is sometimes overlooked is the air pollution caused by the war, directly and indirectly. Due to the energy crisis, some countries have resorted to using biomass for residential heating, significantly increasing air pollution (Aghaei et al., 2024).

Among the multiple geopolitical consequences of the war, the search for alternate trade routes to maintain connectivity with Asia has also brought to spotlight other nations. While the EU was faced with the suddenness of the war, steps are being taken to reduce reliance

on Russian trade and routes. One such initiative is the Trans-Caspian International Transport Route (TITR), (also referred to as the “Middle Corridor”, see Figure 9) as an alternative to the route through Russia and Belarus. TITR includes Central Asia, Caucasus, and Turkey (Eldem, 2022). While it is not expected that TITR will entirely replace the route through Russia and Belarus between the EU and China, this initiative will bring closer trade relations of the EU with Turkey and Central Asia.

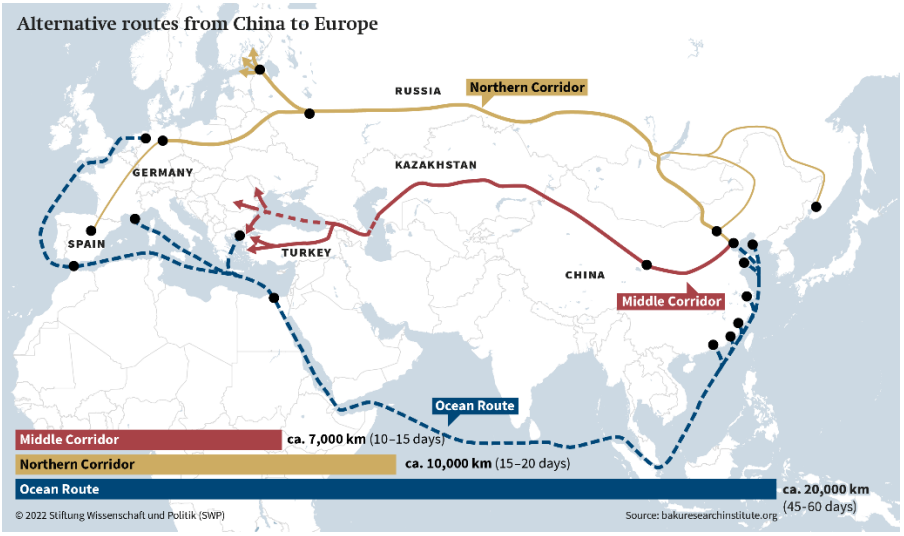

Figure 9: TITR as a “Middle Corridor” (Eldem, 2022)

4.4.1 *Impact*

Transport Network

The war caused loss of critical infrastructure in the region of conflict and as a traffic authority personnel (011-011123) expressed: “*Of course, the war is the biggest one because it's blocking all things, but they are also causing the damage for the infrastructure. Repairing them takes a long time, so that's why they have quite a big severity*”. The war in Ukraine has had profound impacts on the European transport network, catalysing a series of disruptions that have reshaped the landscape of transport and trade across the continent. The conflict's ramifications have extended far beyond the immediate region, influencing energy prices, rail freight operations, maritime activities, and air travel routes.

The surge in energy prices, a direct consequence of the war, significantly increased the operational costs of rail freight, which had increasingly relied on clean energy sources to align with the EU's sustainability goals. This shift made rail freight less economically viable compared to fossil fuel-based transportation methods, which, despite environmental concerns, emerged as more reliable and cost-effective options during this period of heightened energy costs. When asked about the impact of the war on their operations, a multimodal operator (010-271023) expressed: “*Heavily. Let's take the Ukrainian war, which is a human disaster, but after that, we all had to encounter a dramatic energy price inflation, explosion. So, I couldn't offer the same services for the same price anymore due to geopolitical events.*”. The geopolitical tensions and sanctions against Belarus dramatically affected Lithuanian railways, which had previously capitalized on profitable routes through Belarus. The sanctions necessitated a re-evaluation of these routes, resulting in infrastructural challenges and a loss of employment for nearly 30% of the railway's staff,

highlighting the immediate and tangible impacts on employment and infrastructure within the region (Interview: 07-231023).

The maritime sector experienced direct disruptions, particularly in the Black and Azov Seas, where shipping activities were significantly curtailed. Efforts like the Ukraine grain initiative restarted maritime transportation for a while under a wider humanitarian umbrella (and with the rare case of humanitarian organisations taking over from logistics service providers in orchestrating maritime transportation) but were eventually terminated in 2023. The suspension of activities in Black Sea ports prompted increased maritime activities in neighbouring countries like Romania, Moldova, and Georgia, underscoring the regional shifts in trade flows and port activities. Rerouting through Danube ports was identified to aid trade efforts with Ukraine, though limitations in vessel size and wait times presented new challenges. Shipping costs surged due to increased insurance costs, wartime premiums, and the logistical implications of longer shipping distances and the need to source gas, oil, and grain from more distant locations. These factors collectively contributed to heightened transit times and expenses, with global average bunker prices experiencing a significant year-on-year increase. Despite these disruptions, the rail freight connectivity between China and the EU through Russia and Belarus remained active, not subjected to Western sanctions. This route, valued for its speed and cost-effectiveness compared to oceanic and aerial alternatives, has maintained a crucial link in Eurasian trade, albeit with some cargo being rerouted through TITR.

The transport disruptions resulting from the war in Ukraine have necessitated a complex array of responses from the European transport network. From increased energy costs impacting rail freight viability to the geopolitical reshaping of maritime and rail routes, the conflict has forced a re-evaluation of transportation strategies and infrastructure. These adaptations highlight the intersectionality of transport disruptions, where geopolitical conflicts, energy crises, and infrastructural challenges converge, demanding resilience and innovation from the transport sector and its stakeholders.

Supply Chain

The war in Ukraine has caused widespread disruptions across European supply chains, fundamentally altering the landscape of energy markets, agricultural trade, and insurance costs, with far-reaching implications for global supply and demand dynamics.

The conflict's immediate and severe impact on the European gas markets, exemplified by a dramatic surge in energy prices, has necessitated a comprehensive rethink of long-term energy strategies across the continent. With Russia being a primary source of natural gas and crude oil for the EU, the war-induced supply constraints have intensified the urgency to diversify energy sources. This scenario has catalysed a renewed focus on renewable energy sources and Liquefied Natural Gas (LNG) as alternatives to mitigate the reliance on Russian fossil fuels. However, the situation has also paradoxically reinforced the role of fossil fuels in the short to medium term, as countries scramble to secure alternative energy supplies to ensure continuity and energy security.

Ukraine's role as a significant supplier of agricultural products to many developing economies has underscored the global interconnectedness of food supply chains. The war has led to a spike in the prices of basic food commodities by more than 50% in some

countries, exacerbating food insecurity and economic pressures in already vulnerable regions. This disruption highlights the vulnerability of global agricultural supply chains to geopolitical conflicts and the need for diversified sources of food production and distribution.

The increased risk associated with transporting goods through or near conflict zones has resulted in higher insurance premiums for shipping. These added costs have further complicated the economics of international trade, contributing to higher overall transportation costs and, ultimately, consumer prices. This factor, among others, has added layers of complexity to managing supply chains, demanding greater resilience and adaptability from businesses and logistics providers.

Efforts to support Ukraine through new trade deals have introduced additional dynamics into local markets within the EU. The influx of cheaper Ukrainian labour and agricultural produce has had a dual effect, providing essential support to Ukraine's economy while simultaneously challenging local industries and employment in some regions. These developments have prompted discussions about the need to balance support for Ukraine with the protection of local economies, labour markets, and agricultural sectors.

The transport disruptions resulting from the war in Ukraine have had profound impacts on supply chains at multiple levels, from energy and agriculture to insurance and local labour markets. These disruptions underscore the complex web of dependencies that characterize modern supply chains and highlight the necessity for strategic planning, diversification of sources, and enhanced resilience to navigate the challenges posed by geopolitical conflicts and their far-reaching consequences.

Society

The war in Ukraine has had profound societal impacts beyond the immediate tragedy of loss of life and displacement, particularly manifesting through the energy crisis in the European Union. This crisis represents one of the most severe and direct impacts on the everyday lives of EU citizens, exacerbating economic pressures and reshaping the landscape of household finances. The sharp rise in energy prices, due to the disruptions in gas supply from Russia, has led to a significant increase in household living expenses across the EU. Heating, electricity, and transportation costs have surged, placing an additional financial burden on families. This increase in living expenses came at a time when many EU countries were experiencing economic slowdowns, further compounding the financial strain on individuals and families. The difficulty in making ends meet became a widespread concern, affecting a broad cross-section of the EU population and leading to increased calls for governmental intervention and support.

The economic ramifications of the war extended beyond increased living expenses, impacting the job market and employment opportunities within the EU. As described by an expert in multi-modal transport (04-181023), an immediate effect on the job market was: "*When the war against Ukraine started, that people left the country, left their job to defend their country*". Certain sectors, especially those directly affected by trade disruptions and the shifting focus towards supporting Ukraine, faced challenges, including the transport sector due to a sudden shortage of Ukrainian truck drivers. While the EU's extension of support to Ukraine through special trade provisions was a necessary geopolitical and humanitarian response, it inadvertently placed pressures on parts of the EU workforce. Sectors that

competed directly with the influx of Ukrainian labour or agricultural produce experienced tensions, contributing to concerns over local unemployment and economic stability.

In response to the energy crisis and its cascading effects on the economy and society, EU governments implemented a range of measures aimed at mitigating the impact on households and businesses. These included energy tax abatements, price ceilings, and substantial financial allocations to address the crisis. While these interventions provided crucial relief, they also underscored the broader challenges of balancing immediate crisis response with long-term economic and social stability.

The societal impact of the transport disruptions and broader consequences of the war in Ukraine highlight the interconnectedness of geopolitical events, energy policy, and individual livelihoods. The crisis has brought to the forefront the need for resilient energy strategies, economic policies that protect vulnerable populations, and a nuanced approach to international support that considers the multifaceted impacts on society in a world that is perceived as increasingly volatile.

4.4.2 *Response*

Transport Network

In response to the transport disruptions caused by the war in Ukraine, significant adjustments have been made to the European transport network, particularly concerning the rerouting of major transport routes that traditionally passed through Russia and Belarus. This shift has been necessitated by the closure of airspace and the imposition of sanctions, leading to a comprehensive re-evaluation of logistics and transport strategies across the continent. The immediate aftermath of the conflict saw the diversion of air and land transport routes to avoid Russian and Belarusian airspace and territory. This rerouting presented logistical challenges but also underscored the resilience and adaptability of the European transport network in maintaining connectivity and ensuring the continuity of trade and movement despite geopolitical tensions. Airlines, shipping companies, and logistics providers quickly adapted to these new routes, albeit with increased operational costs and longer transit times for goods and passengers.

Despite the widespread disruptions and sanctions, the rail freight connectivity concerning Russia as a transit country (e.g. between China and the EU) has been considerably less affected. This rail connection has served as an important link for trade between Europe and Asia since it offers a faster alternative to ocean freight and a cheaper option compared to air transport. The continued operation of this rail freight route highlights a strategic decision to maintain this vital supply chain link, recognizing its importance for European businesses reliant on the timely and efficient transport of goods to and from Asia. Keeping rail freight connectivity relatively operational, amidst broader transport re-routings, illustrates a nuanced approach to maintaining trade flows and logistics operations in the face of geopolitical challenges. It reflects the complexity of balancing political and economic considerations, ensuring that essential trade routes remain open while navigating the intricacies of international sanctions and regulatory environments.

The response to the transport disruptions caused by the war in Ukraine demonstrates the European transport network's dynamic resilience. By adapting to altered geopolitical landscapes, rerouting major transport pathways, and preserving crucial logistics corridors, the network has managed to sustain trade and mobility, highlighting the critical role of transportation in global commerce and connectivity amidst unprecedented challenges.

Supply Chain

In response to the profound supply chain disruptions wrought by the war in Ukraine, the EU took decisive steps to support Ukraine's economy while navigating the complexities of sanctions against Russia, Belarus, and Iran. These measures aimed to ensure the continuation of trade, especially for critical agricultural products, while adhering to the EU's stance on the conflict. The EU acted swiftly to facilitate Ukrainian trade by establishing alternative land routes through Poland and utilizing three ports, Reni, Izmail, and Kiliia, on the Danube River. These initiatives were crucial in bypassing the blockades and disruptions caused by the war, providing lifelines for Ukrainian exports to reach European markets. Additionally, grain deals were negotiated to allow Ukrainian agricultural products, a cornerstone of Ukraine's economy and a critical resource for global food supply chains, to continue flowing into the EU. These actions not only supported Ukraine in a time of crisis but also helped stabilize global food prices by ensuring the supply of essential commodities.

The EU implemented a comprehensive regime of sanctions targeting Russian, Belarusian, and Iranian businesses, banks, and imports. These sanctions, aimed at penalizing the aggressors and their allies, had significant implications for supply chains, necessitating the rerouting of goods and the search for alternative suppliers. Additionally, the EU imposed restrictions on the export of dual-use goods and technology to these countries, further complicating the trade landscape. To mitigate the impact of these sanctions and facilitate humanitarian support to Ukraine, the EU also adjusted market rules, including waiving authorizations or tolls for humanitarian aid. This measure streamlined the process of delivering critical supplies to Ukraine, demonstrating the EU's commitment to supporting the Ukrainian people while maintaining pressure on Russia and its allies.

These responses underscore the EU's efforts to adapt its supply chain strategies in the face of unprecedented challenges. By establishing new trade corridors, enforcing sanctions, and facilitating humanitarian aid, the EU sought to maintain economic pressure on Russia while supporting Ukraine's resilience. Businesses within the EU had to navigate these changes, seeking new suppliers, and adapting to the shifting regulatory landscape, which underscored the importance of agility and flexibility in global supply chains.

Society

In response to the societal impacts of the transport disruptions and broader consequences of the war in Ukraine, the European Union took significant steps to provide support to refugees fleeing the conflict, highlighting a compassionate and coordinated approach to a humanitarian crisis of substantial scale. Recognizing the urgent need for assistance, the EU implemented several aid packages and policy adjustments to address the immediate needs of refugees and facilitate the provision of humanitarian aid to Ukraine.

The EU's response was swift and substantial, extending a wide array of support measures to those displaced by the war. Recognizing the immediate needs of refugees for shelter, food, medical care, and security, the EU, along with its member states, approved several aid packages aimed at alleviating the hardships faced by individuals and families forced to flee their homes. This assistance was not only directed at the refugees themselves but also at the countries hosting them, many of which saw a significant influx of displaced persons in a short period. The support aimed to bolster the capacities of these host countries to provide care and assistance, ensuring that refugees received the help they needed. Beyond financial support, the EU made critical changes to its policies to streamline the flow of refugees and humanitarian aid into and out of Ukraine. These policy adjustments included simplifying border controls, providing legal protections and rights to refugees, and establishing corridors for the safe and efficient transport of humanitarian aid. Such measures were instrumental in ensuring that assistance reached those in need quickly and that refugees could find safety and support upon arriving in the EU.

4.4.3 *Resilience*

Transport Network

The resilience of the European transport network in response to the disruptions caused by the war in Ukraine has been notably demonstrated through strategic adaptations and collaborative efforts. These actions have ensured the continuity of trade and maintained vital supply chains in the face of unprecedented challenges.

One of the most significant developments has been the increased prominence of TITR via Turkey as an alternative to the traditional freight traffic through Russia and Belarus. This re-routing effort has been instrumental in preserving the flow of goods between the EU and Asia, mitigating some of the impacts of the disrupted routes through Eastern Europe. TITR has not only served as a vital logistical pathway but also as a strategic pivot in response to geopolitical tensions, showcasing the transport network's capacity for dynamic resilience—adapting quickly to external shocks and finding innovative solutions to maintain operations.

In the immediate aftermath of Russia's military aggression against Ukraine, the EU swiftly convened the Network of National Transport Contact Points. This assembly of Member States, the European Commission, other EU bodies, and Ukrainian representatives has played a critical role in the transport network's resilience. The Network has facilitated a forum for discussing and coordinating actions to establish new transport routes and supply chains while striving to preserve existing ones to and from Ukraine. Through these coordinated efforts, the Network has exemplified the European transport network's ability to respond collectively to crises, ensuring that vital transport links are maintained or adapted as necessary. The proactive and collaborative approach adopted by the Network highlights the importance of communication and cooperation among different stakeholders in enhancing the resilience of the transport network. By pooling resources, sharing information, and aligning strategies, the EU has managed to navigate the complex logistical and geopolitical landscape shaped by the war in Ukraine.

The resilience demonstrated by the European transport network in the face of the war in Ukraine reflects both the system's inherent strengths and the effectiveness of collaborative approaches to crisis management. The strategic rerouting of freight traffic through TITR and the active coordination through the Network of National Transport Contact Points underline the network's capability for both static and dynamic resilience—maintaining functionality under duress and adapting rapidly to ensure continuity and security of supply chains. Through strategic adaptations and collaborative efforts, the European transport network has managed to sustain vital connections and support the ongoing needs of commerce and humanitarian assistance, emphasizing the importance of preparedness, flexibility, and cooperation in overcoming crises. One of the terminal operators interviewed in this study (06-231023) from Central Europe also mentioned how capacity on routes involving Russia was diverted to other routes: "*And since we do have the Ukraine crisis since quite a while, and there is the Russia embargo, there are lots of trucks that usually have been engaged in transports between Poland and Russia or Europe and Russia, and they are, of course, available to do something else, and they are covering stretches that prior to that have not been covered by direct trucks*".

Supply Chain

In the wake of the transport disruptions caused by the war in Ukraine, the resilience of supply chains, particularly those connecting the EU and Ukraine, has been critically tested and demonstrated. The establishment of solidarity corridors in 2022 stands out as a significant adaptive response, facilitating continued trade between Ukraine and the EU via land routes. This initiative reflects the dynamic resilience of supply chains, showcasing their capacity to recover from external shocks by establishing alternative routes and mechanisms for trade continuity. The introduction of solidarity corridors was a strategic move to bypass the disrupted traditional trade routes affected by the conflict and sanctions. These corridors have enabled the movement of agricultural products, raw materials, and finished goods, ensuring that Ukraine could maintain its trade activities with the EU. However, the implementation of these corridors has not been without challenges. Economic losses have been reported by locals in the regions surrounding these corridors, attributed to the influx of Ukrainian products that do not adhere to the EU's green agriculture conditions. This situation highlights the complex interplay between maintaining trade flows and managing the economic impact on local EU markets.

The prohibition on the transit via the territory of Russia of more goods and technology has further compelled supply chains to adapt. This restriction necessitated a re-evaluation of logistics strategies, pushing companies to seek alternative routes and supply sources. The resilience demonstrated by these supply chains in navigating the new regulatory landscape and logistical challenges underscores their ability to use remaining resources efficiently (static economic resilience) and to reconfigure operations swiftly in response to new constraints (dynamic resilience). The responses to these disruptions have involved a mix of short-term tactical adjustments and longer-term strategic planning. Companies have had to reassess their dependency on specific routes and markets, exploring new supply chain configurations that can withstand geopolitical tensions and restrictions. This period of adaptation has also fostered innovation, with businesses exploring more diversified and sustainable supply chain models to mitigate future risks.

The resilience demonstrated by supply chains in the context of the war in Ukraine highlights their capacity to maintain operations under challenging conditions and to recover by establishing new pathways for trade. The solidarity corridors represent a critical component of this resilience, enabling trade continuity but also prompting discussions on the need for balanced approaches that consider the impacts on local economies within the EU.

Society

The resilience demonstrated by society in the face of the transport disruptions and broader ramifications of the war in Ukraine, particularly the energy crisis following sanctions on Russia, highlights a collective adaptability and determination to navigate through unprecedented challenges. Societal resilience has been evident in various forms, from individual adjustments in daily life to community support initiatives, underpinned by governmental efforts to alleviate the economic pressures on households. The sanctions on Russia led to a significant surge in energy prices, placing considerable stress on household finances across Europe. Families found themselves grappling with increased costs for heating, electricity, and transportation, necessitating changes in consumption habits and a renewed focus on energy efficiency. This situation tested the resilience of individuals and communities, who responded by seeking alternative energy sources, reducing usage, and sharing resources to mitigate the impact of rising costs.

In response to the cost-of-living crisis exacerbated by the energy crisis, governments across the EU implemented a variety of measures aimed at supporting households. These included energy tax abatements, price ceilings, direct financial assistance, and subsidies for energy-efficient home improvements. Such initiatives represented crucial steps in counteracting the financial strain on families, demonstrating the role of policy in societal resilience. By cushioning the economic impact of the energy crisis, these measures helped maintain social stability and allowed individuals and businesses the breathing room necessary to adapt.

The war in Europe, a phenomenon not witnessed in decades, introduced a level of insecurity and uncertainty that permeated societal consciousness. This anxiety, however, also galvanized a sense of solidarity among European societies. Communities rallied to support not only each other but also those more directly affected by the conflict, such as refugees from Ukraine. The mobilization of support networks, fundraising efforts, and volunteer initiatives showcased societal resilience in the face of adversity, highlighting a collective commitment to uphold principles of humanity and support.

However, since the war has now prolonged into the third year, some negative consequences of the EU policies for supporting Ukraine are being felt across economies of the neighbouring countries. Due to this, strikes and road closures are being observed across the borders, creating hurdles for humanitarian aid. As described by an expert in humanitarian logistics (013-021123) “*and now you have a new disruption at the border because Poland and Romania and Bulgaria and all the neighboring countries of Ukraine for political reasons, because of the price of grain is going down, which hits the agricultural production in Poland. They have shut down trucks from Ukraine to go out, meaning you now have 40 kilometers of queues of trucks on both sides, simply for political reasons, because the Polish farmers, they are losing money on the price of grain. So, this is like the current eruption where you have no control, and where political diversities or differences change*

the whole game". This indicates that while initial efforts helped address the issues of the sudden onset of the war, a new set of policies is now required to address the well-being of not just Ukraine, but the countries supporting its trade and refugees.

4.5 COVID-19 pandemic

The COVID-19 pandemic caused a complete lockdown across many EU countries from 18 March 2020, as Europe was declared as the epicentre of the pandemic (WHO, COVID19, 2024). When the lockdowns were announced, there were bottlenecks at EU borders causing delays and interruptions of supply chains. First lockdowns saw a fear of truck drivers getting stuck in quarantine zones and thereby a sudden driver shortage in various regions, and border closures within the EU further caused initial disruptions in freight transportation (Kovacs et al., 2023). The transportation of medicines and even personal protective equipment needed in the pandemic was particularly affected by travel bans and their effects on air transportation since a significant proportion of medical freight is transported as the belly cargo of passenger planes (Falagara Sigala et al., 2022).

Eventually, green lanes were introduced to keep road freight moving. However, all road cargo was deemed essential and since all freight carriers used the green lanes, long queues were building up (IRU, 2020). The situation became even more complicated for non-EU vehicles, which required additional paperwork. Drivers were unable to upgrade the licenses and other paperwork due to closures of several offices. The road freight operations are often conducted at low margins without cash reserves and hence were badly hit economically (IRU, 2020). The pandemic was long drawn, with impacts lasting over two years. However, due to the measures taken by the governments, road transport was able to recover by 2021. A 7% growth was reported in terms of tonne-kilometres in 2021 as compared to 2020 (Eurostat, 2022b). On a similar note, rail freight was up by 8.7% in 2021, after a decrease of 6.1% in 2020 (Eurostat, 2022a). To further compensate the losses, in 2022, the European commission approved a state aid of EUR 374 million to Italian rail freight transport to compensate for the losses faced in March 2020 (European Commission, 2022).

The pandemic threatened the food supply chain, which was a source of massive concern (Aday & Aday, 2020). However, an auditor's report in 2023 observes that the EU responded swiftly and adequately, by granting direct support, issuing useful guidelines and market measures such as crisis distillation. Some member states struggled with implementing guidelines due to insufficient clarity. It has been recommended that the commission share good practices in future as well (European Court of Auditors, 2023). Figure 10 shows the timeline of the measures taken by the EU in response to the pandemic. CAP refers to Common Agricultural Policy.

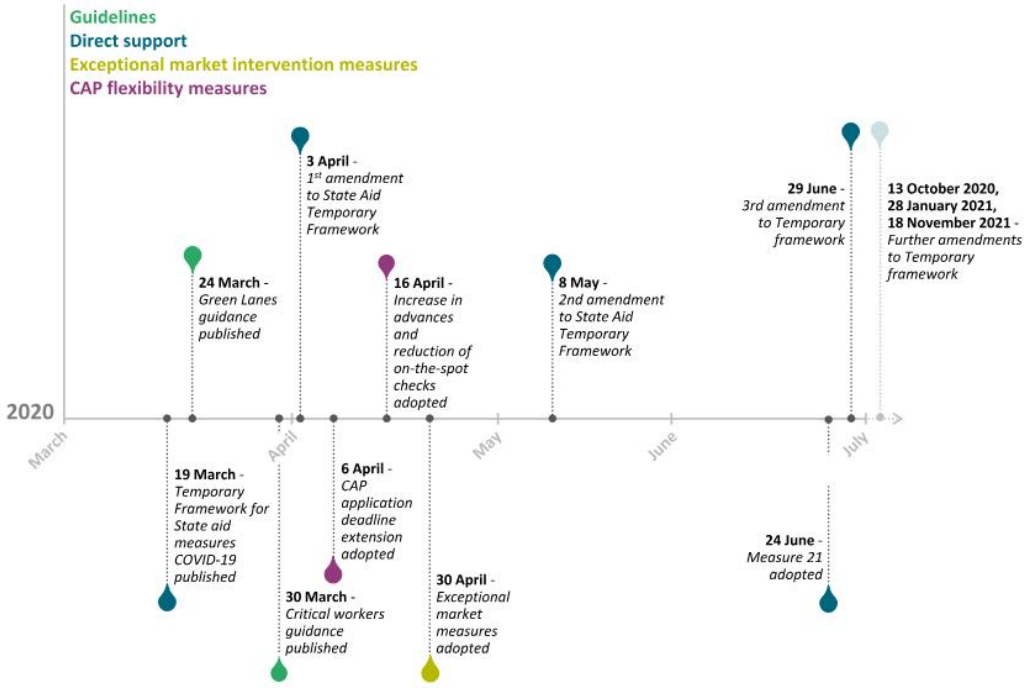

Figure 10: EU measures in response to COVID-19 (European Court of Auditors, 2023)

4.5.1 *Impact*

Transport Network

The COVID-19 pandemic's onset and the subsequent lockdown measures imposed across many EU countries led to significant transport disruptions, particularly impacting the road (and air) freight sector. This period was marked by a notable contraction in demand for transport services, which, combined with logistical challenges and operational restrictions, severely affected the transport network at various levels.

In 2020, the European road freight sector experienced a contraction of between 6.8-8.3% compared to the previous year, underlining the severe economic impact of the pandemic on this crucial component of the transport network. This downturn was part of a broader trend affecting the land transport sector, which saw sales in land transport, including both freight and passenger rail along with road transport, contract by 10.3%. The pandemic's restrictions not only slowed economic activity but also led to a reduction in the movement of goods, exacerbating the challenges faced by the sector.

The fall in demand forced carriers to lower their prices to attract business, putting additional financial pressure on operators already dealing with thin profit margins. Lockdown measures caused unprecedented bottlenecks not only at EU borders but also within the EU, leading to slowed shipments, long queue build-ups, and the necessity for additional paperwork. Furthermore, the sector grappled with driver shortages, exacerbated by the pandemic's health risks and the closure of offices responsible for processing essential paperwork, including license upgrades. Another problem highlighted by an intermodal operator (010-271023) was "*I'm not able to run trains due to COVID sick drivers, train drivers. Lots of disruption on that side*".

The pandemic highlighted the transport network's vulnerabilities to global shocks, with the road freight sector taking a significant hit due to reduced demand, logistical bottlenecks, and operational challenges. Despite these difficulties, the sector began showing signs of recovery by 2021, driven by governmental measures and the industry's resilience and adaptability in navigating the challenges presented by the pandemic. This period of disruption and recovery underscores the critical importance of flexibility, preparedness, and support mechanisms in ensuring the sustainability and efficiency of the transport network in the face of unforeseen global crises.

Supply Chain

The COVID-19 pandemic and the ensuing transport disruptions had a significant impact on global supply chains, triggering a series of adaptations and challenges across various sectors. From the surging demand for household electronics to the stress on food supply chains and the rapid shift towards digitalization, the pandemic reshaped the landscape of global trade and manufacturing.

The lockdowns and the shift to remote work and learning fuelled a global rise in demand for household electronics, such as laptops, tablets, and other digital devices. This surge placed immense pressure on the semiconductor supply chain, a critical component in electronics manufacturing. Semiconductors, already in high demand, were diverted from other supply chains to meet the needs of electronics production. This reallocation had a cascading effect on other industries reliant on these components, most notably the automotive sector. The EU's car production suffered a massive hit due to the semiconductor shortage. Automakers found themselves competing for a limited supply of chips, leading to production delays, shutdowns, and significant financial losses. This scenario highlighted the interconnectedness of global supply chains and the vulnerabilities of relying on a limited number of sources for critical components.

The food supply chain faced its own set of challenges during the pandemic. Lockdown measures and the closure of restaurants and food services led to shifts in demand and distribution channels. Supply chains had to adapt quickly to changing consumer behaviours, including a significant increase in online grocery shopping. The agility and flexibility of food suppliers and retailers were tested as they scrambled to meet the demand while ensuring the safety of their products and workforce.

The pandemic accelerated the digitalization of businesses, making online transactions more relevant than ever. Companies that were able to pivot to online sales and digital platforms found a competitive edge in the new market reality. However, the transition to digital operations and the need to maintain safety protocols introduced additional overheads. The costs associated with sanitizers, safety checks, and adapting workplaces to comply with health guidelines increased operating costs for businesses across sectors.

Society

The societal impact of transport disruptions during the COVID-19 pandemic was deeply felt across communities, illustrating the critical role that transportation plays in our daily lives and economies. The immediate effects were not just on the mobility of people but also on the accessibility of goods and services, which had cascading consequences on various

aspects of society. The lockdowns and bottlenecks at borders directly affected the supply chains, leading to shortages of essential goods, including food and medical supplies. This scenario put a strain on the availability of daily necessities, causing anxiety and stress among the public. The panic buying episodes witnessed in many countries were symptomatic of the fear and uncertainty caused by these disruptions.

Transport disruptions had a direct impact on employment, particularly for those working in logistics, retail, and specially manufacturing sectors reliant on timely deliveries. The road freight sector, crucial for the delivery of goods across Europe, saw a significant contraction, leading to job losses and financial instability for many workers. Small businesses, especially those dependent on the import and export of goods, faced severe challenges, contributing to a rise in unemployment and economic hardship within communities. The transport disruptions exacerbated existing societal inequities, affecting disproportionately those in precarious economic situations or living in remote areas with limited access to alternative supply routes. The dependence on public transportation in urban areas also highlighted the vulnerabilities within these systems, as reduced services and fear of contagion affected people's ability to access work, healthcare, and other essential services.

On a positive note, the pandemic and the ensuing transport disruptions also showcased societal resilience and adaptability. Communities came together to support the most vulnerable, whether through informal networks providing groceries to those unable to leave their homes or through the adaptation of businesses to online platforms to maintain supply chains. The increased relevance of online transactions and the digitalization of businesses were critical adaptations that helped mitigate some of the pandemic's adverse effects on supply chains and employment. The transport disruptions during the COVID-19 pandemic had far-reaching societal impacts, from exacerbating economic and employment challenges to highlighting systemic vulnerabilities and inequities. These challenges prompted significant adaptations within societies, underlining the importance of resilient and flexible transport networks and the critical role of community solidarity and innovation in facing global crises.

4.5.2 *Response*

Transport Network

In response to the transport disruptions caused by the COVID-19 pandemic, significant measures were undertaken at the transport network level to ensure the continuity of freight movements and mitigate the economic impacts on the transport sector. These responses demonstrated a commitment to maintaining supply chains and supporting the transport industry during unprecedented times. One of the pivotal initiatives introduced was the implementation of 'green lanes.' This measure aimed to expedite the movement of freight across borders by ensuring that border crossings remained open to all freight vehicles. The directive that any checks or health screenings at these crossings should take no more than 15 minutes was a critical step in minimizing delays and maintaining the flow of goods, especially essential supplies such as food and medical equipment. The green lanes served as a lifeline for the transport of goods across the EU, ensuring that despite lockdowns and travel restrictions, supply chains could remain as uninterrupted as possible. Another unique response in the pandemic was when production changeover was adapted to transportation to refit passenger to cargo planes and thereby reinstate the flow of medical goods.

Recognizing the profound economic challenges posed by the pandemic, particularly for the railway sector, the EU introduced measures to alleviate financial burdens on railway undertakings. Member States were authorized to allow infrastructure managers to reduce, waive, or defer the payment of track access charges. This intervention provided much-needed financial relief to railway operators, ensuring the sustainability of rail transport services, which are crucial for the long-distance movement of goods. By lessening the economic strain on these operators, the EU aimed to preserve the integrity of rail networks as an essential component of the transport ecosystem.

The recognition of logistics jobs as “essential services” helped in not only reinstating them to continue critical operations for society but also helped in reallocating people from other sectors to keep transport nodes such as warehouses open or to support last mile deliveries. For example, in Helsinki, city workers from other sectors were reassigned as drivers to support the “Helsinki apu” endeavour of the city, delivering food and medicine to people in lockdown.

These measures, aimed at facilitating the movement of goods and supporting the transport sector financially, reflect the EU's agile response to the challenges posed by the COVID-19 pandemic. The implementation of green lanes and the financial support for railway undertakings underscore the importance of maintaining robust and resilient transport networks capable of adapting to crises. These initiatives not only helped to mitigate the immediate impacts of the pandemic on transport and supply chains but also highlighted the critical role of cohesive policy action in addressing large-scale disruptions. Through these responses, the EU demonstrated a commitment to ensuring that its transport networks could continue to operate effectively, supporting economies and societies in the face of the pandemic's challenges.

Supply Chain

The COVID-19 pandemic served as a catalyst that not only accentuated preexisting issues within global supply chains but also expedited the shift in priorities towards building more resilient, agile, and transparent systems. As disruptions rippled through the supply chains due to lockdowns, border closures, and fluctuating demand, businesses rapidly adapted their strategies to mitigate the impact and prepare for a future where such disruptions could become more common.

The pandemic underscored the critical importance of visibility in supply chains. Companies recognized the need to have real-time insights into their operations, from sourcing of raw materials to delivery of finished goods. This visibility became crucial in identifying bottlenecks early and devising contingency plans.

Consequently, resilience emerged as a priority, with businesses looking to diversify their supplier base, invest in inventory management solutions, and develop strategies to adapt to sudden changes in market conditions. Companies and their supply chains were also vital in a response to the pandemic. Production changeover in various industries freed up capacities to manufacture much needed ventilators for health care, hand sanitizer, or personal protective equipment.

The disruptions brought on by the pandemic accelerated the push towards digitization and automation within supply chains. Digital tools and technologies, including AI, IoT, and blockchain, were leveraged to enhance visibility, streamline operations, and improve the efficiency of supply chains. Automation of repetitive and manual tasks not only helped in reducing the dependency on human labour, which was a significant concern during lockdowns, but also increased the accuracy and speed of supply chain processes.

Perhaps one of the most significant changes was the shift in strategic priorities from cost reduction to agility. The pandemic made it clear that the ability to quickly respond to changes in the market or disruptions in the supply chain could be a decisive factor in a company's survival and competitiveness. Agility in supply chain operations, facilitated by digital tools and an upskilled workforce, became a key focus area. Companies invested in training and development programs to enhance the decision-making capabilities of their staff, equipping them with the skills needed to operate in a rapidly changing environment.

The emphasis on upskilling the workforce recognized the importance of human capital in navigating complex supply chain challenges. By fostering a culture of continuous learning and adaptability, companies aimed to enhance their strategic decision-making capabilities and innovate in response to emerging trends and challenges.

Society

In response specifically to the transport disruptions caused by the COVID-19 pandemic, society adapted in several targeted ways, reflecting resilience and innovation under constrained mobility. These adaptations were not just about coping with reduced transport services but also about reimagining access to goods, services, and connections in a period of unprecedented restrictions. Faced with transport disruptions, society swiftly shifted consumer behaviour towards local sourcing and online shopping. With international supply chains disrupted and local deliveries becoming more reliable, there was a notable increase in support for local businesses. Communities rallied to keep these smaller enterprises afloat, recognizing their crucial role in the local economy during and post-disruptions.

The community and businesses innovated to overcome transport hurdles. For example, in urban areas, bicycle courier services saw a surge in demand for delivering a wider range of products, not just food. This adaptation not only addressed the immediate challenge of transport disruptions but also contributed to a reduction in carbon footprints, aligning with broader sustainability goals. The pandemic accelerated the use of digital platforms to facilitate connectivity in lieu of physical transport. Virtual meetings and events became the norm, allowing professional and personal connections to continue. Educational institutions and workplaces adopted remote operations, significantly reducing the need for commute, and thereby mitigating the impact of public transport disruptions.

Societal response also saw the emergence or strengthening of community support networks. With public transport disruptions affecting access to essential services for vulnerable populations, volunteer groups organized ride-sharing initiatives and delivery services for groceries and medications, showcasing community solidarity. As transport services began to resume, society's response included heightened awareness and compliance with safety protocols. Wearing masks, maintaining social distance on public

transport, and favouring walking or cycling where possible were among the behavioural adaptations that helped mitigate the risk of virus transmission during essential travel.

These targeted societal responses to transport disruptions during the COVID-19 pandemic highlighted a collective adaptability. By shifting consumption habits, embracing digital solutions, fostering community support, and adhering to safety protocols, society navigated the challenges of reduced mobility, laying the groundwork for more resilient and flexible approaches to transport and connectivity in the future.

4.5.3 *Resilience*

Transport Network

In response to the transport disruptions caused by the COVID-19 pandemic, the EU took significant strides towards enhancing the resilience of its transport network. The pandemic underscored the critical need for a robust and flexible transport system capable of withstanding and rapidly recovering from external shocks. Drawing from this experience, the EU emphasized the importance of the transport system's integrity and the coordinated use of multiple transport modes to ensure continuity and efficiency during crises.

The EU recognized that solutions to problems in one transport mode should not be developed in isolation but should consider and leverage the strengths of the entire transport network. This approach entails a holistic view of the transport ecosystem, ensuring that measures introduced in response to disruptions in road transport, for example, complement and are supported by rail, maritime, and air transport sectors. By optimizing the use of all transport modes, the EU aims to enhance the system's overall resilience, minimizing the impact of disruptions and ensuring the smooth movement of goods and people.

The EU's response reflects a blend of static and dynamic resilience. Static resilience is evident in the immediate measures taken to maintain the functionality of the transport network during the pandemic, such as the introduction of 'green lanes' for freight transport. These measures ensured that essential goods could continue to be transported efficiently across borders, despite lockdowns and travel restrictions. Dynamic resilience is highlighted in strategies of reassigning workforce to drivers or refitting transportation vehicles from passenger to freight transportation as ways to counteract driver shortages due to health considerations, or cargo capacity overall.

The EU's approach to building resilience in the transport network also involves a significant learning component. By analysing the challenges and responses during the COVID-19 pandemic, the Commission intends to identify best practices and areas for improvement. This learning process will inform the development of comprehensive contingency plans that consider the interconnected nature of different transport modes and the need for a coordinated response to ensure the system's integrity during crises.

Supply Chain

The resilience of supply chains in the face of transport disruptions during the COVID-19 pandemic was tested and demonstrated through a series of adaptive strategies and innovations. As the pandemic magnified pre-existing vulnerabilities within global supply chains, it also accelerated a re-evaluation of priorities towards enhancing visibility, flexibility,

and digital integration. This shift was crucial in maintaining the flow of goods despite unprecedented challenges.

A key aspect of resilience was the increased emphasis on supply chain visibility. Companies invested in technology and systems that provided real-time data on supply chain operations, from procurement to delivery. This visibility allowed for quicker responses to disruptions, such as identifying alternative suppliers or rerouting shipments to avoid bottlenecks. Flexibility in supply chain design, including diversification of suppliers and the adoption of multi-modal transport strategies, proved vital in navigating the uncertainties of the pandemic. By shifting from a focus on cost reduction to prioritizing agility, companies could adapt more swiftly to changing conditions, demonstrating dynamic resilience.

The pandemic underscored the importance of digitization as a resilience-building measure. The rapid adoption of digital platforms facilitated remote work, online ordering, and virtual management of supply chains, minimizing the impact of physical transport disruptions. Technologies such as blockchain for secure and transparent transactions, AI for predictive analytics, and IoT for monitoring goods in transit became more integral to resilient supply chain operations. This technological integration contributed to both static resilience, by maintaining operational functionality through digital means, and dynamic resilience, by enabling efficient resource utilization for recovery and adaptation.

Another dimension of resilience was the strengthening of collaboration across supply chain stakeholders. Partnerships between businesses, governments, and logistics providers deepened, focusing on shared goals of maintaining supply chain continuity and addressing common challenges. This collaborative approach enhanced the collective ability to respond to disruptions, share risks, and co-develop solutions such as production changeover in various industries.

Recognizing the importance of human capital in resilient supply chains, companies focused on upskilling their workforce to better manage complex, digitally driven supply chain operations. Investment in training and development ensured that employees could effectively utilize new technologies and adopt innovative practices to enhance decision-making and operational efficiency.

Society

The resilience demonstrated by society in response to freight transport disruptions during the COVID-19 pandemic highlights an adaptive and collaborative effort to ensure the continuity of goods and services under challenging conditions. This societal response, particularly concerning the movement of essential goods, reflected innovative approaches and strategic shifts to mitigate the impacts of these disruptions. Faced with disruptions in international and long-haul freight transport, there was a marked shift towards local sourcing. Communities and businesses prioritized purchasing from local suppliers, reducing dependency on disrupted supply chains, and supporting local economies. This shift not only helped sustain local businesses but also minimized the transportation distance for goods, contributing to resilience in supply availability.

The freight transport disruptions prompted businesses to adapt their delivery models rapidly. Companies leveraged digital platforms to manage orders and deliveries more effectively,

employing contactless delivery methods to ensure safety. Additionally, the use of local logistics networks saw an increase, with businesses pooling resources to facilitate the movement of goods, demonstrating flexibility in adapting logistics strategies to the new reality. The pandemic accelerated the adoption of digital technologies for supply chain management. Companies utilized digital platforms to track and manage inventory levels, predict demand more accurately, and communicate with suppliers and customers in real time. This digital transition was crucial for navigating the uncertainties and fluctuations in supply and demand caused by the pandemic.

Recognizing the critical need to maintain supplies of essential goods, communities and volunteer groups collaborated to ensure deliveries reached vulnerable populations. This collaboration extended to working with local businesses and logistics providers to identify and resolve bottlenecks in the supply chain, showcasing a collective effort to maintain access to essential goods. Businesses and logistics providers explored innovative solutions to overcome freight transport disruptions. This included the diversification of transport routes, the exploration of alternative modes of transport, and investment in resilient logistics infrastructure. For instance, the shift towards rail freight as an alternative to road transport in certain contexts demonstrated an adaptive approach to maintaining the flow of goods despite challenges.

4.6 Port strike in Finland

The Finnish unions initiated a four-week strike during March and April 2024 to protest the labour market reforms and social security cuts by the current government. The strikes halted the handling of goods at key export ports, disrupted both rail freight and fuel delivery services. Among these disruptions, the strike affecting port operations was considered the most critical for Finland's transport network (Teivainen, 2024). The strike complicated the operations of supply chains for those process industries that rely on the railways and maritime for transport of raw materials and products. The strikes also affected transport of fuel for public transport and airports. Helsinki-Vantaa airport faced some fuel shortages (*Helsinki-Vantaan Lentokenttää Uhkaa Polttoainepula Jo Viikon Päästä*, 2024). Flights to Helsinki have been advised to refuel at other airports, while the Lapland airport is served from Sweden. The strikes have also significantly impacted shipping at Finnish ports, with some incoming cargo ships seeking other ports. Delivery delays of months have been feared in the worst case (Sailaranta, 2024).

Strikes and demonstrations may halt transportation across Europe, due to either road blockages, or the direct impact of transportation workers on strike. Finland often being considered an island, logistically speaking, increases the impacts of port strikes.

4.6.1 *Impact*

Transport Network

The *four-week* transport workers' strikes in Finland during March and April 2024 profoundly impacted the nation's transport network, especially affecting maritime and rail freight

operations. With the closure of key ports as part of the strike action, the import and export activities by sea came to a near standstill, creating significant bottlenecks and delays in the movement of goods into and out of Finland. Thousands of shipping containers were left stranded on ships at sea, waiting dockside in other European ports, or not even dispatched from their country of origin. The port of Hamina-Kotka, one of Finland's major export ports, operated at a mere fraction of its normal volume, around 10 percent, highlighting the severe capacity reductions caused by the strike. Similarly, the Port of Helsinki's Vuosaari harbour experienced a drastic reduction in its usual freight shipments, operating at only about half its capacity for handling self-contained freight shipments, such as shipping containers. The impact at Helsinki's harbours alone was staggering, affecting around 20,000 shipping containers and 10,000 lorry trailers, underscoring the extensive disruption to Finland's maritime transport infrastructure.

The effects of the strike extended to the railway network as well, halting cargo shipments and further complicating the logistics of transporting raw materials and finished products across the country. This disruption hampered the domestic distribution of goods. Given Finland's geographical challenges, notably its limited land transport links to neighbouring Sweden and Norway, the country faced unique vulnerabilities during the strike. With the eastern border closed due to geopolitical tensions arising from the war in Ukraine, Finland's transport network was effectively isolated, exacerbating the impact of the strike and compounding the difficulties in rerouting goods through alternative channels.

The aftermath of the strike is expected to reverberate through the transport network until early summer, indicating a prolonged period of recovery and normalization at the ports and across the transport system. This scenario paints a clear picture of the significant challenges faced by Finland's transport network during the strikes, highlighting the critical role of efficient and reliable transport operations in supporting the country's economic and logistical needs.

Supply Chain

The transport disruptions resulting from the strikes in Finland had a profound impact on supply chains, both domestically and internationally. As a country heavily reliant on its ports for the import of raw materials and components, as well as the export of finished goods, Finland experienced significant challenges across various sectors due to the halt in the flow of goods. The strikes disrupted the critical lifelines for supplier and customer companies alike, leading to delays in shipments, increased operational costs, and potential shortages of goods.

The heavy industry sectors, including chemistry, forestry, and steel, were among the hardest hit by the strike actions. Finnish forest industry companies, such as UPM, Metsä, and Stora Enso, faced forced closures of mills in locations like Kaukaa, Kouvola, Rauma, Jämsänkoski, Joutseno, and Imatra due to acute shortages of parts and raw materials (*Metsä Group Ja UPM Pysäyttävät Tehtaitaan Kuljetusalan Lakon Vuoksi*, 2024). These shortages were further exacerbated by the limited capacity for storage of finished goods, which are typically shipped directly to customers, leading to a significant operational disruption.

The steel industry also felt the impact, with key mills in Outokumpu and Raahe shutting down operations. The direct economic impact of these closures on the companies and the broader Finnish economy was substantial, with estimates from SSAB indicating a reduction in operating profit for its SSAB Europe unit by approximately 27 million euros, for the two weeks of the strike alone. The availability of raw materials and goods became a critical issue for most Finnish companies, with the recovery expected to be prolonged. The halting of port operations and the cessation of railway freight transportation indirectly affect production facilities not directly targeted by the strike. Despite the cessation of the strike, the repercussions of delivery disruptions may persist for several months. The situation was further complicated by cascading effects on transportation routes, such as challenges in the Red Sea, adding layers of complexity to the already strained supply chains.

Online purchases ordered from abroad did not halt at the port despite the strike, but there were delays in deliveries. The crucial factor lies in the type of vessel used for transporting the cargo. Unloading of container ships halts due to the dockworkers' strike. However, traffic continues unabated with roll-on/roll-off (ro-ro) vessels, where containers are transported on trucks. The truck driver drives the vehicle onto and off the ship independently.

One of the most significant long-term consequences of the strikes on supply chains could be the loss of customers' trust. Businesses unable to fulfil orders on time or maintain consistent service levels risk damaging their reputation, which can have lasting effects on competitiveness and market share. The trust that customers place in a company's reliability and efficiency is difficult to rebuild once eroded. The strikes have underscored the vulnerability of supply chains to labour disputes and the importance of flexibility in mitigating these impacts. The strikes not only caused immediate logistical challenges and financial losses but also posed significant risks to long-term customer relationships and market positions for Finnish companies.

Society

The transport disruptions resulting from the Finnish strikes have had profound and multifaceted impacts on society, affecting the national economy, industries, workers, and consumers alike. While the full scope of these effects remains to be completely assessed due to the recency of the strike, early predictions indicate significant negative repercussions on Finland's national economy and GDP. Given that 96% of Finland's foreign trade typically transits through its ports, the strike has created critical bottlenecks, severely hampering the country's import and export capabilities. The ramifications have been particularly acute for the forestry, steel, and chemical industries, which are major clients of the ports. The forest industry and technology industry, which account for approximately 73 percent of Finland's exports. The consequent shutdowns and loss of production not only have direct economic impacts on these sectors but also lead to broader societal repercussions, including the suspension of wage payments for workers at the closed factories. This suspension has direct implications for the income and livelihood of thousands of workers and their families, exacerbating financial insecurities in already challenging times.

On the consumer side, the strike has led to shortages and difficult availability of certain products, notably wines and specific food items, directly impacting daily life and consumer

choices. These shortages underscore the intricate dependencies within Finland's supply chains and the wide-reaching effects of disruptions in the transport sector.

The Confederation of Finnish Industries' early estimates suggested that strikes across various sectors had already inflicted losses exceeding a billion euros on Finland's economy by the beginning of March. With the strikes extending beyond initial projections, the economic losses have escalated, further straining the national economy. The challenging economic conditions brought on by the strikes may have long-lasting implications beyond the immediate disruptions. Economists have highlighted concerns that some companies may opt to maintain or increase production overseas on a permanent basis, a shift that could significantly reduce demand for local subcontractors and further impact Finland's industrial landscape. The strikes underscore the critical role of the transport sector in maintaining economic stability and the cascading effects that disruptions in this sector can have on a nation's economy, its industries, and its citizens.

4.6.2 *Response*

Transport Network

In response to the significant transport disruptions caused by the strikes, particularly the halting of operations at key export ports, ships were rerouted to alternative European harbours. This rerouting of ships required coordination and communication between shipping companies, port authorities, and logistics operators across Europe to identify viable alternative ports and manage the increased logistical complexity. Nevertheless, it is important to acknowledge that containers redirected to alternative ports remain in wait for subsequent shipment to Finland post-strike, contributing to an extended aftermath.

The transport network leveraged some flexibility of multimodal transport solutions to circumvent the stoppages affecting the ports. Specifically, cargo continued to move via trucks on ferries to and from neighbouring countries like Estonia and Sweden. By utilizing ferry services, which did not require the direct involvement of the striking workers, the transport network was able to maintain a critical flow of goods, mitigating some of the broader economic impacts of the strike. However, there are some limitations to modal shift, as mentioned by a port operator from Northern Europe "*Also, when there was the strike in Finnish ports, when you cannot handle containers, but you can handle some of the RoRo cargo, then again, you saw a shift to RoRo. But then again, if one of the big players is having their vessels renewed or something like that, then you see the shift to other directions. So, then people use containers. So, to a certain extent, you can always change between modes, but sometimes that also requires you to change the port. Because not all ports handle all types of traffic.*". They mentioned that not all ports can support all types of traffic and hence modal shift options may be limited.

These measures—utilizing ferries for truck transport and rerouting ships —reflect the transport network's static resilience, showcasing the ability to maintain a certain level of functionality amid significant external shocks. Despite the considerable challenges posed by the strike, these adaptive strategies helped preserve the continuity of supply chains, ensuring that essential goods could still be transported in and out of Finland.

Supply Chain

In response to the transport disruptions caused by the Finnish strikes, supply chain strategies varied based on the position and role of companies within the supply chain. The strikes posed substantial challenges, particularly for the export-driven segments of the Finnish economy, leading companies to adopt a range of adaptive strategies to mitigate the impact on operations and customer relationships.

One of the primary responses was the search for additional storage space for finished goods. With key export ports halted and the transport of goods severely disrupted, companies faced the critical issue of accumulating inventory with nowhere to go. This response underscores the importance of flexibility in logistics and warehouse management, especially in times of crisis. Finding alternative routes for shipping goods was another strategy employed, albeit with varying degrees of difficulty. The geographical positioning of Finland made this particularly challenging. This required significant logistical re-planning and coordination with new transport partners, illustrating the dynamic aspect of supply chain resilience.

For the shortages in the incoming flow of raw materials and components, some companies mitigated the impact by relying on previously established larger safety stocks. This proactive approach provided a buffer that allowed production to continue despite the supply disruptions, highlighting the value of inventory management strategies in supply chain resilience. Proactive communication with customers about potential delays and alternative solutions was critical in maintaining trust and managing expectations. By keeping customers informed, companies aimed to minimize dissatisfaction and preserve long-term relationships, recognizing the importance of transparency in customer service during times of disruption. The decision by some companies to shut down mills or factories was a drastic but necessary response to the immediate challenges posed by the strike. This measure, while protective of the company's long-term interests, underscores the severe economic implications of the transport disruptions. Companies also attempted to sell products earmarked for export within the domestic market or to Sweden, where operational connections were established.

The aftermath of the strike is expected to have a lasting impact, with recovery and normalization of operations anticipated to take months. These responses at the supply chain level reflect a multifaceted approach to crisis management, emphasizing the importance of strategic planning, operational flexibility, and effective communication in navigating the challenges presented by the Finnish strikes.

Society

The transport disruptions resulting from the Finnish strikes in early 2024 sparked extensive discussions and heightened awareness among the public, reflecting the societal response to these significant events. The strikes, driven by opposition to labour market reforms and social security cuts proposed by the government, were mainly a political issue, drawing attention to the broader implications for supply chain security and the vulnerabilities within Finland's logistics and industrial sectors. Media coverage and public discourse around the strikes were intense. The prolonged nature of the strike, extending to four weeks,

underscored the issue of supply security, highlighting how industrial actions can expose and exacerbate vulnerabilities in national and international supply chains.

The societal response to the Finnish strikes reflects a community grappling with complex issues at the intersection of politics, economics, and labour rights. The lively public discourse and the government's negotiations with trade unions highlight a society actively engaged in shaping the outcomes of such disputes. This engagement underscores the importance of dialogue, negotiation, and compromise in addressing the challenges posed by significant transport disruptions and their wider implications for society.

4.6.3 *Resilience*

Transport Network

In the wake of the labour strikes in Finland, the resilience of the transport network, particularly at the level of ports, has been critically tested. The strikes led to significant disruptions, creating extensive backlogs that have posed substantial challenges to the network's recovery. The process of resolving these backlogs, crucial for restoring the flow of goods internationally, is expected to take months, underscoring the importance of both static and dynamic resilience in the transport network.

Static resilience has been demonstrated through the network's ability to maintain a level of operational functionality, albeit reduced, through alternative means such as leveraging truck transport via ferries to neighbouring countries.

Dynamic resilience is evident in the ongoing efforts to recover from the disruptions caused by the strikes. The capability and speed of the transport network to overcome the backlog of shipments at ports are crucial for minimizing the long-term impacts of the strike. This involves not only the physical task of moving goods through the system but also the logistical and administrative challenges of coordinating a vast number of delayed shipments, reallocating resources, and managing the expectations of businesses and consumers relying on the timely delivery of goods.

The recovery process requires an efficient utilisation of resources for repair and reconstruction efforts over the recovery period. Strategies being employed include prioritizing shipments based on urgency and economic impact, increasing manpower and operational hours where possible, and employing technology for better tracking and management of cargo flows. The experience of navigating the backlog and restoring functionality is likely to inform future resilience planning, contributing to the development of a more robust and responsive transport network capable of withstanding similar challenges. This includes revisiting contingency plans, enhancing flexibility in operations, and improving communication channels among all stakeholders involved in the transport network.

Supply Chain

The strikes in Finland, which led to substantial transport disruptions, have also served as a catalyst for resilience at the supply chain level. Companies affected by the strikes, facing halted operations at key ports and consequent delays in shipments, have been prompted to re-evaluate their supply chain designs and make strategic adjustments to mitigate similar disruptions in the future. Static Resilience has been observed as companies utilize their

remaining resources more efficiently in the face of these disruptions. One strategy that emerged was the increase in buffer stocks. By maintaining larger inventories of critical components and finished goods, companies could cushion the immediate impact of the strikes, ensuring a degree of continuity in production and supply to customers.

Dynamic resilience is reflected in the longer-term strategic adjustments the companies are considering in response to the vulnerabilities exposed by the strikes. The disruptions have underscored the risks associated with heavy reliance on specific ports and transport modes, prompting companies to evaluate the flexibility and robustness of their supply chain designs. The strikes have highlighted the importance of proactive communication with suppliers, logistics partners, and customers. Companies are recognizing the value of transparency and timely information sharing as key components of supply chain resilience, enabling all parties to better manage expectations and plan for contingencies.

Society

The resilience of Finnish society in response to the transport disruptions caused by the labour strikes demonstrates a capacity to adapt and manage under challenging conditions. Despite the significant logistical challenges posed by the strikes, the overall security of supply in Finland was not severely affected, a testament to the country's relative self-sufficiency, particularly in the food sector. With a domestic food industry, Finland was able to largely maintain its food supply chain, ensuring that the daily needs of its citizens were met without significant shortages. However, the strikes did lead to some fuel shortages, impacting public transportation and flights in some scale, and highlighting vulnerabilities in Finland's energy supply chain.

In recognition of the critical importance of certain supplies for national security and welfare, Finnish authorities permitted the unloading of goods deemed essential, such as energy-related materials, medicines, hospital supplies, animal feed, and live animals, at Finnish ports. This decision reflects a prioritization of societal needs and the safeguarding of public welfare during the strikes. It is an example of static resilience, where despite external shocks, the system maintained a high level of functionality for critical supply chains by efficiently using the available infrastructure and resources. By highlighting areas of dependency and risk, the strikes have potentially paved the way for strategic planning and investment in supply chain diversification and resilience, aiming to mitigate the impact of future disruptions on society.

5. Discussion

5.1 Impact of climate change on natural hazards and disruptions to the transport network

Climate change modifies the frequency and intensity of natural hazards (Fischer et al., 2021). As explored in sections 4.1 and 4.2, droughts and floods have posed significant challenges to the European transport network. One objective of the ReMuNet project was to use climate model projections for the future climate to analyze changes in natural hazards

and possible impacts on transport networks. While flooding is influenced by several factors, including land cover, soil type, properties, and topography, one of the primary drivers is heavy rainfall. Climate change is expected to intensify heavy precipitation events and drought conditions.

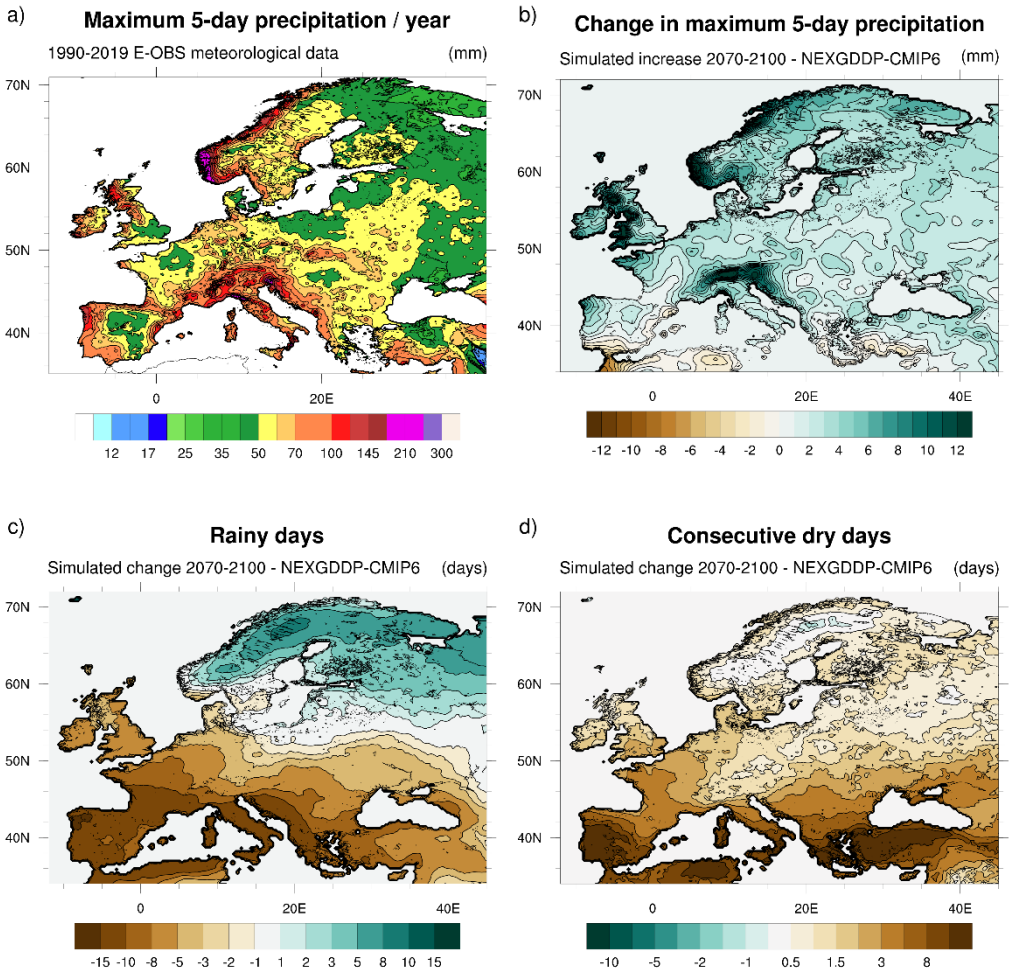

Figure 11: a) Maximum 5-day precipitation per year averaged over the years 1990-2019 based on E-OBS meteorological data, b) Change in maximum 5-day precipitation x) Rainy days per year and d) Maximum consecutive days without precipitation per year, 1990-2019

Figure 11a shows the maximum precipitation over five consecutive days each year, averaged from 1990 to 2019, based on the E-OBS gridded observational dataset for Europe (Cornes et al., 2018). Figure 11b illustrates projected changes in this metric through the end of this century under an intermediate greenhouse gas emissions scenario, SSP2-4.5, using NASA's Earth Exchange Global Daily Downscaled Projections from 28 climate model simulations (Thrasher et al., 2022). These projections indicate that there will be periods of more intense precipitation across most of Europe, except for some small southern coastal regions. More intense precipitation could directly disrupt the European freight transport network and increase the frequency and magnitude of flooding.

Climate model projections for the future indicate a decrease in the number of rainy days per year in regions outside of Northern Europe (see Figure 11c). Additionally, the period of consecutive dry days is expected to become longer across all of Europe, particularly in Southern Europe (Figure 11d). Longer drought periods cause declining water levels in rivers

and lead to transport disruptions. Overall, climate model projections for the future suggest that disruptive events caused by droughts in the Rhine and flooding in both the Rhine and Danube rivers will become more frequent and severe. However, the extent of these changes will strongly depend on how our greenhouse gas emissions evolve and the overall magnitude of climate change.

5.2 Intersectionality of disruptive events

Transport disruptions sit within a wider environment of disruptions within and beyond Europe. The overlap and convergence of multiple disruptive events that occur either simultaneously or in close succession can exacerbate challenges at transport network, supply chain, and societal level (Steinfield et al., 2021).

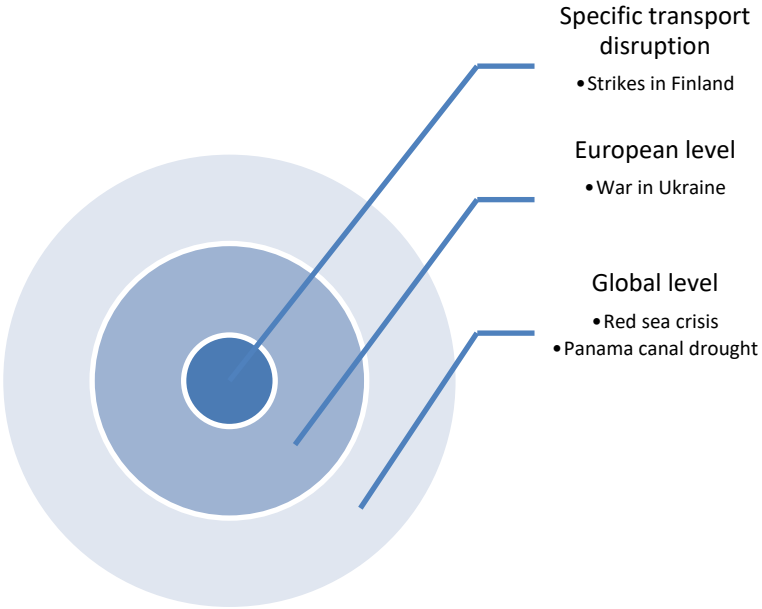

Figure 12: Intersectionality of European and global disruptions and the strikes in Finland.

Taking the example of the strikes in Finland, the specific transport disruption was closely bounded at the national level with workers at ports and railways on strike. However, its impacts were felt beyond Finland's borders as airlines flying into Finnish airports had to be prepared for fuel shortages and ships headed for Finnish ports were rerouted or held in other countries. The effects of the strike were exacerbated by the war in Ukraine, which had resulted in the closure of Finland's Eastern border with Russia (Finnish Government, 2024), effectively making Finland an island regarding its transport network as its only other land borders, with Norway and Sweden, are in the Arctic and offer very limited freight transport capacity. Therefore, the ability of supply chains to substitute for products coming in overland was nullified and the importance of the ports much higher. This occurred in the context of wider global transport disruptions as at the time shipping experienced severe challenges due to the Houthi attacks on commercial shipping in the Red Sea and the drought in Panama severely limiting transport through both of the world's great canals, resulting in delays at ports, higher shipping cost, and issues with container flows (Notteboom et al., 2024). Finland, as a comparatively small market, had a minor impact on global shipping markets, but was still affected by the challenges evident at the global level.

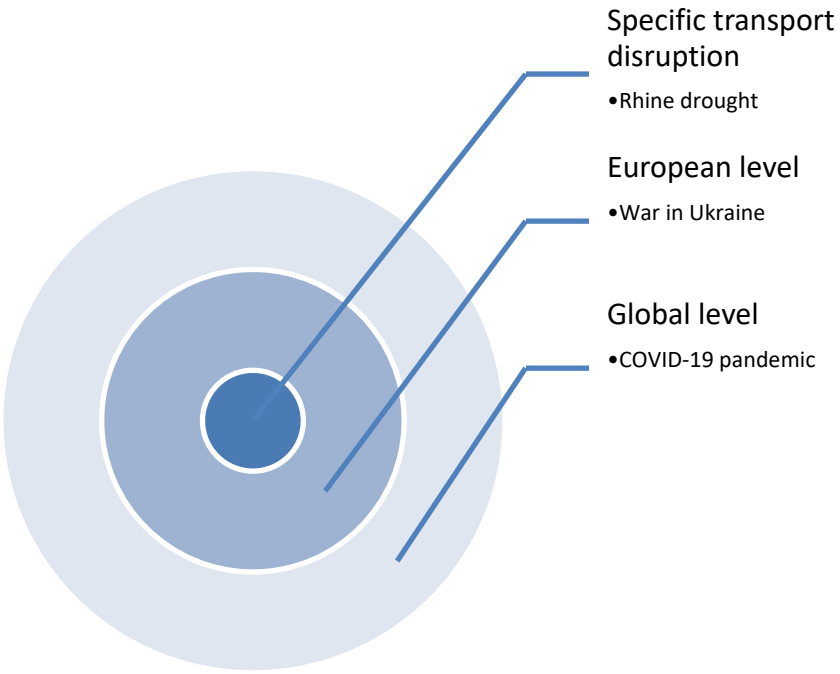

Figure 13: Intersectionality of European and global disruptions and Rhine drought.

While droughts are a recurrent event along the Rhine River (Vinke et al., 2024), the 2022 drought presented as a case study here was peculiar in that the importance of Rhine River shipping had been heightened because of another European transport network disruption, namely the war in Ukraine. As a result of the war, pipeline transport of fossil fuels from Russia to Europe had been cut or severely reduced (Maneejuk et al., 2024). The large German economy was particularly hard hit by this and was struggling to replace the fuel needed for its energy markets from non-Russian sources, relying heavily on coal and gas being transported on the Rhine (Gritz & Wolff, 2024). This is particularly interesting from the societal perspective. There was already a heightened awareness of rising energy prices and a looming energy crisis during the following winter, which made the reduced fuel transport on the Rhine much more pertinent to the average consumer, as well as to policy makers. The 2022 drought occurred at a time when supply chains across Europe were still recovering from the COVID-19 pandemic, making them more vulnerable to disruptions to transport movements, as well as increases to prices because capacity on the Rhine was more limited. The war in Ukraine also influenced road transport across Europe because many long-distance truck drivers from Ukraine had returned to their country, thus limiting road freight capacity (Shchedrina, 2022).

5.3 Ripple effect of disruptive events and bidirectionality of impact

Disruptive events not only cause a direct impact on transport networks, but also trigger secondary disruptions which, in turn, may further affect transport networks. For example, flooding causes blockages of roads due to standing water which disrupts transportation. Further, flooding has also damaged bridges and caused landslides which damage roads and rails. This necessitates infrastructural repair or replanning (away from areas now prone

to landslides) which further disrupts transport networks and slows down relief work and regrowth of economy.

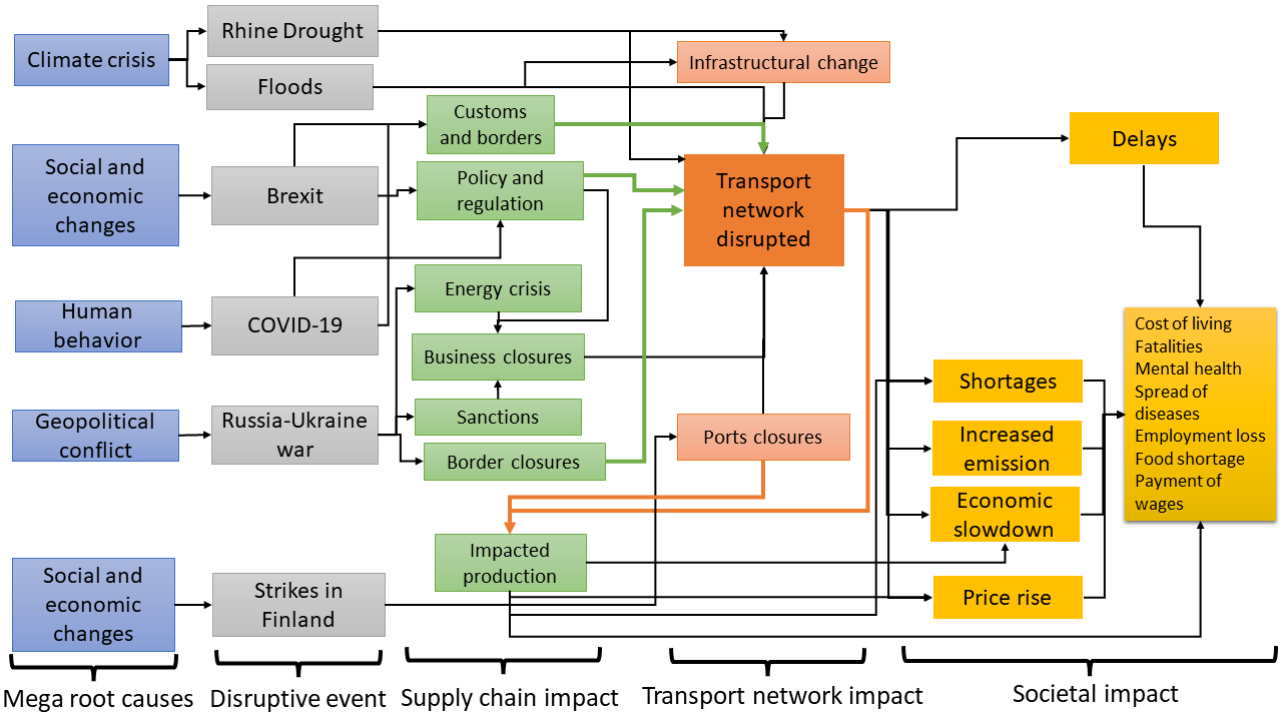

Figure 14: Ripple effects of disruptive events in the EU transport network.

The change of policies and introduction of new regulations due to COVID-19 pandemic and the Brexit caused transport network disruptions due to additional paperwork, complicated border control, requiring adaptations by all stakeholders. These changes also permanently closed certain businesses, rendering them out of profitability, which caused further transport network disruptions (for example, operators of small trucking businesses). The Russia-Ukraine war has caused perhaps the most complex set of disruptions. From the earliest and most impactful energy crisis that directly affected transport networks and the homes of people, to the impact of the Ukraine-supporting policies implemented by the EU which has resulted in severe loss of employment and income for many citizens of bordering countries.

As one of the terminal operators (02-161023) we interviewed mentioned: "*Let's say, of course, last three years has been the most crazy years in the world. You have COVID, then... We have the cyberattack, then we have COVID, then we have a financial crisis, then we have the logistical crisis in the world. So, it is one crisis following the other one. And in last... Now we are swimming in this financial crisis*". In other words, intersectionality has exacerbated the troubles of the transport network. Another terminal operator (06-231023) from Central Europe agrees to this sentiment and adds "*So, lots of disruptions that we are facing now, that we are being impacted by now, have their roots in the COVID pandemic, I think, because everything started to collapse. It was a situation nobody was used to. We had already very, we had severe downtimes, but never ever comparable to the current case*". Another interesting aspect highlighted by the same stakeholder is that the intersectionality of disruptions has caused a reversal of the modal shift, now from rails back to the trucks: "*Fortunately, for the climate and for us, the trucks can adjust quite quickly to*

circumstances. So, what we see for the time being, everybody loves trucks because they are really flexible. For the time being, we do not face a lack of truck drivers any longer. Fewer went down versus the electricity on rail is still on a very high level. So, climate friendly transport modes are having a hard time competing with trucks for the time being. There is no lack of drivers. There is lots of capacity available. So, currently, it looks like a reverse modal shift to us."

This report has generally analysed the levels of impact from transport network to supply chain to society. However, in the analysis it became apparent that impact is not always so unidirectional. The case studies demonstrate that the societal level can also impact on the supply chain or even the transport network level and the supply chain level can impact on the transport network level. As seen in Figure 14, the green arrows indicate the supply chain impacting the transport networks and the orange arrows indicate the transport network impact the supply chains. For the societal level impacting the supply chain level, a prime example is the COVID-19 pandemic, where due to lockdowns and health concerns, consumer behaviour shifted to a heavy reliance on online shopping even in consumer segments that up till then had mainly relied on brick-and-mortar stores (Sharma & Jhamb, 2020). This shift forced supply chains to adapt to a higher volume of e-commerce transactions, which in turn influenced the transport network in terms of inventory levels, warehouse locations, and last-mile delivery demands (Singh et al., 2021).

In the case of Brexit, the societal decision in the UK to exit the EU had profound implications on supply chains, with businesses needing to re-evaluate sourcing strategies, compliance with new trade regulations, and customs procedures (Jucyte et al., 2021). This resulted in reconfiguration of supply chains, inventory buildup, and changes in supplier relationships. This in turn had an impact on the transport network, for example with the longer waiting times at the port of Dover requiring investment in larger parking facilities (Ke et al., 2022).

The strikes in Finland stemmed from the public response to labour market reforms that disrupted the transport network as key export ports were closed (Bruno, 2023). This required a rapid reassessment of transportation routes and mechanisms, including the increased use of ro-ro ferries to maintain the flow of goods. In this case, response at the transport network level mitigated some of the disruption at the supply chain level.

Figure 15: Bi-directional impact.

The Rhine drought offers a particularly interesting example of the interplay between the transport network and the supply chain level. Initial disruptions on the inland waterway impacted supply chain operations. In response, companies switched their cargo to alternative transport modes with the modal shift from river to rail and road requiring transport networks to accommodate increased demand (*Drought Hits Germany's Rhine River*, 2022).

Similar effects are likely to be evident in many disruptive events that affect one mode of transport over others. A large-scale example of supply chain impacts affecting transport networks comes from the war in Ukraine. Disruptions of supply chains, particularly in energy and agriculture, had a cascading effect on transport networks. The search for alternative energy sources led to new routes and methods of transportation, increased reliance on LNG carriers and a reorientation of rail freight routes to avoid conflict areas (Burroughs, 2023).

5.4 Societal impact of transport disruptions

Transport disruptions in Europe, ranging from natural disasters to geopolitical events and health crises, have had a profound impact on society.

Table 6 summarises the key societal impacts found in the six case studies. From this, conclusions can be drawn regarding the main societal impacts of transport disruptions in the European transport network.

Case Study	Key Societal Impacts
Rhine Drought	- Economic slowdown due to impacted industrial production - Increased prices for consumers
Floods across the Rhine-Danube corridor	- Strain on economies due to rebuilding infrastructure - Disruption in local trade and community life
Brexit	- Job losses and economic uncertainty - Increased cost of living due to higher import/export costs - Disruptions in local trade especially in Ireland and Northern Ireland - Loss of employment, requirement for new qualifications for drivers and workers
War in Ukraine	- Global rise in energy prices, stressing household finances - Increased poverty levels and economic inequality - Unemployment due to affected businesses
COVID-19 Pandemic	- Surge in unemployment and closure of small businesses - Limited product availability and shortages - Shift to online platforms for shopping and home delivery of goods
Strikes in Finland	- Economic impact due to halted industrial production - Job losses in the transport sector and related industries - Increased prices and supply chain disruptions affecting consumers

Table 6: Key societal impacts across case studies

Case Study	Key Societal Impacts
Rhine Drought	- Economic slowdown due to impacted industrial production - Increased prices for consumers
Floods across the Rhine-Danube corridor	- Strain on economies due to rebuilding infrastructure - Disruption in local trade and community life
Brexit	- Job losses and economic uncertainty - Increased cost of living due to higher import/export costs - Disruptions in local trade especially in Ireland and Northern Ireland - Loss of employment, requirement for new qualifications for drivers and workers
War in Ukraine	- Global rise in energy prices, stressing household finances - Increased poverty levels and economic inequality - Unemployment due to affected businesses
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Strikes in Finland	- Economic impact due to halted industrial production - Job losses in the transport sector and related industries - Increased prices and supply chain disruptions affecting consumers

The most pervasive categories of societal impact are:

Economic impact and unemployment: The ripple effect of transport disruptions on the economy is significant, as seen in the Rhine drought, which slowed down industrial production due to limited shipping capacity, and the strikes in Finland, which halted industrial production entirely in some organisations, leading to workers not receiving their wages.

Increased cost of living: Supply chain disruptions often lead to a surge in the cost of living. During the Rhine drought and the Finnish Strikes, the inability to transport goods efficiently led to price hikes for consumers.

Local trade and community impact: Disruptions can isolate communities and affect economies, as seen in the floods across the Rhine-Danube corridor, where community life was upended, and local trade was significantly disrupted.

Societal behaviour changes: The changes in societal behaviour due to disruptions can have a substantial feedback effect on transport networks and supply chains. The COVID-19 pandemic dramatically shifted consumer behaviour towards online shopping, putting additional pressure on delivery services and logistics networks, which were forced to scale up operations to meet the new demand pattern. This pivot to digital consumption reflects a broader trend towards e-commerce that transport networks must continue to adapt to.

Shortages: Transport disruptions becomes most apparent to consumers through product shortages. Early in the COVID-19 pandemic, panic buying of staples like toilet paper and pasta exposed the fragile nature of supply chains and underscored the vital role of logisticians. Such shortages prompt consumers to alter purchasing habits and can lead to a deeper appreciation of the complexities involved in supply chain management.

These categories illustrate the impact transport disruptions can have on society. **The case studies reveal a complex web where the transport network, supply chains, and societal factors are interdependent, each influencing the other.** Therefore, enhancing the resilience of Europe's transport networks is not just a matter of economic imperative but also of social stability and wellbeing. Addressing these challenges requires a holistic approach, involving strategic investments in infrastructure, diversified supply chains, and policies that support rapid adaptation to changing conditions. This will be further explored in the recommendations set out at the end of this report.

5.5 Resilience

In the case studies, resilience was evident across all levels, encompassing both dynamic and static resilience. Static resilience is exemplified by the immediate measures implemented to preserve the continuity of transport systems amid disruptive events. For instance, during the Rhine drought, established monitoring systems allowed for real-time adjustments to shipping strategies, ensuring that vital industrial supply chains remained operational, albeit at reduced capacity. Similarly, during the floods along the Rhine-Danube corridor, pre-existing flood defences were activated, showcasing infrastructure preparedness. In the Brexit scenario, the transition period and the creation of green and red lanes helped maintain the flow of goods across borders despite new regulatory challenges. During the COVID-19 pandemic, 'green lanes' and deferral of track access charges for railways enabled critical supply chains to function despite severe mobility restrictions. Each of these examples reflects static resilience where existing resources, systems, and policies were utilized effectively to maintain function during a shock.

In terms of dynamic resilience, the capacity for systems to adapt and recover over time is highlighted by the strategic actions taken in the wake of disruptions. Post-Brexit, supply chains showed dynamic resilience by diversifying trade partners and restructuring operations to align with new regulatory landscapes. After the floods across the Rhine-Alpine and Rhine-Danube corridors, the adaptation involved reconstructing and reinforcing infrastructure, while incorporating future flood risk assessments. In the context of the war in Ukraine, the European transport network and supply chains found dynamic resilience in the development of new routes, such as the middle corridor, which avoided conflict zones and sanctions. Each case demonstrates dynamic resilience through the ability to reconfigure, innovate, and strengthen systems in response to and anticipation of future challenges. Table 7 provides a synthesis of resilience across the cases at different levels.

Table 7: Synthesis of resilience across cases

Case Study	Transport Network Resilience	Supply Chain Resilience	Societal Resilience
Rhine Drought	Adjustment of shipping strategies, usage of shallower vessels, and alternative transport methods like rail and road.	Diversification of transport modes by companies, investment in drought-resistant vessel types.	Communities and industries adapt to new water levels, policy discussions on

			infrastructure improvements.
Floods across the Rhine-Danube corridor	Reconstruction of damaged infrastructure, renovation, and utilization of historic flood barriers.	Rerouting logistics, securing new partnerships, and increasing emergency stockpiles.	Evacuation procedures, community rebuilding efforts, and increased investment in flood protection measures.
Brexit	Reconfiguration of transport routes, development of new shipping lanes, increased checks and documentation preparation.	Adaptation to new trade regulations, establishment of new supply chains, shifts in sourcing.	Job requalification programs, public adaptation to new market realities, and changes in local trade practices.
War in Ukraine	Utilization of alternative routes like TITR, contingency planning, and resilience tests to ensure preparedness.	Diversification of energy sources, adoption of new trade corridors, and accelerated digitalization for supply management.	Community support for refugees, governmental interventions to stabilize energy prices, and adjustments to new economic conditions.
COVID-19 Pandemic	Implementation of 'green lanes' for essential goods, refitting vehicles, recognition of logisticians as essential workers, and accelerated digitalization for transport management.	Shift from cost-focused operations to agility and flexibility, increased use of digital platforms, and investment in local sourcing.	Rapid adoption of e-commerce, increased reliance on digital platforms for services, and community collaboration for essential deliveries.
Strikes in Finland	Rerouting of ships, continued movement of cargo via trucks to alternate ports.	Companies seeking storage solutions and alternative transportation, stockpiling, and increased communication with customers.	Public discourse on supply security, efforts to support affected workers, and increased awareness of vulnerabilities in supply chains, negotiations to resolve strikes.

6. Recommendations

Enhancing resilience to future transport networks disruptions in Europe involves learning from past challenges and successes. These cases lend to the following policy recommendations and managerial implications.

6.1 Policy recommendations

Policymakers are pivotal in bolstering resilience within transportation networks, since they provide strategic guidance for long-term planning, resource allocation, and risk management effort. These are thus some policy recommendations:

- **Incorporate resilience in infrastructure design and maintenance:** Allocating resources to develop higher capacity ports, reinforced roadways, and robust rail networks can significantly improve their ability to withstand and swiftly recover from disruptions. A proactive approach to upgrading and maintaining transport infrastructure is needed.
- **Establish financial support mechanisms to alleviate the economic impacts of disruptions on the transport sector:** Access to emergency funds and financial assistance can enable transport entities to navigate economic challenges and implement necessary adaptations without undue financial strain.
- **Invest in hydro-meteorological forecasting and monitoring:** There are various advanced digital tools, technologies, and methods to anticipate hydro-meteorological events such as floods and droughts, combined with monitoring systems for water levels in rivers, that can support transport network development while considering long-term climate risks and short-term weather-related disruptions.
- **Prioritize societal resilience over transport network resilience:** It is recommended that policymakers prioritize societal resilience over transport network resilience, and consciously acknowledge that certain transport routes may face disruption, while ensuring the protection of critical infrastructure such as housing and bridges. A prime example of this concept is evident in flood control strategies employed in Vienna and Budapest. Here, the transport network is intentionally engineered to withstand flooding, prioritizing the protection of housing infrastructure. Despite the anticipated impact on certain transport routes, this approach ultimately bolsters societal resilience, albeit at the risk of transport network disruptions.
- **Establish collaborative networks between the public and private sectors:** Fostering partnerships and avenues for international cooperation facilitates seamless information sharing and coordinated crisis responses. Such collaborative efforts can improve the effectiveness of response measures and enhance resilience.
- **Recognise logisticians as “essential workers”:** The recognition during the pandemic that logisticians are “essential workers” underscores their criticality for societal resilience and should be maintained throughout different scenarios.
- **Support community engagement and public awareness of preparedness and response:** Community engagement and public awareness initiatives are integral to effective resilience-building strategies. Involving local communities in preparedness and response planning can bolster societal resilience and ensure that the public is adequately informed and equipped to adapt to disruption scenarios. By empowering communities and fostering a culture of preparedness, policymakers can enhance the resilience of societies against transport disruptions.

6.2 Managerial implications

In addressing supply chain disruptions, companies can bolster resilience through various strategies.

- **Prioritize preparedness strategies:** Companies should prioritize preparedness strategies to minimize the likelihood or impact of disruptive events. This includes pre-positioning inventory, establishing flexible production capacity, and vetting alternative suppliers, routes, and transportation modes.
- **Increase supply chain visibility:** Early detection of warning signals through supply chain visibility tools is crucial. Companies should invest in these tools to identify potential disruptions and take proactive measures to avert or mitigate their impact.
- **Develop contingency plans:** It is essential for companies to develop contingency plans that enable swift activation of alternative transportation options in response to disruptions. This ensures resilience and minimizes disruptions to operations.
- **Build resilient networks:** Mitigate over-reliance on single sources or routes by building resilient networks of suppliers and logistics partners. Diversifying the network enhances resilience against disruptions.
- **Adopt cargo prioritization strategies:** Implement cargo prioritization strategies to ensure timely transportation of critical goods during disruptions. This helps maintain continuity of operations and minimizes the impact of disruptions.
- **Enhance inventory management:** Improve inventory management practices to sustain production continuity with alternative materials. Companies should develop substitution strategies to address material shortages and ensure uninterrupted operations.
- **Invest in Real-Time Tracking and Predictive Analytics:** Allocate resources towards real-time tracking and predictive analytics technologies. These investments facilitate proactive measures against disruptions by enabling timely response and intervention. Flexible Routing and Mode Allocation: Develop capabilities for rapid rerouting and mode-switching to respond to network disruptions, maintaining service continuity.
- **Provide Workforce Training:** Equip the workforce with training initiatives to adapt to technological advancements and operational changes. This ensures that employees can effectively contribute to urgent tasks such as logistics coordination during disruptions.
- **Focus on Recovery Efforts:** Following a disruption, companies must redirect their efforts towards recovery. This involves reallocating resources and efforts to restore operations and rebuild supply chain resilience.

6.3 Current and future work in ReMuNet

This report concludes the deliverables for Work Package 1 of the ReMuNet project, which aimed to “Develop European multimodal transport ontology and classify disruptive events and their impact on transport networks”. This report addresses the goal of this WP to “understand the impact of disruptive events on transport chains and analyse mitigation alternatives”. Particularly, the societal impacts of disruptions have been studied in this report. This study contributes to the upcoming work in the ReMuNet project in the following ways:

1. The ontology, typology, root-cause analysis (include mega root causes), and synthesis of societal impact and resilience of the most pertinent disruptions in the EU in the recent years will contribute to defining the framework of the ReMuNet reference model being developed in WP2, the unified data pool in the collaborative platform targeted in WP3, and multimodal route planning in the simulation model in WP4.
2. The interviews conducted with the diverse stakeholders in the European freight transport network provide deep insights into the behaviour of the network in the face of disruptions and frequently employed mitigation strategies. These insights will be utilized in developing the algorithm for the route optimization in WP3 and WP4.
3. The studies on intersectionality and ripple effects of disruptions will help enhance the route selection algorithm by incorporating not just the primary effects of the disruptions but also the compounded impact when selecting alternatives.
4. The studies on climate change and their impact on natural hazards will be incorporated in gauging the viability of alternate routes in the ReMuNet tool. Using meteorological data and forecasts for the next several decades, the vulnerabilities on certain routes to natural disasters could be estimated.
5. This report highlighted the resilience shown by society and transport networks, using existing infrastructure and resources, in the face of unforeseen and extreme disruptions. The insights from these studies have been utilized to draft recommendations for policy makers in this report. These insights will also be incorporated in the ReMuNet tool wherever applicable, to obtain more sustainable and resilient routing options.

7. Conclusions

The analysis derived lessons from the varied responses and degrees of resilience exhibited, which contribute to the development of a more robust and adaptable European transport system. This illustrated how disruptions have differing impacts depending on their nature and context, necessitating tailored responses and strategies to bolster the transport network’s resilience. The study contributes to the ongoing discourse on enhancing the European transport network’s ability to withstand and recover from disruptive events. This is particularly pertinent given the increasing complexity and interconnectedness of the transport systems within the European economic area and society at large.

In conclusion, this study has highlighted the complex nature of transport disruptions and their far-reaching impacts on society, the economy, and the environment. Through the analysis of six varied case studies, including the Rhine drought, floods across the Rhine-Danube corridor, Brexit, the war in Ukraine, the COVID-19 pandemic, and strikes in Finland, we have gleaned valuable insights into the factors contributing to resilience in transport networks and supply chains.

The cross-case analysis illuminated recurring themes such as the need for diversification, the importance of infrastructure integrity, the pivotal role of digitalization, and the value of collaborative networks. These elements form the cornerstone of effective resilience strategies, enabling transport network operators, supply chain managers, and policymakers to adapt to and recover from disruptions. From the Rhine's low water levels affecting industrial shipments to the logistical realignments necessitated by Brexit and the pandemic-induced pivot to e-commerce, each case study has underscored the importance of preparedness and flexibility. The societal impacts—spanning economic slowdowns, increased cost of living, and shifts in employment—have revealed the human dimension of transport disruptions, necessitating policies and actions that address not only the operational but also the social aspects of resilience.

The recommendations offer a roadmap for stakeholders to enhance the robustness of transport systems against future disruptions. By investing in resilient infrastructure, adopting cutting-edge technologies, fostering collaborative networks, and prioritizing sustainability, the resilience of transport networks and supply chains can be significantly improved.

As we look to the future, transport disruptions, whether caused by natural events, geopolitical tensions, or global health crises, will continue to pose challenges. However, the lessons learned from this study provide a strategic framework for mitigating the impacts of such disruptions, ensuring that transport networks and supply chains are not only capable of withstanding shocks but can also adapt and thrive in an ever-changing global landscape. This study serves as a testament to the resilience and ingenuity inherent within our transport systems and the societies they support.

8. References

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Appendix

Appendix A: Interviewee details

Table 8 shows the interviewee details from the qualitative study. The codes are used to the cite quotes and remarks made by the interviewees.

Table 8: Interviewee details at a glance

S.No	Code	Role	Sector	Country
1	01-131023	Technical director	Combined transport	Belgium
2	02-161023	Member of management board	Terminal operator	Estonia
3	03-171023	Founder	Road freight relay	Germany
4	04-181023	Manager	Network planning	Germany
5	05-201023	Head, digitalization	Air freight	Switzerland
6	06-231023	Managing director	Terminal operator	Austria
7	07-231023	Transport consultant	Combined transport	Lithuania
8	08-251023	Head of sales	Network planning	Germany
9	09-271023	Senior project manager	Combined transport	Germany
10	010-271023	Managing director	Combined transport	Germany
11	011-011123	Logistics development manager	Government transport agency	Finland
12	012-021123	Sales manager, specialist	Terminal operator	Finland
13	013-021123	Consultant	Humanitarian logistics	Denmark
14	014-031123	Founder	Combined transport	Germany
15	015-101123	Consultant	Maritime shipping	Estonia
16	016-201123	Data manager	Terminal operator	Finland
17	017-211123	Project manager	Combined transport	Germany

Appendix B: Document analysis

Rhine:

1. Niedrigwasser: Vor allem Rohstoffe und Güter am Anfang der Produktionskette verzögert | Kiel Institut (ifw-kiel.de)
2. IfW: Niedrigwasser kostet Wirtschaftsleistung - DVZ
3. Dürre: Sieben Fakten zum Rhein-Niedrigwasser - WELT
4. 220623_nw_download18.pdf (bafg.de)
5. Der aktuelle Wasserstand des Rheins weckt Erinnerungen an das Jahr 2022 (dbresearch.de)
6. Niedrigwasser am Rhein schadet Wirtschaft – DW – 08.08.2022
7. Rhein häufiger von Niedrigwasser betroffen: IKSR beginnt ab Herbst 2022 mit Aktualisierung der Strategie zur Anpassung an den Klimawandel (umweltwirtschaft.com)
8. Rhine closes to barge traffic, with water depth set to hit record lows - The Loadstar
9. BASF deploys new freight vessel on Rhine River to cope with lower water levels | Clean Energy Wire

10. Europe's Low Water Levels Threaten Rhine River, Hit $80B Trade Lifeline - Bloomberg
11. Drought in Europe: Shipping threatened in Germany as Rhine water levels continue to drop | Euronews
12. Low water hampers Rhine river shipping in Germany | Reuters
13. 2. FREIGHT TRANSPORT ON INLAND WATERWAYS - CCNR - Observation Du Marché (inland-navigation-market.org)
14. Ripple effects - Exploring the impact of low Rhine water levels on the Dutch economy - ABN AMRO Bank
15. Rhine water levels fall to new low as Germany's drought hits shipping | Germany | The Guardian
16. Droughts are damaging supply chains on waterways | World Economic Forum (weforum.org)
17. Rhine's low water levels hit German shipping – DW – 08/08/2022
18. Droughts leave cargo riverboats high and dry (bbc.com)
19. Rhine River Water Level Hits New Low, Forcing Some Barges to Halt Transport (insurancejournal.com)

Floods:

1. https://adore.ifrc.org/Download.aspx?FileId=718945
2. Slovenia was devastated by flooding in 2023 - how is it preparing for extreme rain in the future? | Euronews
3. Slovenia: Floods - Aug 2023 | ReliefWeb
4. Flooding in Slovenia - August 2023 | Copernicus EMS - European Flood Awareness System
5. Government measures for flood relief | GOV.SI
6. Slovenia – Record Rain and Floods Cause Widespread Damage – FloodList
7. Italian floods in May 2019 proved hard to predict | ECMWF
8. Germany – Heavy Rain from Storm Axel Causes Flooding – FloodList
9. Flooding in Germany, December 2023 | Copernicus EMS - European Flood Awareness System
10. Deutschland: Hochwasserlage bleibt angespannt | tagesschau.de
11. Hochwasser 2023 - eine Einordnung (daswetter.com)
12. Ursachen für das Hochwasser in Niedersachsen 2023/2024 | Nds. Ministerium für Umwelt, Energie und Klimaschutz
13. Alluvione 2019 in Piemonte: stanziati altri 15 milioni - Protezione Civile, Il Giornale della (ilgiornaledellaprotezionecivile.it)
14. Un anno fa la terribile alluvione del 21 ottobre 2019 nell'Alessandrino - Dati Meteo Asti
15. Alluvione a Prato: esondano fiumi e torrenti, un morto. Appello del sindaco: "Andate ai piani alti delle case" (lanazione.it)
16. Alluvione, due miliardi di danni in Toscana. A Prato coinvolte oltre 3.700 aziende e diecimila abitazioni | TV Prato
17. River Danube bursts its banks in Budapest, water highest since 2013 | Reuters
18. Floods in Europe: Hungary, Netherlands and Lithuania brace themselves | Euronews
19. Karácsonyi árvíz: a Duna tetőzött Budapestnél, de a Tiszán újabb árhullám érkezik (vg.hu)
20. Árvíz: csaknem 1200 kilométeren van készültség, a Duna Budapestnél csütörtökön tetőzik | hirado.hu
21. Croatian army steps in as heavy rains flood homes, roads and schools | AP News
22. Torrential Rain Overflowing Rivers, Cause Chaos in Bosnia, Croatia | Balkan Insight

Brexit:

1. Overcoming challenges due to Brexit logistics impact | Maersk
2. 5 key impacts of Brexit on logistics in the UK and Europe | Michael Page
3. Impact of Brexit on the transport sector | Industry sector analysis | Brexit | Global law firm | Norton Rose Fulbright
4. The impact of Brexit on the transportation and logistics industry (thecooperativelogisticsnetwork.com)
5. Brexit's impact on logistics in the UK and the EU | DSV
6. New Brexit food checks will test Britain's supply chains (bbc.com)
7. Brexit for Global and European supply chains (logistics.org.uk)
8. Supply Chain Latest: UK Business Struggle With Brexit - Bloomberg
9. Supply chain problems | Institute for Government

10. What does Brexit mean for Procurement? | CIPS
11. UK manufacturers warn Brexit is undermining their place in EU supply chains (ft.com)
12. Dover port pushing UK government on biosecurity after Brexit changes | Reuters
13. Dover delays are a lesson in Brexit realities – and they may be about to get worse | Business News | Sky News
14. The port of Dover is vulnerable to delay and disruption (economist.com)
15. No-deal Brexit scenario would create serious traffic congestion and supply chain chaos (theconversation.com)
16. Brexit: what the UK/EU customs changes mean for businesses from January 1 (theconversation.com)
17. quick-brexit-guide-for-business.pdf (enterprise.gov.ie)
18. Import, export and customs for businesses: detailed information - GOV.UK (www.gov.uk)
19. Preparing your logistics for the impact of Brexit (alpegagroup.com)
20. Guide to Importing and Exporting After Brexit (axa.co.uk)
21. Northern_Ireland_Trade_Explainer_V7.pdf (publishing.service.gov.uk)
22. Moving goods to or from Northern Ireland (logistics.org.uk)
23. The Protocol on Ireland and Northern Ireland explained - Consilium (europa.eu)

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1. Factsheet (iata.org)
2. Immediate and long-term impacts of the Russia-Ukraine war on supply chains (kpmg.com)
3. The supply of critical raw materials endangered by Russia's war on Ukraine (oecd.org)
4. Russia-Ukraine War Impact: Global Supply Chain & Logistics Crisis | GEP Blogs
5. War in Ukraine: the supply chain impact (themanufacturer.com)
6. Ripple effects from Russia-Ukraine war test global economies | MIT Sloan
7. How the War in Ukraine Is Further Disrupting Global Supply Chains (hbr.org)
8. PARC-Industry-Insight_The-War-in-Ukraine-and-its-Impact-on-Global-Supply-Chains_FINAL.pdf (cardiff.ac.uk)
9. Impact of Russia-Ukraine war on global logistics and supply chain (freightify.com)
10. How the Russia-Ukraine conflict is impacting supply chains (consultancy.eu)
11. Ukrainian war compounding Europe's truck driver shortage - Inside Logistics
12. Drivers taking up arms for Ukraine worsens European trucker shortage - FreightWaves
13. The effects of the Ukraine war on China's 'new Silk Road' (midnight-trains.com)
14. Ukraine war shakes up China-Europe railway express – POLITICO
15. Food shortages, millions of refugees, and global price spikes: the knock-on effects of Russia's Ukraine invasion (theconversation.com)
16. Why Russia pulled out of its grain deal with Ukraine – and what that means for the global food system (theconversation.com)
17. Ukrainian grain exports explained - Consilium (europa.eu)
18. How much grain is Ukraine exporting and how is it leaving the country? (bbc.com)
19. Five essential commodities that will be hit by war in Ukraine (theconversation.com)

Pandemic:

1. Transportation during the pandemic - European Commission (europa.eu)
2. RESEARCH FOR TRAN COMMITTEE Relaunching transport and tourism in the EU after COVID-19 - Part V: Freight transport (europa.eu)
3. Effects of Covid-19 on Europe's Road Freight Market — Sixfold
4. Road freight transport: Weakened European sector remains subject to further disruptions due to Covid-19 | Credendo
5. Sources of supply chain disruptions and their impact on euro area manufacturing (europa.eu)
6. The New Normal: Supply Chain Interruptions (globaleurope.eu)
7. Supply Chain Disruptions Could Cost European Economies Up to €920 Billion in GDP by 2023, According to Accenture Report
8. _iru_report.pdf (itf-oecd.org)
9. European road freight recovering well from pandemic (index1520.com)
10. COVID-19 and road transport: Road transport operators warn of a "perfect storm" in supply chain crisis (ilo.org)

11. IRG-Rail publishes report on Impacts of the COVID-19 crisis and national responses on European railway markets in 2020 - Press release - IRG Rail
12. Freight transport in a pandemic: a status report - Rail Cargo Group Blog
13. The European Rail Freight Market - Competitive Analysis and Recommendations-1649762289.pdf (erfarail.eu)
14. PowerPoint Presentation (unece.org)
15. Inland waterway transport hits a decade low in 2022 - Eurostat (europa.eu)
16. THE IMPACT OF COVID 19 ON CARGO TRANSPORT BY INLAND WATER TRANSPORT IN EUROPE DURING THE PANDEMIC YEARS - Svet Dopravy | Svet Dopravy
17. The Impact of COVID-19 Pandemic on Air Freight | Customs Support

Strikes:

1. Finland – Transport worker’s union strike impacting all operations | Maersk
2. https://www.helsinkitimes.fi/finland/finland-news/domestic/24980-finnish-unions-announce-two-week-strike-with-ramifications-for-cargo-transport-fuel-distribution.html
3. Backlash from Finland transport strike brings supply chain chaos - The Loadstar
4. Strikes affect freight transports to and from Finland - Varova
5. Transport workers' strike in Finland extended again - The Loadstar
6. Strike paralyzes Finnish ports: A look at the widespread impact (helsinkitimes.fi)
7. ETF: European Transport Workers' Federation | Political strikes close Finnish ports - ETF: European Transport Workers' Federation (etf-europe.org)
8. Finnish ports unloading essentials, but clothes and bicycles may sit dockside for months | Yle News | Yle
9. Osa juomista on Alkosta jo loppu - Kotimaa | HS.fi
10. Fourteen-day strike announced at Finnish ports (euwid-paper.com)
11. Finnish ports start two-week strike, anticipate delays and disruptions ▸ WorldCargo News
12. The AKT strike will close cargo traffic at Finnish ports for two weeks | Kuehne+Nagel (kuehne-nagel.com)
13. Finnish Unions Plans Two-Week Port Strike Protesting Government Policies (maritime-executive.com)
14. Relief as Finnish port strikes are set to cease in bid to start talks - The Loadstar
15. Strikes in Finland close ports | ITF Seafarers
16. Strike-related diesel shortage threatens to disrupt public transport in Finland (helsinkitimes.fi)
17. FAQ about the impact of Finland's strikes — "If I'm out of petrol, do I still have to go to work?" | Yle News | Yle
18. HS: Strikes force Finnair to add re-fuelling stops to long-haul flights (helsinkitimes.fi)
19. Strike paralyses freight transports, industries (dailyfinland.fi)
20. Printweek - Supplies from Finnish paper mills hit by strike

The project

ReMuNet identifies and signals disruptive events and assesses their impact on multimodal transport corridors. It reacts quickly and seamlessly upon disruptive events in real-time. It supports TMS providers to improve route planning resilience. ReMuNet communicates alternative, pre-defined, multimodal transport routes to logistics operators and subsequently to truck drivers, locomotive drivers and barge captains. Through this, it enables a faster and adaptive multimodal network response. ReMuNet orchestrates route utilization, suggests transshipment points and optimizes capacity allocation, minimizing damage and shortening the recovery time. What is ReMuNet's core objective? As trailblazer for the Physical Internet, ReMuNet pursues the vision to enable and incentivize synchro-modal relay transport on European rail, road, and inland waterways to increase the holistic network resilience. It significantly reduces emissions and boosts freight transport corridor efficiency in case of disruptive events. stakeholders to ensure Europe-wide practicability and acceptance.

Coordinator: FORSCHUNGSINSTITUT FUER RATIONALISIERUNG (FIR)

PARTNER		SHORT NAME
fir RWTH Aachen University	FORSCHUNGSINSTITUT FUER RATIONALISIERUNG	FIR
HANKEN	SVENSKA HANDELSHOGSKOLAN	HANKEN
PTV GROUP	PTV PLANUNG TRANSPORT VERKEHR GmbH	PTV
4PL Intermodal	4PL INTERMODAL GMBH	INT
MANSIO truck meets truck	MANSIO GMBH	MAN
Fraunhofer AUSTRIA	FRAUNHOFER AUSTRIA RESEARCH GMBH	FHA
HAFEN WIEN ein unternehmen der wienholding	HAFEN WIEN GMBH	HWI
WHITE	WHITE RESEARCH SRL	WRE
UIRR UNION INTERNATIONALE POUR LE TRANSPORT COMBINE RAIL-ROUTE	UNION INTERNATIONALE DES SOCIETES DE TRANSPORT COMBINE RAIL-ROUTE SCRL	UIR
CONTARGO® trimodal network	CONTARGO GMBH & CO KG	CON
vediа	VEDIAFI OY	VED

	DANSK RODE KORS (DANISH RED CROSS)	DRC
	ILMATIETEEN LAITOS	FMI
	ALLIANCE FOR LOGISTICS INNOVATION THROUGH COLLABORATION IN EUROPE	ETP-ALICE
	SCHACHINGER IMMOBILIEN UND DIENSTLEISTUNGS GMBH & CO OG	SCH