Engineering the Resilience of the European Land Transport Sector

An Analysis of the Current Challenges, Risks and Recommendations

efca

European Engineering Consultancies

Content

Foreword

The resilience of the European land transport system is a critical factor in ensuring the continent's socio-economic stability and achieving its climate ambitions. This document has been produced by EFCA's Future Trends Committee, in association with the University of Marburg. It provides a comprehensive analysis of the current state of the European land transport sector, identifying key vulnerabilities from internal and external risks alike, and proposing strategic solutions to enhance its resilience, including examples from other countries. Our document also highlights the consulting engineering sector's vital role in addressing structural and operational challenges, mitigating geopolitical and climate-related risks, and ensuring a sustainable transport system and economy for Europe.

With a number of recommendations regarding both policy and operational/management aspects, we hope that this paper, part of our annual *Future Trends Report*, will stimulate further dialogue with EU and national policy makers and we look forward to sharing EFCA's expertise at this pivotal moment. The importance of modernising and expanding our transport infrastructure at this moment in time cannot be overstated.

I would like to extend my gratitude to all the contributors who have dedicated their time and expertise to this important work, which are listed below. Their invaluable insights and collaborative efforts have been instrumental in shaping this comprehensive study.

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Executive Summary

OVERVIEW OF THE SECTOR'S CURRENT STATE

The European transport sector remains vital to economic strength, mobility, and crisis response. However, its foundational infrastructure is under increasing strain.

Key points:

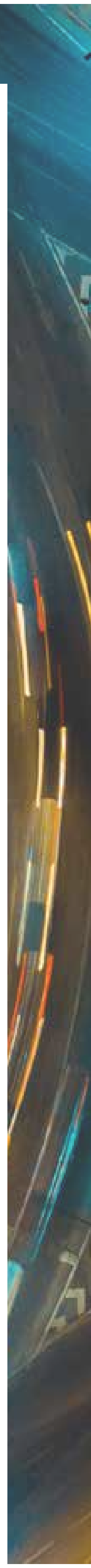
1. Europe's transport system spans roads, rail, air, maritime and inland waterways, with uneven development across regions;
2. while Northern and Western Europe benefit from modern networks, Eastern and Southern regions suffer from outdated or incomplete infrastructure;
3. investment efforts have been significant, but the vision of a cohesive, interconnected European transport network is still far from reality;
4. capacity growth, especially in rail, has stagnated, while road transport continues to dominate, contributing heavily to emissions.

IDENTIFICATION OF KEY VULNERABILITIES

The sector's resilience is hindered by systemic weaknesses in structure, funding, and governance.

Core vulnerabilities include:

1. ageing infrastructure: many roads and bridges are nearing or exceeding their intended lifespan and frequent maintenance is no longer sufficient;
2. underinvestment: chronic funding shortfalls, especially for maintenance, leave critical assets deteriorating;
3. bureaucratic delays: infrastructure projects often face years of legal and administrative hurdles before implementation;
4. fragmentation: cross-border transport remains inefficient due to technical incompatibilities and national-level silos;
5. digital dependence: increasing reliance on ICT and electrification creates cascading risks in the event of failure or attack.



SUMMARY OF EXTERNAL THREATS TO THE TRANSPORT SECTOR

Transport infrastructure is increasingly exposed to external shocks, both man-made and environmental.

Primary external risks:

1. geopolitical instability: the war in Ukraine, tensions in the Red Sea and disruption in global trade routes highlight Europe's exposure;
2. cybersecurity threats: cyberattacks in the transport sector have surged dramatically, targeting rail, aviation and maritime systems;
3. climate change impact:
   - sea-level rise, extreme heat, flooding and storms pose growing threats to roads, railways and ports;
   - inland waterways face drought-related disruption, while alpine and coastal zones are increasingly at risk of landslides and erosion.

PROPOSED RECOMMENDATIONS

Building resilience requires proactive, integrated strategies across technical, political and operational domains. The main recommendations in this respect are:

1. set up transport infrastructure stress tests for geopolitical threats;
2. prioritise projects' actions and enhance cybersecurity systems;
3. modernise infrastructure using climate-resilient materials, smart technologies (e.g. digital twins, sensor-integrated systems), dual-use constructions (heavy load options) and expand e-charging system;
4. streamline planning and permitting processes to reduce administrative delays and accelerate project delivery;
5. prioritise cross-border integration, particularly in rail and logistics corridors, to improve both civilian and military mobility;
6. invest in preventive maintenance and adapt current infrastructure for extreme weather and cyber-resilience;
7. promote cross-sector cooperation and knowledge exchange between engineers, policymakers, and digital experts to foster innovation.

Introduction

HOW IS TRANSPORT CRITICAL INFRASTRUCTURE?

Critical infrastructure (CI) ensures the delivery of essential services such as electricity, water, healthcare and logistics. The European Council defines CI as systems vital to societal function, safety, the economy and environmental protection (Council of the European Union, 2008). The European Commission identifies eleven CI sectors, including energy, finance, healthcare and transport (European Commission, 2024). Among these, transport stands out due to its high interconnectivity with other infrastructures.

Transport supports everyday mobility and plays a pivotal role in emergencies, ensuring supply chains, fuel distribution and healthcare logistics remain functional (BBK, 2024). It encompasses road, rail, air, maritime and public transport systems, as well as transit hubs inter-connecting different transport modes and ensuring energy-efficient multimodal transport systems, all crucial to Europe's economic and social stability.

RELEVANCE OF THE REPORT

Transport influences nearly every aspect of modern life. On average, households spend 13.2% of their income on transport-related services (the Joint Research Centre (JRC) of the European Commission, 2024), underscoring its societal and economic relevance. The importance of the transport sector spans three critical domains: security, economy and sustainability.

Economically, transport is the backbone of trade and development. It connects production to consumers, sustains competitive supply chains and ensures labour mobility. Disruption, such as those during the COVID-19 pandemic, resulted in (at least) €112.7 billion in losses across the Eurozone in 2021 alone (Ollagnier et al., 2022). A modern, integrated system increases resilience and productivity, and supports approximately 10 million direct jobs across the EU transport sector, contributing around 5% to GDP (JRC, 2024).

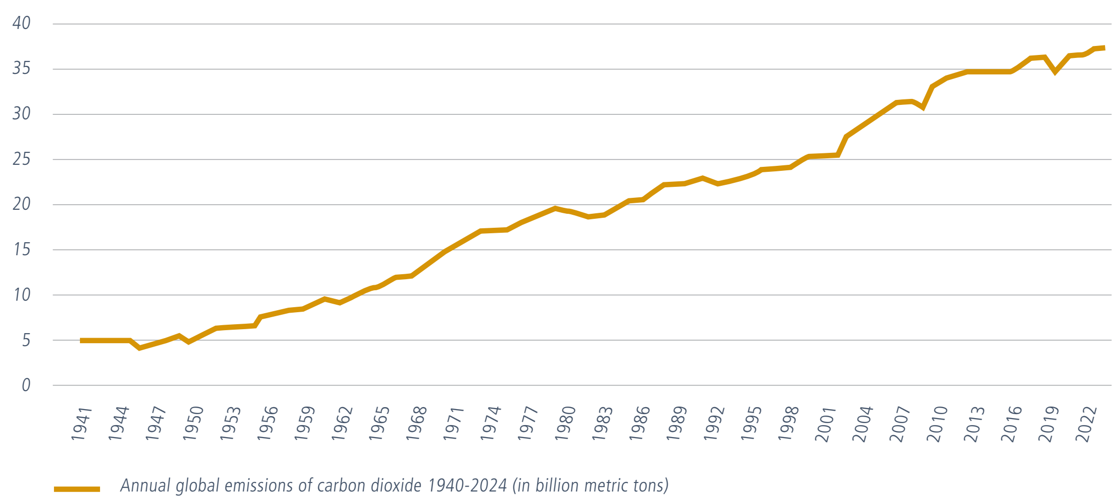
From a security perspective, transport is integral to military mobility. The EU's Action Plan on Military Mobility 2.0 emphasises the need for resilient, cross-border transport infrastructure tailored to military logistics (European Commission, 2022). Enhanced infrastructure strengthens defence readiness and civilian-military coordination.

This report thus identifies transport as a strategic priority. Its dual role as a societal enabler and a pillar of autonomy makes it central to Europe's resilience strategy. Consulting engineers must therefore lead the efforts to modernise and decarbonise the sector, to ensure its readiness for future crises.

In 2023, the transport sector generated 21.11% of global CO_2 emissions, mostly from road traffic. Shipping and aviation followed, while rail accounted for less than 0.5%, making it the greenest mode of transport (IEA & Statista, 2023). Given the rising vehicle numbers in the EU, reducing emissions from road freight and private transport is vital to achieving the climate targets (Eurostat, 2024f). The transport sector must still undergo substantial changes in order to reduce its emissions, and these must be done while at the same time implementing other changes, in particular those related to resilience and competitiveness.

As road and rail are the biggest segments in Europe of the entire transport sector, the focus of the report will be on how to address resilience in these segments, plus the inter-/multi-modal aspects.

Figure 1. Annual carbon dioxide (CO_2) emissions worldwide from 1940 to 2024 (in billion metric tons) (Statista, 2024)



Current State of the Sector

OVERVIEW OF THE SECTOR

Rail plays an important role in sustainable mobility due to its potential for high-capacity, low-emission freight and long-distance passenger transport. As of 2022, the EU's rail network spanned nearly 200,000 km, with Germany, France and Poland together accounting for close to half the total (Eurostat, 2024d). However, this potential is not being fully realised. Network growth has stagnated – up only 0.1% since 2014 – and usage levels remain modest. In 2022, rail accounted for just 17% of freight transport and only 7% of passenger journeys in the EU (Eurostat, 2024d). These figures show that, despite its environmental advantages, rail is currently unlikely to make a decisive contribution to reducing the overall emissions of the transport sector.

Figure 2. Length of European motorways in km (Eurostat, 2024e)

State	2014	2022	+/- %	+/-
Spain	15.049	15.856	5,36%	807
Germany	12.949	13.172	1,72%	223
France	11.560	11.751	1,65%	191
Italy	6.844	7.558	10,43%	714
United Kingdom	3.760	3.859	2,64%	99
Türkiye	2.278	3.633	59,48%	1.355
Portugal	3.065	3.115	1,63%	50
Netherlands	2.678	2.793	4,29%	115
Sweden	2.088	2.193	5,03%	105
Hungary	1.577	1.868	18,41%	290
Poland	1.556	1.802	15.81%	246

Furthermore, the structural and economic limitations of rail must be acknowledged. In rural regions, where rail networks are often sparse or non-existent, it is difficult to meet everyday mobility needs without relying on road-based transport. Expanding and operating a comprehensive rail network in these areas would be prohibitively expensive and logistically complex. As a result, climate protection strategies in the transport sector must look beyond rail and include a broader mix of solutions.

Road freight, in contrast, has seen strong growth – rising from 1.6 to 1.9 million tonne-kilometres between 2014 and 2023 – highlighting its dominant role in goods movement. Passenger rail also experienced a strong rebound following the COVID-19 drop in 2020, more than doubling by 2023, though this was primarily a recovery effect rather than sustained organic growth (Statistisches Bundesamt, 2025).

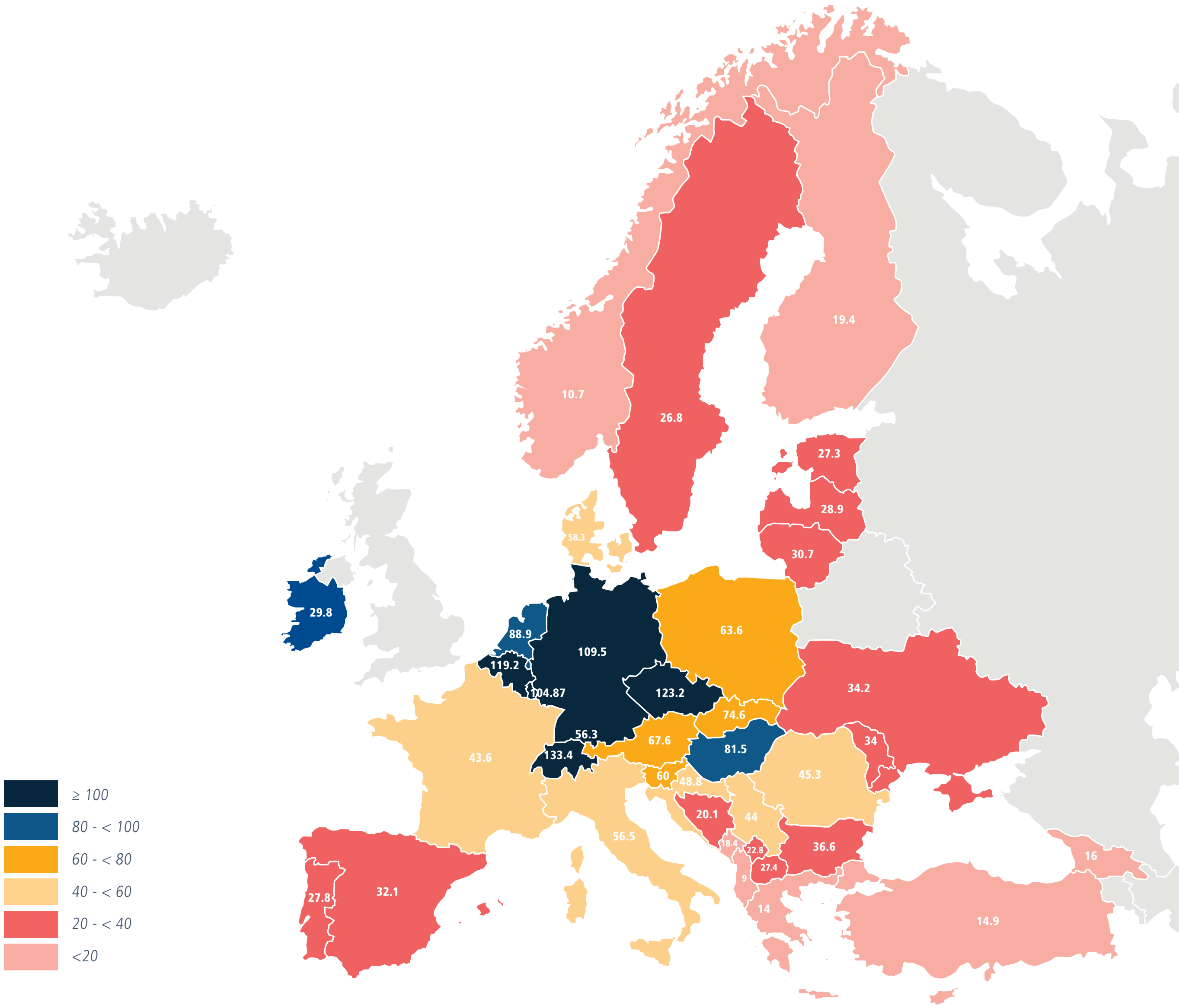
While some countries like Spain continue to expand their rail networks, others like France have reduced them, contributing to the EU-wide stagnation. Germany, France, Spain, Italy, and Poland consistently account for the bulk of transport volume, while smaller countries such as the Netherlands and Czech Republic demonstrate high density relative to size (Eurostat, 2024h; 2025a).

Meanwhile, Europe's ageing infrastructure is showing signs of strain. Insufficient maintenance, growing usage and extreme weather events have led to structural failures, as seen in the 2024 Carola Bridge collapse in Dresden and the 2018 Morandi Bridge collapse in Genoa (Kelch, 2024; ZDFheute, 2023).

Figure 3. Length of European railway lines in km (Eurostat, 2024d)

State	2014	2022	+/- %	+/-
European Union - 27 coutries (from 2020)	201.701	201.923	0,11%	221
Germany	38.659	38.836	0,46%	177
France	29.568	27.604	-6,64%	-1.964
Poland	19.240	19.355	0,60%	115
Italy	16.722	16.829	0,64%	107
Spain	15.182	16.468	8,47%	1.286
United Kingdom	16.202	16.430	1.41%	288
Sweden	10.881	10.914	0,30%	33
Türkiye	10.087	10.615	5,59%	564
Romania	10.777	10.615	-1,50%	-162
Czechia	9.559	9.521	-0,40%	-38
Hungary	7.209	7.907	9,68%	698

Figure 4. Density of the national railway networks, 2023 (metres of railway line per km2) (Eurostat, 2024a)



REGIONAL VARIATIONS

Significant disparities in transport infrastructure exist across Europe. Rail infrastructure density is high in Central Europe but sparse in the North and Southwest, and Eastern Europe lags behind in electrification (Eurostat, 2024a). Motorway density varies more broadly: the Netherlands, Belgium and Western Germany have the highest, while Eastern and Northern states have considerably less (Eurostat, 2024c). Southern regions have historically faced infrastructure deficits, explaining recurring congestion in major cities, although recent investments have led to improvements (Directorate-General for Mobility and Transport, 2024b).

In maritime transport, Northwestern states - Belgium, the Netherlands, and Germany - lead in container shipping, while Southern Europe handles more bulk and passenger traffic. Maritime activity is less prominent in Central and

Northeastern regions. Airport traffic shows a similar divide: Western and Southern airports are hubs for long-haul and seasonal tourism traffic, whereas Eastern airports lag behind in capacity and volume (Directorate-General for Mobility and Transport, 2024b).

EXISTING RESILIENCE MEASURES

Recognising the increasing vulnerabilities of critical infrastructure, the European Union has launched a series of policies and investments to improve resilience across sectors, particularly in transport.

A cornerstone initiative is the Directive on the Resilience of Critical Entities, which took effect in January 2023 and had to be transposed into national law by October 2024. It requires Member States to identify critical facilities and conduct risk assessments. These facilities must then implement technical, organisational and security measures to bolster resilience against threats like natural hazards, terrorism and public health emergencies. Special support is provided to institutions serving six or more EU countries (European Parliament and the Council of the European Union, 2022).

Significant funding can be used to support resilience measures in the transport sector. For instance, in July 2024, €7 billion from the Connecting Europe Facility (CEF) were awarded to 134 transport projects (Directorate-General for Mobility and Transport, 2024a). Between 2021 and 2027, the European Climate, Infrastructure and Environment Executive Agency (CINEA) will manage nearly €26 billion in transport funding, with €2 billion allocated to military mobility. Notably, 83% of the 2024 investment targets the Trans-European Transport Network (TEN-T), particularly rail infrastructure, which receives 80% of that allocation.

TEN-T aims to develop a high-quality, multimodal transport network across the EU. Its three-phase implementation includes:

- Core Network (by 2030) – linking major cities and hubs;
- Extended Core Network (by 2040) – expanding coverage;
- Comprehensive Network (by 2050) – connecting all regions (European Commission, 2025b).

While the TEN-T's main scope is the roll-out of high-quality transport infrastructure, resilience measures are part of any good design phase when it comes to such investments.

To address emerging threats, the EU established a joint task force with NATO focused on critical infrastructure resilience. Prompted by incidents like the Nord Stream sabotage and the war in Ukraine, this task force coordinates risk assessments, sets higher security standards and fosters cross-border cooperation (EU-NATO Task Force on Resilience, 2023). The EU also adopted the Action Plan 2.0 on Military Mobility in November 2022. It aims to align transport infrastructure with military needs by upgrading routes to handle military vehicle size, weight, and volume, and by streamlining cross-border procedures, including those from the TEN-T (European Commission, 2022).

Finally, a 2024 Council Recommendation introduced a blueprint for EU-level coordination in response to disruption affecting critical cross-border infrastructure. It emphasises improved situational awareness and communication among Member States to ensure swift, unified responses (Council of the European Union, 2024).

Vulnerabilities Assessment

STRUCTURAL WEAKNESSES

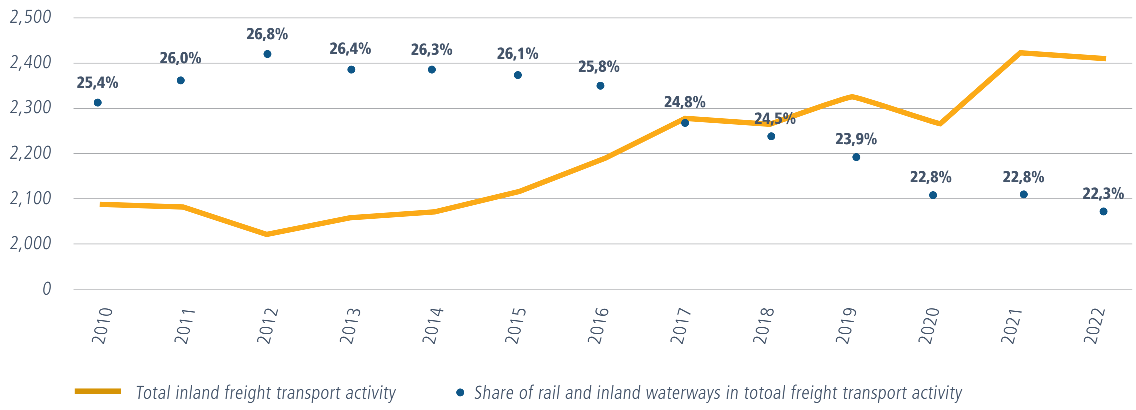
Europe's transport infrastructure is fundamental to societal and economic functioning, yet much of it is ageing and under significant strain. Many bridges in Europe are over 100 years old, and much of the network was not designed to handle today's traffic volumes. According to Andreas Schweinar and Christian Tridon (FIEC), the deterioration is largely due to environmental exposure and material fatigue from overuse.

Most transport structures built over the last century rely on steel and concrete - materials that, while durable, degrade over time. Steel corrodes when exposed to air and especially to sodium chloride (used in road salt), while concrete is vulnerable to cracking from freeze-thaw cycles and thermal stress. Asphalt surfaces also harden and crack over time due to oxidation and temperature fluctuations (Das, 2014; Luger, 2009).

Ageing is compounded by increased traffic loads. Freight volumes have risen dramatically: by 74% in Germany between 1991 and 2021, and by 45% across the EU since 1995 (EEA, 2025b; Starck, 2024).

Vehicle sizes and weights have also grown. According to Autobahn GmbH, one truck causes as much wear as thousands of cars (Tagesschau, 2024b). Infrastructure built decades ago is now

Figure 5. Share of inland waterways and trains in total inland freight transport in the EU-27 (European Environment Agency, 2024)



reaching or exceeding its intended lifespan, with many bridges rated as "insufficient" or only "still sufficient" (Tagesschau, 2024a).

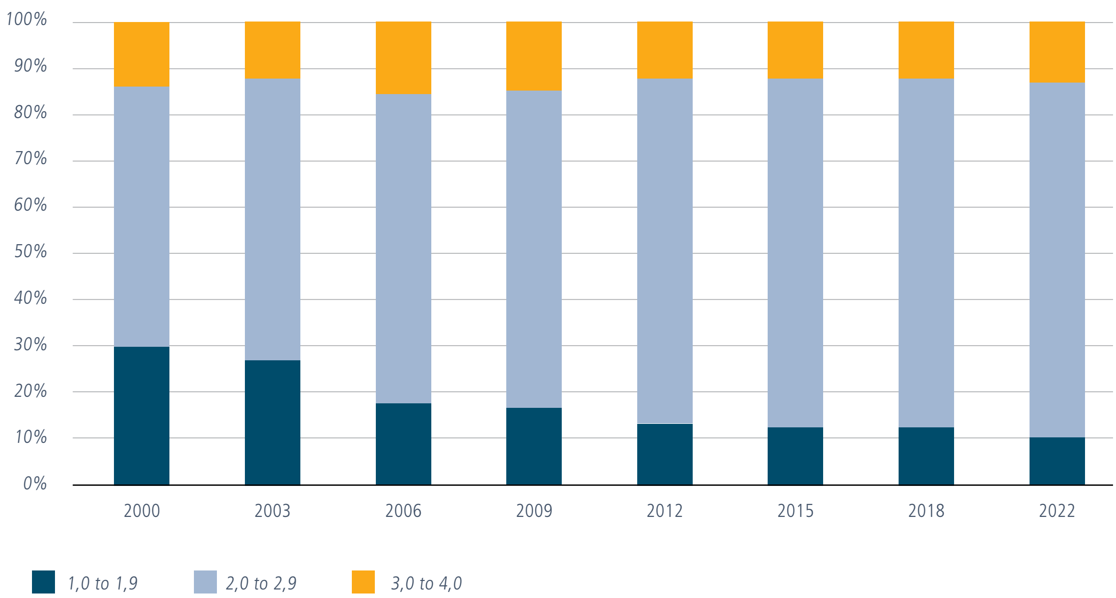
Surveys reflect this reality. A 2018 World Bank poll found that most EU transport sectors (except airports) were rated as poor in quality. Business surveys by the German Economic Institute further confirmed worsening conditions in all transport modes. For rail, over 37% of long-distance trains in Germany were delayed in 2024, with 80% of disruption linked to outdated infrastructure (Tagesschau, 2025).

Congestion and capacity shortages are also worsening, particularly in urban areas (DG MOVE, 2019; 2024b). Autonomous driving could further increase traffic volumes, according to Schweinar. Delays affect not only road and rail, but also airports and ports, which suffer from insufficient expansion to match growing demand (Directorate-General for Mobility and Transport, 2024b).

Cross-border rail infrastructure remains fragmented, unlike in the road sector. Incompatibilities in track gauge, power supply and signalling systems hinder seamless rail travel between EU countries (Directorate-General for Mobility and Transport, 2024b). Many cross-border routes are underdeveloped or non-existent.

Finally, historical cost-cutting in infrastructure design has led to long-term inefficiencies. Safety-enhancing technologies – such as built-in load sensors – were often excluded to lower upfront costs. Moreover, separating construction from maintenance responsibilities has resulted in designs that are costly to maintain, due to a lack of consideration for long-term practicality.

Figure 6. Condition grades for bridges on federal transfer roads (percentage of bridge areas) (Hauptverband der deutschen Bauindustrie e.V., 2024)



OPERATIONAL CHALLENGES

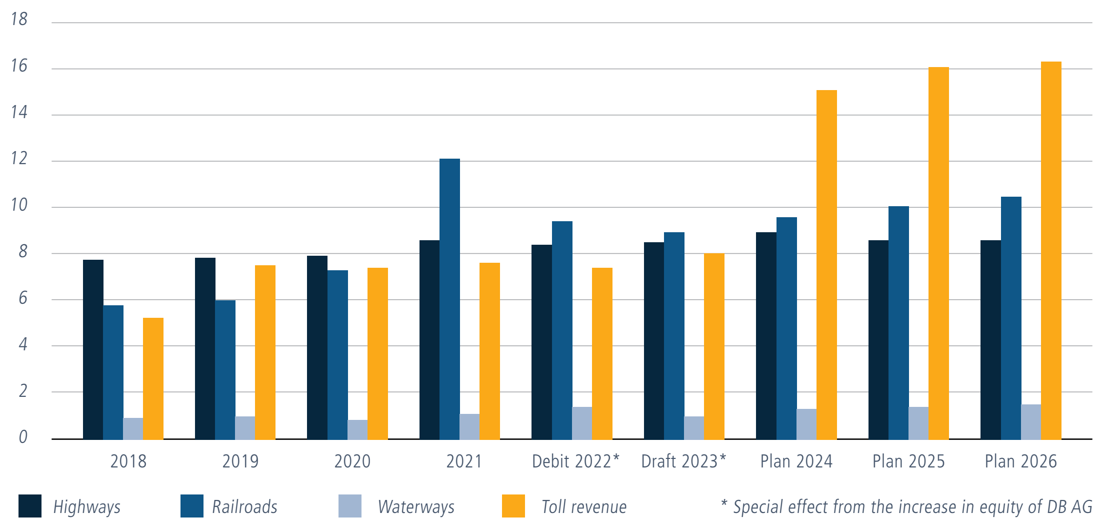
Beyond ageing infrastructure, chronic underfunding has significantly contributed to the deteriorating condition of Europe's transport systems. Since the 2008 financial crisis, investment levels have consistently fallen short of actual needs. Current minimum capital investment requirements in Europe in the transport sector are estimated at around €130 billion/year, while the actual level has been, since the beginning of the crisis, on average €100 billion/year (European Union, 2015; European Court of Auditors, 2018).

Bridge maintenance alone requires roughly €30 billion/year, based on an estimated 1.5% of the total value of Europe's one million bridges. According to Christian Tridon, current investment levels are far below this benchmark. Price inflation exacerbates the gap: in Germany, real construction output remains at 2005 levels despite higher nominal investment (Puls, 2020). Furthermore, EU funding prioritises new infrastructure over maintenance, creating a backlog of outstanding repairs.

Sascha Steuer (VBI) emphasises that financing remains a key bottleneck. Even fully planned infrastructure projects often face long delays due to insufficient funding. As a result, road and rail conditions continue to worsen despite a clear need for maintenance (Directorate-General for Mobility and Transport, 2019; Tagesschau, 2024b).

Maintenance inefficiencies compound the problem. Andreas Schweinar notes that small-scale, disjointed maintenance such as repairing

Figure 7. German federal investments in federal transportation routes and toll revenues (In billions of €) (Puls, 2023)



overhead lines and rails separately forces repeated closures of the same rail sections. Similarly, road maintenance is often fragmented to maintain partial traffic flow, leading to inefficiencies. Full-section maintenance closures would be more effective but are rarely used due to logistical constraints. The collapse of the Morandi Bridge in Genoa illustrates the risks of ageing infrastructure combined with poor maintenance.

Additionally, rail infrastructure presents unique technical and operational challenges. Operating a rail network requires a high degree of technical expertise and system-wide coordination, from signal boxes to network control and maintenance. The growing skills gap across Europe poses a serious threat to this capability. According to a report by Süddeutsche Zeitung (August 29, 2024), Deutsche Bahn had to temporarily cancel entire train connections because it was unable to staff its signal boxes. Similar staffing shortages are anticipated in rail maintenance, where experienced personnel are already in short supply. These labour issues directly impact network reliability and resilience.

Infrastructure maintenance 'under traffic' presents another major obstacle. Performing upgrades while keeping essential routes open is both technically complex and economically disruptive. A high-profile example is the renewal of the Lueg Bridge on the Brenner Pass route, one of the EU's most important north-south corridors. Due to the design of the bridge deck, traffic had to be drastically reduced in both directions during the works, resulting in significant economic impact. The reconstruction is expected to take five years, during which freight and passenger flows through this crucial corridor will be severely constrained.

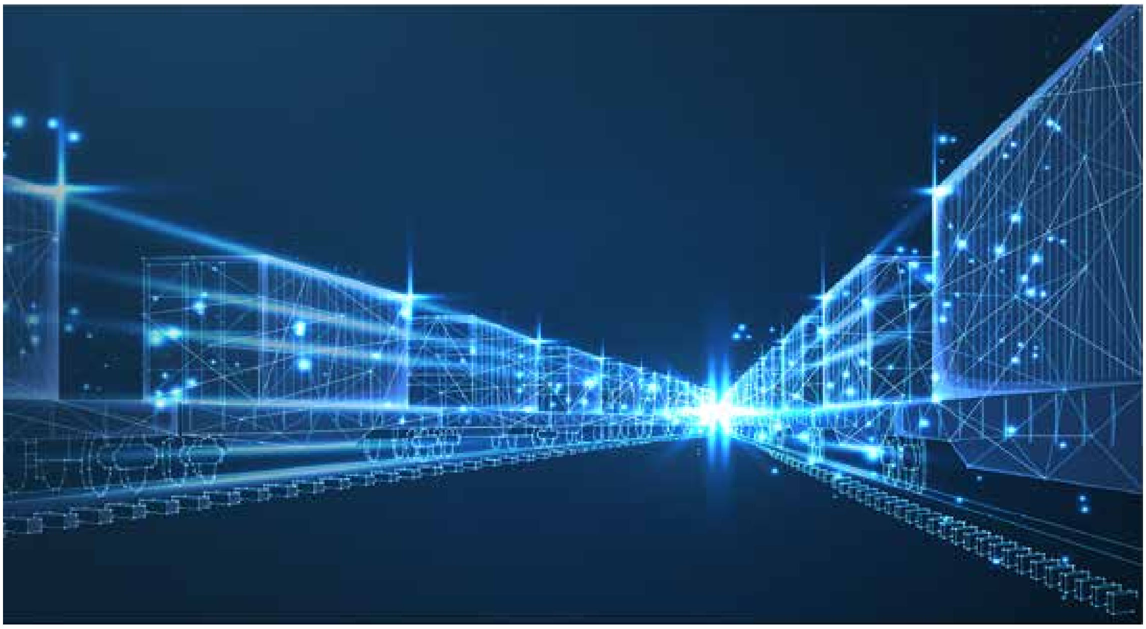
Improved coordination could significantly boost efficiency. Involving all stakeholders early in the planning phase would allow for more cost-effective and easily maintainable infrastructure designs.

Bureaucratic and legal hurdles remain a critical issue. A European Court of Auditors review found that building a marina required 33 permits; a port project took 22 years to begin (European Court of Auditors, 2018). Andreas Schweinar reports that German rail projects can take up to 20 years from planning to construction. Legal action frequently delays projects, as seen with the project to deepen Hamburg's Elbe, postponed by 17 years due to lawsuits (Puls, 2020). Administrative burdens are increasing, not decreasing, despite EU-level acceleration efforts.

Sascha Steuer contrasts these delays with the rapid construction of liquefied natural gas (LNG) terminals following the Russian invasion of Ukraine, where most approval procedures were suspended. No similar streamlining has occurred in the transport sector. The reconstruction of Dresden's Carola Bridge, expected to take eight years, underscores these delays, largely due to revised design, environmental assessment and approval procedures.

Labour shortages add to the strain. Between 2020 and 2021, the EU faced a 40% increase in driver shortages, hindering efforts to shift to public transport in urban areas (Expert Group for Urban Mobility, 2022). The construction sector also faces workforce bottlenecks, affecting both new projects and maintenance (Puls, 2020).

Finally, there is a disconnect between EU-level resilience strategies and their implementation at the national level. Sascha Steuer notes that despite strong EU guidance, many member states including Germany are slow to adapt long-term strategies for resilient infrastructure.



CROSS-SECTOR INTERDEPENDENCE

The transport sector is deeply interlinked with other critical infrastructure systems, particularly energy and ICT. In 2022, transport accounted for 31% of the total energy consumption in the EU, with road transport making up nearly 74% of that share (Eurostat, 2024b). As energy prices in the EU nearly doubled as compared to those in the US and China in 2023, the cost burden on transport and logistics sectors has significantly increased, impacting their global competitiveness (IEA, 2024).

The shift toward electrification amplifies transport's reliance on the energy sector. As highlighted by Matthias Van Steendam, the success of electric vehicles hinges on the availability of charging infrastructure and sufficient grid capacity. Without this, large-scale EV adoption remains constrained. A power outage could paralyse electric transport systems – from rail and e-buses to EVs – particularly in regional areas (FOCUS online, 2013).

Even conventional transport systems are energy-dependent. Fuel-based vehicles and their supply chains are vulnerable to fuel price volatility and availability (Haucap et al., 2012). Grid disruption impact traffic management systems, such as lights, streetlamps, movable bridges and rail signalling, reducing safety and operational efficiency (Bundesregierung, 2025; FOCUS online, 2013).

Additionally, the growing digitalisation of transport systems increases their dependence on ICT. Failures in ICT infrastructure can disable traffic control centres, disrupt real-time public transport updates, compromise traffic control and impair autonomous vehicle systems (Atack, 2024). This raises concerns about operational continuity and cybersecurity.

Importantly, the interdependence is mutual. Sectors like healthcare and food distribution rely heavily on transport for timely delivery. A breakdown in the transport system can therefore trigger cascading effects across multiple critical services (EEA, 2025a).

Analysis of Geopolitical, Climate-Related and Other Risks

GEOPOLITICAL RISKS

Europe's transport infrastructure is increasingly exposed to geopolitical risks that threaten economic activity, civilian mobility and defence readiness. The war in Ukraine has highlighted the urgent need for dual-use infrastructure that can support both civilian and military operations. However, much of Europe's existing infrastructure is not designed for military use, lacking the capacity to handle heavy and oversized equipment (EESC, 2025).

Despite strategic recognition, the expansion of dual-use infrastructure faces funding constraints. Of the €6.5 billion initially proposed by the European Commission for military mobility in the current EU budget (2021-2027), only €1.7 billion was approved (Chihaia, 2023). Nevertheless, aligning military logistics with the TEN-T – with 93% of military corridors overlapping – presents a cost-effective opportunity to improve resilience for both civilian and defence purposes.

The war has also disrupted international supply chains. Airspace bans, sanctions on Russian freight and suspended overland and maritime trade routes have cut critical links between the EU, Russia and China (IHK München, 2025). Similarly, the Israel-Gaza conflict and related Houthi attacks in the Red Sea have severely disrupted traffic through the Suez Canal, which is vital for Europe's energy imports from the Gulf. Many vessels now reroute around the Cape of Good Hope, adding 12 days of transit and significantly raising emissions and costs. These delays have driven up energy prices, with losses from disrupted trade routes estimated at €360 million per hour (ZEIT Online et al., 2024).

Cyberattacks present another growing threat. Between July 2022 and June 2023, reported incidents in the EU transport sector surged by nearly 700%, with aviation, maritime and rail systems being the most affected (Theocharidou, 2023). Targets included airlines, ports, vessel systems and railway operators. Over half of attacks were financially motivated, but nearly a quarter were geopolitically driven, often linked to state actors aiming to disrupt services or undermine public trust (the European Union Agency for Cybersecurity (ENISA), 2023). In response, ENISA has intensified collaboration with sector-specific agencies to bolster cybersecurity defences across the transport system (ENISA, 2024).

INFRASTRUCTURE HAZARDS

The increasing frequency of extreme weather events has exposed the vulnerability of European land transport infrastructure. For instance, in 2023, severe flooding in the United Kingdom led to the temporary closure of major railway lines, including parts of the West Coast Main Line, disrupting commuter traffic and freight logistics across the country (Network Rail, 2023). Similarly, the unexpected closure of the Gotthard Base Tunnel in Switzerland after a freight derailment in 2023 forced freight traffic onto longer, less efficient routes through the Alps, delaying cross-border supply chains between Northern and Southern Europe (SBB, 2023). These incidents highlight the susceptibility of critical land corridors to both natural and operational hazards, posing risks to economic continuity, regional connectivity and the resilience of European logistics networks.

BIOLOGICAL HAZARDS

The COVID-19 pandemic disrupted all transport modes across Europe and exposed weaknesses in logistics and infrastructure. Rail freight showed resilience by maintaining essential goods flows, while passenger rail traffic collapsed under travel restrictions (DB Cargo, 2021). Road transport faced delays, driver shortages and stricter hygiene protocols, squeezing logistics providers (PwC, 2020). Air transport was hit especially hard, with grounded passenger flights reducing cargo capacity and raising freight costs. Maritime shipping saw rising freight rates due to port congestion and container imbalances, especially as Asian factories reopened (DB Cargo, 2021).

Public transport usage dropped by up to 80% during lockdowns, prompting contactless ticketing and hygiene upgrades to restore confidence. The pandemic also accelerated digitalisation and regionalisation in supply chains, as businesses sought to reduce global dependence and enhance resilience (PwC, 2020; DB Cargo, 2021).

CLIMATE CHANGE-RELATED EFFECTS

General Effects of Climate Change

Climate change is reshaping global conditions, with higher temperatures and more frequent heatwaves threatening infrastructure stability. Roads, railways and airports are vulnerable to extreme heat, which increases maintenance needs and disruption (European Commission, 2025a). As weather becomes more volatile, traditional infrastructure planning based on historical norms faces growing limitations.

Southern Europe is increasingly affected by drought, lowering river levels and disrupting inland shipping and hydropower. Northern regions, meanwhile, face heavier rainfall and rising flood risks. Sea-level rise (60–80 cm projected by century's end) endangers ports, coastal roads and railways, while saltwater intrusion corrodes infrastructure materials. Water scarcity, worsened by evaporation and erratic precipitation, challenges cooling systems in transport hubs like airports and train stations (European Commission, 2025a).

The growing intensity and frequency of extreme weather events such as storms, floods and heatwaves expose the vulnerabilities of Europe's transport networks and underline the urgency of adaptive infrastructure measures.

Impact of Climate Change on the Individual Transportation Infrastructure Segments

Road Transport
Higher temperatures soften asphalt, leading to rutting, potholes and damage to bridge joints, particularly during heatwaves. According to

the JRC PESETA II assessment, weather-related stresses account for 30–50% of current road maintenance costs in Europe – approximately €8–13 billion per year – with extreme events alone responsible for around €0.9 billion annually (JRC, 2014). Additionally, a 2024 UNEP-FI report estimates the direct annual cost of extreme weather damage to road and railway assets at €2.8–3.2 billion, primarily due to events like heatwaves and heavy rainfall.

Construction delays are another concern, as extreme heat limits activity in humid regions. Meanwhile, more intense storms cause soil erosion and flood damage to tunnels, bridges and roads, particularly in topographically complex regions like the Alps and Eastern Europe. These impact increase maintenance demands and construction costs.

Sea-level rise also poses long-term threats. In the UK, up to 1,600 km of roads and 650 km of rail lines may be submerged by 2080 (Committee on Climate Change, 2018).

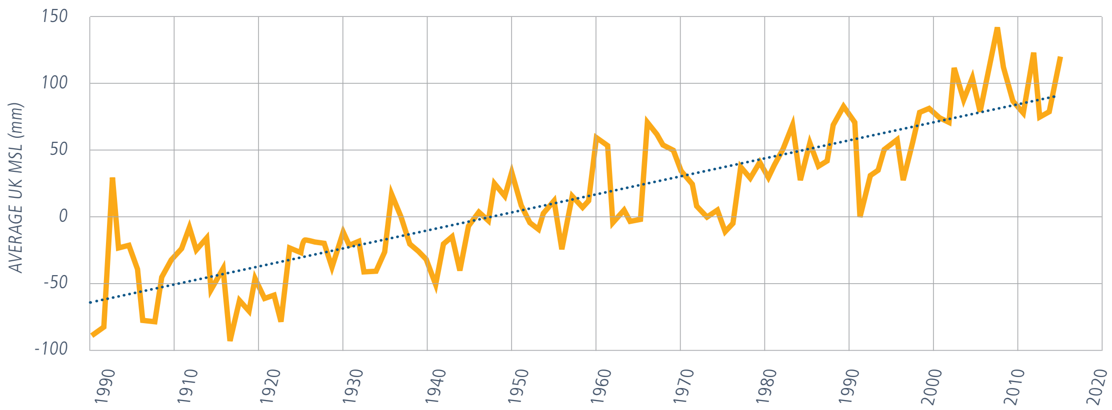
However, milder winters could reduce frost-related damage in Northern and Central Europe, yielding annual savings between €170 and €508 million. Still, regional differences remain stark: Southern Europe faces heat-related deterioration while Alpine regions risk landslides due to heavier rainfall (Nemry & Demirel, 2012).

Rail Transport

Railways are increasingly vulnerable to high temperatures, which can cause tracks to expand and buckle, raising derailment risks. Southern Europe could face up to 70 additional days annually above critical temperature thresholds (Nemry & Demirel, 2012). Measures such as imposing speed restrictions to prevent rail track buckling during heatwaves can incur annual economic losses of around €35 million across the EU.

Climate change also intensifies rainfall and storms, which can flood tracks and disrupt service. Events like Hurricane Sandy in 2012 demonstrated how storm surges can shut

Figure 8. Observations of relative (i.e. corrected for land movement) UK mean sea level rise (Committee on Climate Change, 2018)

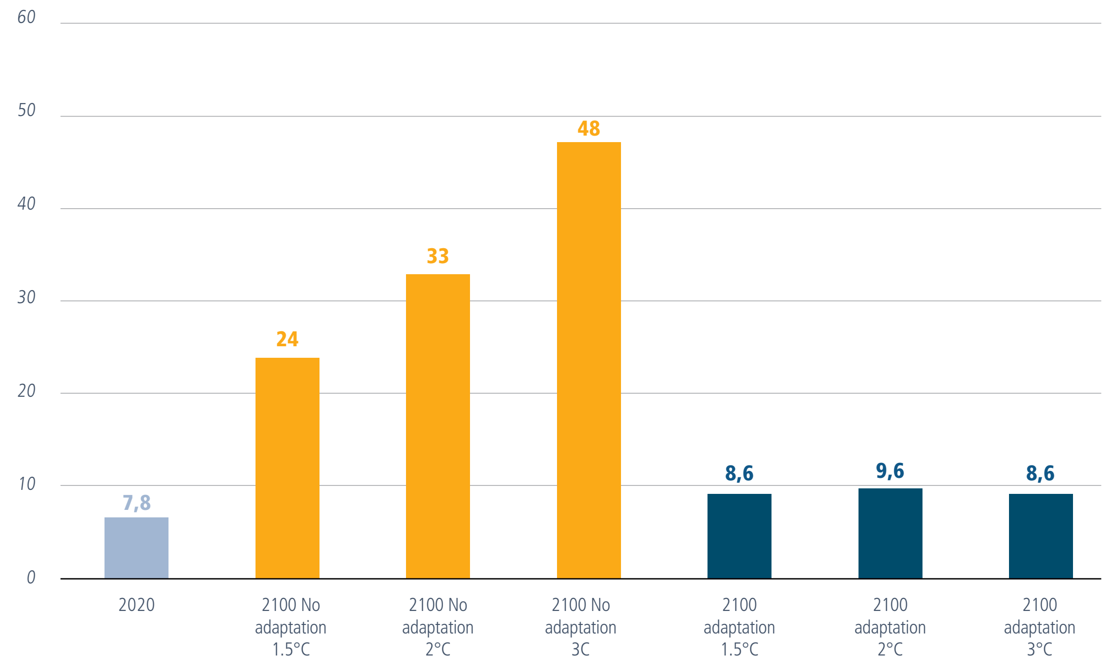


down entire subway systems. Coastal and underground railways are especially at risk from sea level rise, requiring drainage upgrades and flood protection (EPA, 2025).

Bridges
Bridge stability is increasingly threatened by scouring – soil erosion around foundations caused by flooding. By 2100, 20% of river crossings may need protection like riprap or reinforced foundations. Eastern Europe, Scandinavia and the Alpine region face the greatest risks, with flood peaks expected to rise by 20–40% (Nemry & Demirel, 2012).

While preventive measures cost €262–381 million annually, failures would cost far more. Investing in protection is both a safety necessity and an economic priority.

Figure 9. Economic damage due to river flooding in the European Union in 2020 and 2100, by adaptation and warming scenario (in billion euros per year) (Statista, 2023)



Recent Initiatives and Projects for Greater Resilience

CASE STUDIES

"Klimaphalt" Project

German road construction entrepreneur Lutz Weiler developed "Klimaphalt," a climate-resilient road surface that mimics natural processes. It features a three-layer structure: a light-coloured, water-permeable top layer that reflects more sunlight, a permeable bituminous base and an unbound base layer made partly from crushed bricks. A microplastic filter lies beneath to prevent pollution (Scheuermann, 2020).

This innovative design offers multiple benefits: it reflects 20% more solar radiation, reducing surface temperatures by 6–8°C, and absorbs road noise through its open-pored surface. It also retains up to 100 litres of rainwater per square meter, helping manage heavy rainfall. During heatwaves, stored water evaporates, cooling the surface (Weiler, 2025).

A 150 m² test field was installed in Offenbach am Main to study its durability under real traffic conditions, though long-term results are still pending (Scheuermann, 2020).

Geothermal Road Systems

At the University of Kassel, researchers are testing geothermal road systems to regulate asphalt temperatures. The concept uses embedded water pipes in the road surface to absorb heat in summer, which is stored via a heat exchanger and reused in winter to prevent ice formation.

While the idea isn't entirely new, current research focuses on optimising aspects such as pipe spacing and aggregate selection. Professor Konrad Mollenhauer notes this could reduce surface temperatures by up to 20°C in summer. A pilot system is currently being tested in Cologne (mb/dpa, 2022).

MetroCHARGE Project

Barcelona's MetroCHARGE project integrates green energy in public transport by combining regenerative braking systems and rooftop solar panels across 16 metro stations. Braking energy and solar power supply the metro network and 33 EV charging stations citywide (TMB, 2025).

A key innovation is the direct cable-based energy transfer from the trains and solar panels to charging stations, bypassing the power grid. This setup enhances energy efficiency and decentralisation. Professor Alvaro Luna from the Polytechnic University of Catalonia highlights this as a distinguishing feature from standard energy distribution models (Wilson, 2024).

GLOBAL INSPIRATION

There are a number of international projects or initiatives to increase the resilience of the transport sector that the EU could use as a guide. This section outlines a few exemplary projects.

City Mobility Simulator (CityMoS)

CityMoS, developed by TUMCREATE (a TU Munich initiative in Singapore), is a powerful urban mobility simulator designed to support transport electrification. Its primary goal is to help Singapore reach 50% EVs by 2030 and full transport electrification by 2040. It also models public transit efficiency, commuter patterns and traffic-related heat emissions. Professor Alois Knoll notes CityMoS is optimised for multi-core processors, enabling fast, city-scale simulations. It also allows co-simulations with energy grids, aiding integrated urban planning. CityMoS evaluates real-time traffic, charge levels and signal systems to determine ideal charging infrastructure placement. DHL is already using it to plan fleet electrification and optimise routing, showcasing its role in global sustainable logistics (TUM, 2022).

Earthquake-Resilient Infrastructure in Japan

Japan is a global leader in transport infrastructure resilience, especially against earthquakes. Its innovation, developed through decades of seismic activity, include base isolation (foundations with shock-absorbing springs), steel-reinforced structures and vibration dampers for tall buildings (Ramakrishnan, 2024; ESKP, 2025). These techniques prevent collapse and reduce damage during seismic events. The success of these methods was clear during the 2011 Great East Japan Earthquake, where damage was minimised and transport infrastructure was quickly restored. Pre-arranged emergency funds and contractor agreements enabled swift reconstruction (Sagara & Ishiwatari, 2013). Japan's model is especially relevant for southern Europe, which faces similar seismic risks. Adopting such strategies could significantly boost infrastructure resilience and disaster preparedness across the EU (Gámez et al., 2017).

Recommendations

RECOMMENDATIONS FOR CONSULTING ENGINEERS

There are many differing perspectives on recommendations for consulting engineers. This section presents a selection of key points based on the weaknesses and risks previously identified.

A primary focus should be the use of (more) resilient and sustainable materials for infrastructure construction and maintenance. Closely linked to this is the need for resource-efficient and sustainable construction methods that tackle future challenges, such as those posed by climate change. Infrastructure should be designed for long-term efficiency, considering not only the construction phase but also maintenance and repair, which should be optimised from the outset.

To achieve this, all relevant stakeholders should be involved throughout the entire process – from planning and construction to long-term upkeep. Additionally, traditional cost-benefit analyses may no longer be sufficient when evaluating projects in the context of increasing resilience and future threats (ITF, 2024).

Another crucial aspect is the integration of modern technologies to enhance infrastructure durability. Digital twin technology, for example, enables the early detection of weaknesses, improving decision-making and optimising construction and maintenance processes (BMDV, 2025). This proactive approach strengthens resilience by allowing for early interventions. However, due to their costs, the use of modern technologies is not yet affordable to many public and private companies. Similarly, projects like CityMoS play a key role in structural planning and transformation, making them valuable not only for engineers but also for the policy makers that are shaping the future infrastructure development.

Furthermore, the engineers should be more involved in the relevant standardisation activities at both the EU (CEN-CENELEC) and international levels (ISO, IEC), to ensure that the standards applicable to the built environment properly include the resilience aspect.

A crucial aspect for both consulting engineers and policymakers is the promotion of information exchange across institutions and countries. Strengthening collaboration fosters more efficient research, development, and implementation of infrastructure projects and initiatives at all levels. By sharing expertise, best practices and technological advancements, stakeholders can accelerate progress and enhance the resilience and sustainability of transport and infrastructure systems. This interdisciplinary and international cooperation is therefore of paramount importance; our frequent call for the New European Bauhaus to give the same importance to infrastructure as is given to buildings, is one way of achieving this

RECOMMENDATIONS FOR POLICY MAKERS

Developing a resilient and sustainable transport sector requires a long-term strategic approach at both the EU and national levels. This subchapter presents a selection of key recommendations, primarily based on an analysis of the weaknesses and risks identified in previous sections.

A clear strategic framework is essential to establish a comprehensive and well-functioning transport network while providing a basis for incentives to promote resilient construction methods. Stable legislation for the long term is crucial to encourage private sector investment in sustainable and resilient technologies, and strengthen defence readiness through investments supporting dual-use, considering criticality and vulnerability of EU peripheral regions. Additionally, decision-makers must anticipate future infrastructure needs, ensuring that transport networks are designed to accommodate long-term challenges and demands (ITF, 2024).

Another critical measure to enhance the flexibility and redundancy of the transport system is the targeted improvement of existing infrastructure. Rather than building entirely new roads, efforts should focus on reinforcing vulnerable sections, such as the Brenner corridor or the Baltic–Adriatic and Rhine–Danube TEN-T corridors, and upgrading bridges and tunnels prone to climate-related disruption. At the same time, modernising and expanding key multimodal hubs – such as those in Constanța, Łódź, or on the Rail Freight Corridor 7 – can improve intermodal connectivity, particularly in Eastern and Southeastern Europe where such infrastructure is still limited. These efforts should reflect regional mobility needs and modal splits, while fostering coordination among stakeholders across road, rail and inland waterway transport to support balanced and effective resilience planning.

The current TEN-T legal framework should be updated, where necessary, to ensure an enhanced resilience of the EU transport infrastructure regarding both climate and man-made threats. In addition, the implementation of the Construction Products Regulation (CPR) will influence hundreds of standards at the EU level, and it is also the duty of the EU and national policy-makers to ensure that these standards properly consider the resilience aspect. This would also mean the prioritisation of standards that have a bigger impact on infrastructure resilience, which can also be done via a Standardisation request (mandate).

Another solution, and not just for transport infrastructure resilience but in general for the sector, is to increase the allocation of funding during the next MFF (2028-2034), so that the TEN-T and other transport infrastructures eligible for funding can be built or modernised in a shorter timeframe. Such changes should also include dedicated EU funding for the maintenance of this infrastructure, or at least key elements of it, the focus here being the bridges.

In addition, while the trend is to simplify the administrative and regulatory procedures related to permitting, this approach to 'cutting red tape' should not be done to the detriment of quality, environmental protection and resilience.

Effective risk management is also essential for maintaining transport resilience. Policymakers must establish well-defined emergency plans that cover a wide range of potential disruption. The better these plans are developed in advance, the more effective the response will be in crisis situations. This includes training and qualification programmes to ensure that personnel responsible for crisis management are adequately prepared (ITF, 2024).

Effective transport resilience requires both preventative measures to minimise the risk of disruption and response strategies to manage and recover from crises efficiently. Since certain extreme events, such as those caused by climate change, can no longer be entirely prevented, a combination of preventative and mitigating measures is essential to ensure stability and continuity in the transport sector (ITF, 2024).

Conclusion and Vision for the Sector

The future of the European transport sector must be guided by a clear, strategic commitment to building a resilient, sustainable and integrated infrastructure network. As outlined in this report, the sector faces a range of internal and external challenges, from ageing assets and funding constraints to geopolitical tensions and climate change impact. Addressing them requires not only targeted investments, but also a shift in mindset toward long-term planning, regional coordination and adaptive infrastructure design.

In this envisioned future, transport networks will be well-maintained and upgraded using durable, climate-resilient materials, reducing deterioration and long-term costs. Multimodal and high(er)-speed rail solutions will help ease pressure on road systems, while promoting low-emission mobility and strengthening cross-border connectivity, especially in peripheral and underserved regions. This will not only facilitate the free movement of goods and people but also contribute to military mobility and the strategic autonomy of the EU.

Technology will serve as a key enabler, with smart infrastructure, real-time monitoring and AI-based maintenance strategies enhancing the adaptability of transport systems. Infrastructure will be designed with built-in redundancy and flexibility, ensuring that alternative routes and response mechanisms are in place to handle cyber threats, natural disasters or geopolitical disruption.

To achieve this vision, policy-makers must establish a predictable legal framework, ensure long-term investment, and modernise regulation, including resilience-focused updates to the TEN-T and Construction Products Regulations. At the same time, collaboration across states, sectors and institutions will be critical to share best practice, harmonise standards and foster innovation. Sustainability must remain central, guided by electrification, renewable energy integration and circular economy principles.

Ultimately, the European transport sector can evolve into a smart, future-proofed system – balancing economic competitiveness, environmental responsibility and strategic resilience in an increasingly complex and interconnected world.

References

Atack, P. R. (2024). Global transport systems struck by IT failure. *Railway Technology.*
https://www.railway-technology.com/news/global-transport-systems-struck-by-it-failure/

BBK. (2024). *KRITIS-Sektor: Transport und Verkehr.* BBK.
https://www.bbk.bund.de/DE/Themen/Kritische-Infrastrukturen/Sektoren-Branchen/Transport-Verkehr/transport-verkehr_node.html?utm_source=chatgpt.com

BMDV. (2025). *Digitale Zwillinge für Bau, Infrastrukturmanagement und -betrieb: Chancen, Anwendungsbereiche, Umsetzungsoptionen.*
https://bmdv.bund.de/SharedDocs/DE/Anlage/DG/umfassende-arbeitsergebnisse-digitale-zwillinge-fuer-bau-infrastrukturmanagement-und-betrieb-chancen-anwendungsbereiche-umsetzungsoptionen.pdf?__blob=publicationFile

Bundesregierung. (2025). *Stromausfall – eine Risikoanalyse | Bundesregierung. Die Bundesregierung informiert | Startseite.*
https://www.bundesregierung.de/breg-de/aktuelles/stromausfall-blackout-2129818

Burgert, T. (2019). *Frankreich: Jede zehnte Brücke in bedenklichem Zustand. verkehrsrundschau.de.*
https://www.verkehrsrundschau.de/nachrichten/transport-logistik/frankreich-jede-zehnte-bruecke-in-bedenklichem-zustand-2976*990*

Chihaia, M. S. (2023). *Advancing military mobility in Europe: An uphill battle.* ***https://www.epc.eu/content/PDF/2023/Military_mobility_PB.pdf***

Christodoulou, A., & Demirel, H. (2018). *Impact of climate change on transport - A focus on airports, seaports and inland waterways.*

Committee on Climate Change. (2018). *Man the coast in a changing climate.*
***h*ttps://www.theccc.org.uk/wp-content/uploads/2018/10/Managing-the-coast-in-a-changing-climate-October-2018.pdf**

Council of the European Union. (2008). *RICHTLINIE 2008/114/EG DES RATES vom 8. Dezember 2008 über die Ermittlung und Ausweisung europäischer kritischer Infrastrukturen und die Bewertung der Notwendigkeit, ihren Schutz zu verbessern.*
https://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:32008L0114

Council of the European Union. (2024). *Council Recommendation of 25 June 2024 on a blueprint to coordinate a response at Union level to disruption of critical infrastructure with significant cross-border relevance.*
https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:C_202404371

Das, P. K. (2014). *Ageing of Asphalt Mixtures: Micro-scale and mixture morphology investigation [KTH, Royal Institute of Technology].*
https://www.diva-portal.org/smash/get/diva2:715945/FULLTEXT01.pdf

DB. (2020). *Deutsche Bahn testet Schutzverfahren gegen Hitze. h***ttps://nachhaltigkeit.deutschebahn.com/de/news/weisseschiene/**

DB Cargo. (2021). *Pasta-Express: Wie Corona die Logistik verändert(e).*
https://www.dbcargo.com/rail-de-de/logistik-news/wie-corona-die-logistik-veraenderte-corona-pandemie-krise-6329824

Deutscher Wetterdienst. (2024). *Entwicklung der Jahresmitteltemperatur in Deutschland in ausgewählten Jahren von 1960 bis 2024 (in Grad Celsius). Statista.* **https://de.statista.com/statistik/daten/studie/914891/umfrage/durchschnittstemperatur-in-deutschland/**

Deutscher Wetterdienst / Extremwetterkongress. (2021). *Was wir heute über das Extremwetter in Deutschland wissen.*
https://www.dwd.de/DE/klimaumwelt/aktuelle_meldungen/210922/Faktenpapier-Extremwetterkongress_download.pdf;jsessionid=C61FD7335DF73D0BA07B79C1941B0A26.live31081?__blob=publicationFile&v=1

Directorate-General for Mobility and Transport. (2019). *Transport in the European Union Current Trends and Issues. European Comission.*
https://transport.ec.europa.eu/system/files/2019-03/2019-transport-in-the-eu-current-trends-and-issues.pdf

Directorate-General for Mobility and Transport. (2022). *Military Mobility: EU proposes actions to allow armed forces to move faster and better across borders - European Commission.*
https://transport.ec.europa.eu/news-events/news/military-mobility-eu-proposes-actions-allow-armed-forces-move-faster-and-better-across-borders-2022-11-10_en

Directorate-General for Mobility and Transport. (2024a). *EU invests record €7 billion in sustainable, safe and smart transport infrastructure - European Commission.*
https://transport.ec.europa.eu/news-events/news/eu-invests-record-eu7-billion-sustainable-safe-and-smart-transport-infrastructure-2024-07-17_en

Directorate-General for Mobility and Transport. (2024b). *Transport in the European Union, Current Trends and Issues.* **https://transport.ec.europa.eu/news-events/news/new-eu-transport-report-current-trends-and-issues-2024-06-27_en**

Directorate-General for Mobility and Transport. (2025). *Logistics.* **https://transport.ec.europa.eu/transport-themes/logistics-and-multimodal-transport/logistics_en**

ECMT. (1996). *SUSTAINABLE TRANSPORT IN CENTRAL AND EASTERN EUROPEAN CITIES.* ***h*ttps://www.itf-oecd.org/sites/default/files/docs/96susttransp_0.pdf**

EEA. (2025a). *Agriculture and food system.* **https://www.eea.europa.eu/en/topics/in-depth/agriculture-and-food**

EEA. (2025b). T*ransport and mobility.* **https://www.eea.europa.eu/en/topics/in-depth/transport-and-mobility**

EESC. (2025). *Deepening the dual civilian-military approach in transport.* **https://www.eesc.europa.eu/en/news-media/news/deepening-dual-civilian-military-approach-transport**

ENISA. (2023). *Understanding Cyber Threats in Transport.* **https://www.enisa.europa.eu/news/understanding-cyber-threats-in-transport**

ENISA. (2024). *The 2024 ERA-ENISA Conference on Railway Cybersecurity seeks to strengthen sector preparedness and resilience against current threats.* **https://www.enisa.europa.eu/news/the-2024-era-enisa-conference-on-railway-cybersecurity-seeks-to-strengthen-sector-preparedness-and-resilience-against-current-threats**

EPA. (2025). *Climate Impact on Transportation [Overviews and Factsheets].* **https://19january2017snapshot.epa.gov/climate-impact/climate-impact-transportation**

ESKP. (2025). *Erdbebensichere Bauwerke.* **https://www.eskp.de/naturgefahren/erdbebensichere-bauwerke-935349/**

U-NATO Task Force on resilience of critical infrastructure. (2023). *FINAL ASSESSMENT REPORT.* **https://commission.europa.eu/system/files/2023-06/EU-NATO_Final%20Assessment%20Report%20Digital.pdf**

European Comission. (2020). *Putting European transport on track for the future. European Comission.* **https://transport.ec.europa.eu/system/files/2021-04/2021-mobility-strategy-and-action-plan.pdf**

European Comission. (2025). *CEF Transport.* **https://cinea.ec.europa.eu/programmes/connecting-europe-facility/transport-infrastructure_en**

European Commission. (2022). *Action plan on military mobility 2.0.* **https://defence-industry-space.ec.europa.eu/action-plan-military-mobility-20_en**

European Commission. (2025a). *Consequences of climate change.* **https://climate.ec.europa.eu/climate-change/consequences-climate-change_en**

European Commission. (2025b). T*rans-European Transport Network (TEN-T).* **https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t_en**

European Court of Auditors. (2018). *Towards a successful transport sector in the EU: challenges to be addressed.* **https://op.europa.eu/webpub/eca/landscape-review-transport/en/**

European Environment Agency. (2024). *Share of inland waterways and trains in total inland freight transport in the EU-27 | European Environment Agency's home page.*

European Parliament and the Council of the European Union. (2022). *DIRECTIVE (EU) 2022/2557 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 14 December 2022 on the resilience of critical entities and repealing Council Directive 2008/114/EC.* **https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32022L2557**

European Union. (2015). *Opportunities for the transport sector under the Investment Plan.* **https://transport.ec.europa.eu/document/download/a602f5fb-766a-4af9-a65b-17c4614e4f9a_en?filename=2015-09-30-non-paper-transport-sg.pdf&prefLang=da**

Eurostat. (2024a). *Characteristics of the railway network in Europe.* **https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Characteristics_of_the_railway_network_in_Europe**

Eurostat. (2024b). *Final energy consumption in transport - Detailed statistics.*
https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Final_energy_consumption_in_transport_-_detailed_statistics

Eurostat. (2024c). *Inland transport infrastructure at regional level.*
https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Inland_transport_infrastructure_at_regional_level

Eurostat. (2024d). *Length of electric and non-electric railway lines by nature of transport.*
https://ec.europa.eu/eurostat/databrowser/view/rail_if_line_na/default/table?lang=en&category=rail.rail_if

Eurostat. (2024e). *Length of motorways and e-roads.*
https://ec.europa.eu/eurostat/databrowser/view/road_if_motorwa/default/table?category=road.road_if

Eurostat. (2024f). *Passenger cars in the EU.*
https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Passenger_cars_in_the_EU

Eurostat. (2024g). *Passengers transported.* **https://ec.europa.eu/eurostat/databrowser/view/rail_pa_total/default/table**

Eurostat. (2024h). *Road freight transport by type of operation and type of transport (t, tkm, vehicle-km) - Annual data.*
https://ec.europa.eu/eurostat/databrowser/view/road_go_ta_tott/default/table

Eurostat. (2025a). *Goods transported.*
https://ec.europa.eu/eurostat/databrowser/view/rail_go_total__custom_15128954/default/table?lang=en

Eurostat. (2025b). *National passenger road transport performance by type of vehicles registered in the reporting country.*
https://ec.europa.eu/eurostat/databrowser/view/road_pa_mov/default/table

Expert Group for Urban Mobility. (2022). *How to deal with the worker shortage and evolving skill requirements of the public transport sector.*
https://transport.ec.europa.eu/document/download/eb3bef7d-ce8d-4f7a-a8d5-05eae1070691_en?filename=EGUM+Recommendations_PT+Subgroup_Topic+4B.pdf&utm_source=chatgpt.com

Federal Highway Administration. (2023). *Resilience Definitions.*
https://highways.dot.gov/research/infrastructure/resilient-pavements/definitions

Fiolka, M. (2025). *Blockade im Suez Kanal. Fraunhofer-Institut für Materialfluss und Logistik IML.*
https://www.iml.fraunhofer.de/de/resilienz/never-let-a-good-crisis-go-to-waste/die-blockade-im-suez-kanal.html

FOCUS online. (2013). *S-Bahn fährt wieder in Berlin. FOCUS online.*
https://www.focus.de/panorama/welt/s-bahn-faehrt-wieder-in-berlin-nach-stromausfall_id_2364095.html

Frauenhofer-Gesellschaft. (2024). *Infrastruktur – Wege aus der Gefahr. Fraunhofer-Gesellschaft.*
https://www.fraunhofer.de/de/forschung/aktuelles-aus-der-forschung/infrastruktur---wege-aus-der-gefahr.html

Gámez, S. G., Darido, G. B., D'Ocon, I. S., & Shibuya, N. (2017). *How to protect metro systems against natural hazards? Countries look to Japan for answers. World Bank Blogs.*
https://blogs.worldbank.org/en/transport/how-protect-metro-systems-against-natural-hazards-countries-look-japan-answers

Gode, K., & Paeglitis, A. (2014). *Concrete Bridge deterioration caused by de-icing salts in high traffic volume road environment in Latvia.*
https://bjrbe-journals.rtu.lv/bjrbe/article/view/bjrbe.2014.25/280

Handelsblatt. (2023). *Huthi-Attacken im Roten Meer – USA kündigen multinationalen Einsatz an. Handelsblatt.*
https://www.handelsblatt.com/politik/international/schifffahrt-huthi-attacken-im-roten-meer-usa-kuendigen-multinationalen-einsatz-an/100003744.html

Haucap, J., Diez, W., Otto, H.-J., & Bontrup, H.-J. (2012). *Öl- und Kraftstoffmarkt? Steigende Benzinpreise: Fehlende Transparenz auf dem.*

Hauptverband der deutschen Bauindustrie e.V. (2024). *Brancheninfo Bau „Zustand der Verkehrswege".*

IEA. (2024). Electricity 2024. *Analysis and forecast to 2026.*
https://iea.blob.core.windows.net/assets/18f3ed24-4b26-4c83-a3d2-8a1be51c8cc8/Electricity2024-Analysisandforecastto2026.pdf

IEA, & Statista. (2023). *Anteil der Verkehrsträger an den weltweiten CO_2-Emissionen aus der Verbrennung fossiler Brennstoffe in den Jahren 2019 bis 2022 [Dataset].*
https://de.statista.com/statistik/daten/studie/317683/umfrage/verkehrsttraeger-anteil-co2-emissionen-fossile-brennstoffe/

IHK München. (2025). *Russland-Ukraine-Krieg: Auswirkungen auf Transport & Logistik.* **https://www.ihk-muenchen.de/de/Service/Internationalisierung/Russland-Ukraine-Krieg/Transport-und-Logistik/**

ITF. (2024). T*ransport System Resilience: Summary and Conclusions.* **https://www.itf-oecd.org/sites/default/files/docs/transport-system-resilience.pdf**

JRC of the European Commission. (2024). *Transport sector economic analysis.* **https://joint-research-centre.ec.europa.eu/scientific-activities-z/transport-sector-economic-analysis_en**

Joint Research Centre (JRC). (2014). *PESETA II: Climate impact in Europe - The JRC PESETA II project. Publications Office of the European Union.* **https://doi.org/10.2791/7409**

Kelch, S. (2024). *Warum die Carolabrücke in Dresden einstürzte. ZDFheute.* **https://www.zdf.de/nachrichten/politik/deutschland/carolabrueke-in-dresden-bruecke-einsturz-100.html**

Luger, M. J. (2009). *Lebenszykluskosten von Brückenbauwerken in Vorarlberg.* **https://monami.hs-mittweida.de/frontdoor/deliver/index/docId/479/file/DA_Lebenszykluskosten_Bruecken_Markus_Luger.pdf**

Maihold, G., & Mühlhöfer, F. (2021). *Instabile Lieferketten gefährden die Versorgungssicherheit. Handlungsoptionen für Unternehmen und Politik.* **https://doi.org/doi:10.18449/2021A80**

mb/dpa. (2022). *Asphalt, der kühlt: Forscher testen klimafreundlichen Straßenbelag. The Weather Channel.* **https://weather.com/de-DE/wissen/klima/news/2022-08-03-asphalt-der-kuhlt-forscher-testen-klimafreundlichen-strassenbelag**

Nemry, F., & Demirel, H. (2012). Impact of Climate Change on Transport: A focus on road and rail transport infrastructures. **http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=5619 https://publications.jrc.ec.europa.eu/repository/handle/JRC72217**

Ollagnier, J.-M., Timmermans, K., & Brueckner, M. (2022). *From disruption to reinvention: The future of supply chains in Europe. Accenture.* **https://www.accenture.com/us-en/insights/strategy/ukraine-future-supply-chains-europe**

Presse- und Informationszentrum Marine/Marineschifffahrtleitung. (2021). *Suez-Blockade: Zeichen strategischer Empfindlichkeit.* **https://www.bundeswehr.de/de/organisation/marine/aktuelles/ever-given-suezkanal-blockade-strategische-empfindlichkeit-5046942**

Puls, T. (2020). *Jenseits des Geldes, Was behindert den Infrastrukturausbau in Deutschland.* **https://www.iwkoeln.de/studien/thomas-puls-was-behindert-den-infrastrukturausbau-in-deutschland.html**

Puls, T. (2023). *Mauteinnahmen und Verkehrsinvestitionen des Bundes. Puls IW-Kurzbericht, 48.* **https://www.iwkoeln.de/studien/thomas-puls-mauteinnahmen-und-verkehrsinvestitionen-des-bundes.html**

PwC. (2020). *Corona und die Folgen: Transport- und Logistikbranche im Krisenmodus. PwC.* **https://www.pwc.de/de/transport-und-logistik/transport-and-logistics-barometer/corona-und-die-folgen-branche-im-krisenmodus.html**

Ramakrishnan, S. (2024). *Erdbeben in Japan: Wie kann man erdbebensicher bauen? – DW – 02.01.2024. dw.com.* **https://www.dw.com/de/erdbeben-in-japan-wie-kann-man-erdbebensicher-bauen/a-67877814**

Sagara, J., & Ishiwatari, M. (2013). *Infrastructure Rehabilitation.* **https://www.gfdrr.org/sites/default/files/publication/knowledge-note-japan-earthquake-4-1.pdf**

Scheuermann, F. (2020). *Offenbach: Neuartiger Asphalt soll Städte abkühlen.* **https://www.fr.de/rhein-main/offenbach-neuartiger-asphalt-soll-staedte-abkuehlen-13782142.html**

Starck, N. (2024). *ZUSTAND DER VERKEHRSWEGE.* **https://www.bauindustrie.de/fileadmin/bauindustrie.de/Zahlen_Fakten/BrancheninfoBau/BiB_-_Zustand_der_Verkehrswege.pdf**

Statista. (2023). *Floods in Europe.* **https://www.statista.com/study/110351/flooding-in-europe/**

Statista. (2024). *Distribution of carbon dioxide emissions worldwide in 2023, by sector [Dataset].* **https://www.statista.com/statistics/1129656/global-share-of-co2-emissions-from-fossil-fuel-and-cement/**

Statista, & Global Carbon Budget. (2024). *Annual carbon dioxide (CO_2) emissions worldwide from 1940 to 2024 (in billion metric tons) [Dataset].* **https://www.statista.com/statistics/276629/global-co2-emissions/**

Statistisches Bundesamt (Destatis). (2025). *Massiver Fahrgastverlust bei der Bahn im Corona-Jahr 2020.* **https://www.destatis.de/Europa/DE/Thema/Verkehr/eisenbahn-passagiere.html**

Tagesschau. (2024a). *Dutzende Autobahnbrücken in bedenklichem Zustand. tagesschau.de.*
https://www.tagesschau.de/wirtschaft/verbraucher/autobahn-bruecken-sanierung-wissing-verkehr-transport-infrastruktur-100.html

Tagesschau. (2024b). *Zustand deutscher Straßen und Schienen hat sich verschlechtert. tagesschau.de.*
https://www.tagesschau.de/inland/infrastruktur-zustand-100.html

Tagesschau. (2025). *Fernzüge der Bahn 2024 so unpünktlich wie seit mindestens 21 Jahren nicht. tagesschau.de.*
https://www.tagesschau.de/inland/fernzuege-verspaetung-102.html

The World Bank. (2018). *Connecting to Compete 2018 Trade Logistics in the Global Economy The Logistics Performance Index and Its Indicators.*
https://openknowledge.worldbank.org/server/api/core/bitstreams/628a4f9d-7faa-54bf-97b0-f6080c6d46cd/content

Theocharidou, M. (2023). *ENISA THREAT LANDSCAPE: Transport SECTOR. ENISA.*
https://www.enisa.europa.eu/sites/default/files/all_files/03-cooperation-information-sharing-03-enisa-theocharidou.pdf

TMB. (2025). *Singular projects and electric mobility. TMB.*
https://www.tmb.cat/ca/coneix-tmb/innovacio-i-projectes/ajudes-next-generation-ue/projectes-singulars-mobilitat-electrica

TUM. (2022). *Singapur: Ein ganzer Stadtstaat als Simulation.*
https://www.tum.de/aktuelles/alle-meldungen/pressemitteilungen/details/singapur-ein-ganzer-stadtstaat-als-simulation

United Nations Environment Programme Finance Initiative (UNEP FI). (2024). *Climate Risk Landscape 2024: A review of tools and data for assessing climate risk.* **https://www.unepfi.org/publications/climate-risk-landscape-2024/**

U.S. Department of Transportation. (2024). *Economic Strength: Creating reliable and efficient access to resources, markets and good-paying jobs.* **https://www.transportation.gov/economic-strength-creating-reliable-efficient**

Weiler, D. I. L. (2025). *Städte klimatisieren. KlimaPhalt.* **http://klimaphalt.de/index.html**

Wilson, J. (2024). *Barcelona subway recycles energy from braking into power to charge electric cars. AP News.*
https://apnews.com/article/spain-climate-subway-electric-cars-barcelona-energy-69cf7212fa8d5e3e4d45d62a2f97c6dd

Wissenschaftliche Dienste. (2023). *Elektrische Straßensysteme (ERS) - Simultanes Laden und Fahren von Elektrofahrzeugen - Einsatzmöglichkeiten, Durchsetzung und Regulierung.*
https://www.bundestag.de/resource/blob/956466/c1e90c78dece214e531ce7045641be4c/WD-5-045-23-pdf.pdf

ZDFheute. (2023). *Italien gedenkt der Opfer der Morandi-Brücke. ZDFheute.*
https://www.zdf.de/nachrichten/panorama/brueckeneinsturz-genua-gedenken-italien-100.html

ZEIT Online, AFP, Reuters, AP, dpa, & Eva Casper. (2024). *Rotes Meer: USA greifen Radaranlage der Huthis im Jemen an. Die Zeit.*
https://www.zeit.de/politik/ausland/2024-01/rotes-meer-jemen-huthi-usa-erneut-angriff

Zierer, M. (2015). *Wechselwirkungen zwischen Verkehrsinfrastruktur und Wirtschaftswachstum – Eine theoretische Untersuchung und empirische Analyse für Deutschland [Universität Regensburg].*
https://epub.uni-regensburg.de/33053/1/Wechselwirkungen%20zwischen%20Verkehrsinfrastruktur%20und%20Wirtschaftswachstum.pdf

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