Evaluation of the climate change impact on rail operations in Türkiye

An executive summary

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About the review

This report, "Evaluation of the climate change impact (CCI) on rail operations in Türkiye," focuses on conducting a comprehensive assessment of how climate change affects railway infrastructure, maintenance, and operations in Türkiye through systematic literature review, stakeholder engagement, and vulnerability analysis of critical rail corridors. The study examines climate-induced hazards, including floods, heatwaves, landslides, and sea-level rise, while evaluating both mitigation strategies (such as modal shift to rail transport) and adaptation measures (including innovative monitoring technologies and resilient infrastructure design) to enhance railway resilience. Findings from this study will inform policymakers in strengthening Türkiye's rail infrastructure resilience, aligning with the country's goal of achieving net-zero emissions by 2050, while supporting national efforts to develop climate-resilient transportation systems and contributing to global knowledge on railway adaptation to climate change. The research identifies critical rail segments vulnerable to climate hazards, particularly in central Anatolia and coastal regions, and provides evidence-based recommendations for prioritising investments in advanced technologies such as real-time monitoring systems, predictive maintenance, and early warning systems to safeguard essential rail corridors that connect Europe and Asia.

Review process

This report was reviewed by David Jaroszweski from University of Birmingham, and Suvarna Pande from 3ie.

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EVALUATION OF THE CLIMATE CHANGE IMPACT ON RAIL OPERATIONS IN TÜRKİYE (CCI&RAIL)

EXECUTIVE SUMMARY

Climate change remains one of the most significant global challenges, with profound impacts on transportation systems. Rising global temperatures, as reported by the Intergovernmental Panel on Climate Change (IPCC), are linked to more frequent extreme weather events, including floods, heatwaves, sea-level rise, etc. These hazards threaten transportation infrastructure worldwide, resulting in economic losses and operational disruptions.

The Mediterranean Basin, including Türkiye, is highly vulnerable to climate change, facing risks such as floods, erosion, reduced rainfall, droughts, and erosion. Türkiye's climate change strategies, outlined in major policy and strategy documents and the 12th Development Plan, emphasise sustainability and resilience as central to its economic growth and infrastructure development. Türkiye's role as a strategic land bridge between Asia and Europe underscores the critical need to protect its railway infrastructure. As part of the Trans-European Transport Network (TEN-T) and other international corridors, Türkiye's railways must remain resilient to climate-induced disruptions.

Aim and Scope of the Project:

This study evaluates the impacts of climate change on Türkiye's railways by:

- Systematically reviewing the global literature on climate change impact on railways
- Identifying critical network segments prone to climate change induced events such as flooding, landslides, and sea-level rise.
- Proposing strategies for resilient infrastructure, maintenance, and operations.
- Integrating innovative technologies to adapt to climate challenges.

Dimensions of the Systematic Literature Review

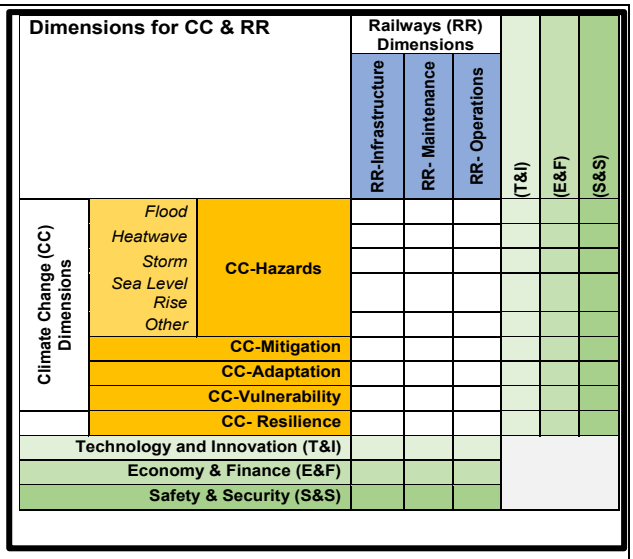
Based on the systematic literature review, the dimensions were organised into two primary categories: Climate Change (CC) and Railways (RR), with additional cross-cutting issues influencing both categories.

CC Dimensions – The research identified four main climate change dimensions:

- Hazards (H) – Encompassing natural climate-related hazards such as floods, heatwaves, storms, and sea-level rise.
- Mitigation (M) – Addressing strategies to reduce carbon emissions via shifting to rail policies and extending rail services and network.
- Adaptation (A) – Involving measures to adapt railway infrastructure and operations to withstand climate-related impacts.
- Resilience (R) – Focused on building resilience within the railway system to better respond to climate-induced challenges.

RR Dimensions - Within the railway sector, three key dimensions were identified:

- Infrastructure (I) – Examining the direct impact of climate change on railway infrastructure, including structural integrity and material resilience.
- Maintenance (M) – Involving the ongoing maintenance requirements necessary to keep railway systems operational under changing climate conditions.
- Operations (O) – Analysing how railway operations are affected by climate hazards and what operational adjustments are needed to mitigate these impacts.



Cross-Cutting Issues - Three cross-cutting dimensions were identified that influence both CC and RR dimensions:

- **Technology and Innovation (T&I)** – Exploring how technological advancements and innovative practices can enhance railway resilience to climate change.
- **Economy and Finance (E&F)** – Addressing the economic and financial considerations, including cost implications, investment strategies, and the economic impact of climate-related disruptions on railway operations.
- **Safety and Security (S&S)** – Focusing on the safety and security challenges posed by climate-related hazards, including developing safety protocols, risk management frameworks, and measures to ensure the security of rail systems against climate-related threats.

Climate Change Related Hazard Impact on Railways

Climate-induced hazards have profound implications for railways, increasing service disruptions, maintenance costs, and safety concerns. For example:

- **Flooding:** Heavy rainfall leads to embankment instability, track flooding and soil erosion, posing risks to structural integrity and causing extensive service disruptions. In addition to hydrodynamic modelling, improved drainage and flood barriers are essential to mitigate these impacts. Technologies like ground-penetrating radar (GPR) are used to monitor soil conditions and enhance infrastructure resilience.
- **Heatwaves:** High temperatures cause track buckling and disrupt power systems, requiring dynamic heat risk management. Overhead lines and signalling systems are also impacted, requiring dynamic heat management strategies, including adjusted speed restrictions and improved maintenance practices.
- **Snow, Ice and Cold Weather**: Cold weather damages switches and signals, impacting freight and passenger operations. Maintaining overhead electrical lines during snowstorms is critical, as sagging and power failures can further impact operations.
- **Sea Level Rise (SLR):** Coastal railways face long-term threats from rising sea levels and storm surges, necessitating significant infrastructure modifications or relocation.
- **Storms and High Winds**: Intense storms and high winds damage railway infrastructure, overhead lines, and signalling systems. Wind speeds above 20 m/s can cause debris to fall on tracks, creating faults and safety risks.

Though not addressed much in the climate change literature, drought and water scarcity further lead to formation of sinkholes, posing threats to rail infrastructure physical elements. This has become a growing concern in Türkiye (particularly in Central Anatolian Region).

Technological Innovations

Advanced technologies are crucial for addressing climate-induced hazards:

- **Flood Monitoring:** Sensor networks and unmanned aerial vehicles (UAVs) enable real-time flood detection, which is essential for the Marmara and Aegean regions.
- **Water (River) Level Monitoring:** Satellite remote sensing and Unmanned Aerial Systems (UAS) equipped with Structure-from-Motion (SfM) photogrammetry provide precise, frequent monitoring of water levels enhance flood and scour risk detection.
- **Heat Adaptation**: AI-powered systems monitor track temperatures, reducing risks of buckling.
- **Snow and Ice Resilience**: Drone inspections and automated switch heaters improve cold-weather performance.

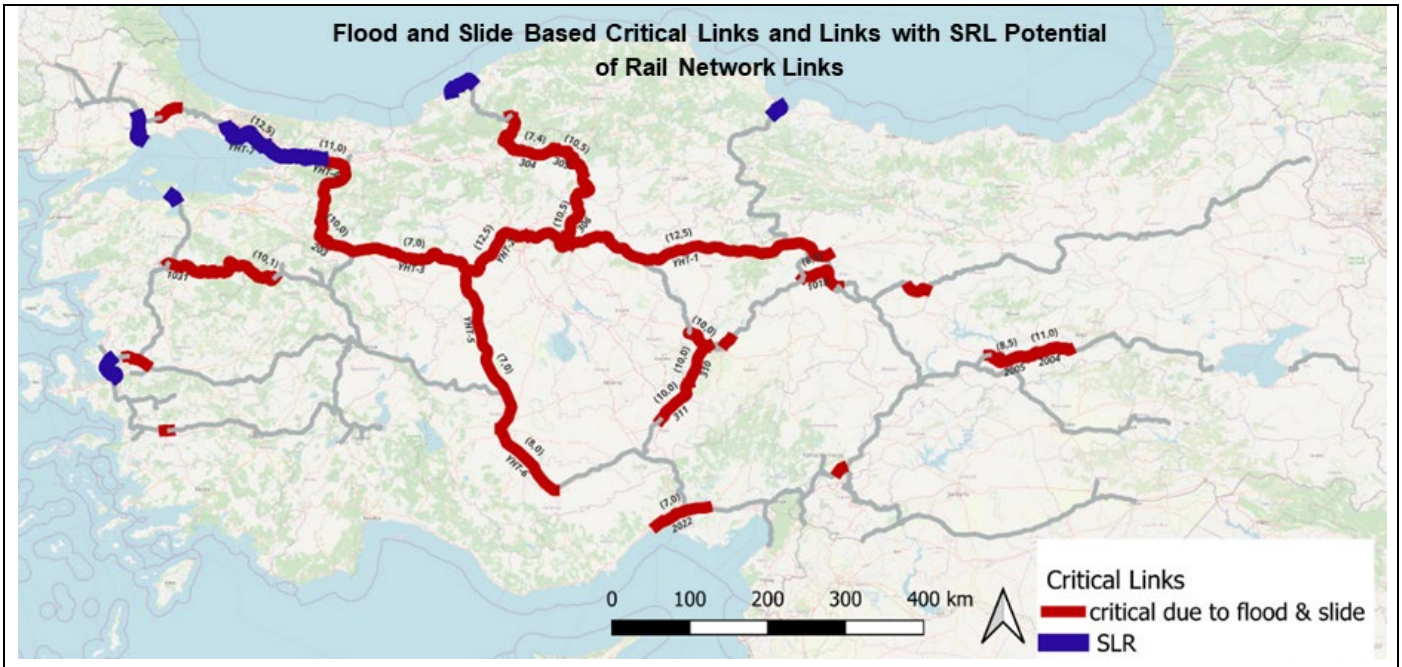
Note: Stakeholders at the UK-Türkiye Rail Forum emphasised i) prioritising these technologies for high-risk regions, particularly flood-prone and coastal areas and ii) the key role of the UK expertise in integrating real-time data analytics with railway infrastructure in providing valuable insights for adaptation and resilience of Turkish rail sector against future climate challenges.

Conclusions and Recommendations

Considering the passenger and freight activity in the Turkish rail network as well as the climate change hazard expectations, critical rail links in terms of climate change impact were detected in **central Anatolia and coastal regions. Flood-prone links, such as those near Sivas and Zonguldak,** require immediate intervention. **Sea-level rise poses long-term risks for links near İzmir, Istanbul, and Samsun**, necessitating protective infrastructure and advanced monitoring systems.

Technological intake should be prioritised in those critical rail links by:

- **Water (River) Level Monitoring:** Essential for flood-prone regions to detect and mitigate risks on the bridge scours.
- **Culvert Monitoring:** Addressing vulnerabilities in embankments/drainage systems.
- **Railway Track Monitoring**: By technologies such as sensors, INSAR, and drone Technologies, Enhancing resilience through real-time data collection and rapid response capabilities through the rail tracks.
- **Predictive Maintenance Systems**: Predictive maintenance, powered by AI and machine learning, uses data from digital twins and IoT sensors, ensuring that repairs are made before climate-related failures occur; and ideally should be developed as a part of a more general asset management systems,



Note: By integrating advanced technologies, updating policies, and fostering international cooperation, Türkiye can transform its railways into a sustainable, climate-resilient transport system supporting regional and global objectives.

Designing a Resilient Railway Network

The study applied a Theory of Change (ToC) framework to map critical areas for enhancing railway resilience:

1. **Policy and Legislative Updates**: Aligning with international standards and incorporating climate adaptation measures.
2. **Institutional Capacity Development:** Training personnel and enhancing management systems.
3. **Increasing Rail Modal Share**: Promoting rail as a sustainable alternative to road transport, contributing to climate change mitigation.
4. **Asset Management Systems**: Optimising infrastructure lifecycle performance through proactive maintenance strategies.
5. **Climate Adaptation Framework**: Integrating adaptation strategies into all railway operations and maintenance aspects.
6. **Risk and Vulnerability Assessments**: Identifying and prioritising critical segments based on exposure and hazard scores.
7. **Innovative Technologies:** Deploying advanced tools for hazard monitoring, predictive maintenance, and real-time analytics.

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