SARIL

Sustainability And Resilience for Infrastructure and Logistics networks

D4.2 Transferability Technical Report

Deliverable Number	D4.2
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Due/delivered Date	30.09.2025
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Dissemination Level	PU
Version of template	1.2

Start Date Project: 2023-06-01 Duration: 36 months Project ID: 101103978

This project has received funding from the Horizon Europe program of the European Union under grant agreement ID 101103978.

Disclaimer:

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Document revisions

Revision	Date	Comment	Author
V01	06.08.2025	Global review	Marta Waldmann
V01	13.08.2025	Global review	Jan Tore Pedersen
V02	04.09.2025	Roles review	Jan Tore Pedersen
V03	12.09.2025	Security review	Ana Maia
V03	12.09.2025	Quality review	Benjamin Lickert

Executive summary

This deliverable presents a transferability study, which evaluates whether the SARIL General Methodology, the green resilience tools, and the mitigation measures developed in D3.3 [1] are transferable to other socio-economic contexts. It represents the report of the work performed in Task 4.2. The transferability of the mitigation measures is assessed from both economic and social perspectives in the proposed new regional, national, and international scenarios. These additional scenarios include environments with lower socio-economic indicators, economically disadvantaged countries, and countries which are not part of the European Union.

The transferability of the *SARIL General Methodology for Green Resilience Assessment* is guaranteed, as it is not limited to any geographic area, network, or threat. The transferability of the green resilience tools was quantitatively analysed, taking into account various factors, such as the type of license required for their use, the diversity of data, its volume and availability, and whether it contains confidential information. The transferability of the mitigation measures was analysed considering the new scenario's levels of development, location, and existing infrastructures.

The findings of this report will enter the work of Task 5.1 (considering recommendations to be derived from the project work) as well as the work of Task 5.2 (business models).

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List of Acronyms

Acronym	Definition
4WDs	Four-wheel drive vehicles
ADT	Average Daily Traffic
BBA	Baltic Sea-Black Sea-Aegean Sea Corridor
DEWS	Digital Early Warning System
EU	European Union
JIT	Just-in-time
MCS	Monte Carlo Simulation
O-D	Origin-Destination matrices
OSM	Open Street Maps
OSRM	Open-Source Routing Machine
SARIL	Sustainability And Resilience for Infrastructure and Logistics networks
SHM	Structural health monitoring
SUMO	Simulation of Urban Mobility
T	Transferability score
TEN-T	Trans-European Transport Network
NINA	Notfall-Informations- und Nachrichten-App
KATWARN	Katastrophen-Warnsystem

1 Introduction

This deliverable presents the outcomes of the transferability analysis of the Green Resilience methodology, tools and mitigation measures developed within the SARIL project. The document introduces new case studies that reflect different socio-economic conditions, broadening the scope of applicability and analysis of the SARIL developments.

The transferability assessment explores the extent to which the results and methodologies can be applied beyond the SARIL scenarios defined in the deliverable "*D1 Scenario cases definition*" and is structured around three key dimensions:

1. Transferability of the **resilience and sustainability methodology**.
2. Transferability of the **SARIL tools.**
3. Transferability of the **mitigation measures defined in deliverable D3.3**.

This work relies on both quantitative and qualitative analysis, applied to new scenarios (see table below) that differ from the SARIL scenarios in terms of socio-economic characteristics. The aim is to assess whether the SARIL approach can be successfully replicated, adapted, or scaled in diverse territorial, institutional and economical settings.

The foundations of this analysis lie in the outputs of Work Package 1, which established the original SARIL scenarios and a common framework for evaluating the sustainability and resilience of logistics networks. It also included early engagement with relevant stakeholders to align the framework with real-world priorities and challenges.

Building upon this, while Work Package 2 identified the optimal methodologies for managing resilience and sustainability, Work Package 3 delivered the simulations and the implementation of the proposed methodology. These simulations served as a comparative baseline for assessing the adaptability of SARIL's outputs in the newly defined socio-economic environments.

Next, the document evaluates the transferability of the three aspects mentioned above. Sections 2 and 3 analyse the factors that affect transferability with respect to the methodology used and the tools developed, respectively, while Section 4 defines the new and different socio-economic scenarios and analyses within them the potential transferability of the mitigation measures defined in document "*D3.3 Green resilience assessment result*".

Table 1-1: SARIL case scenarios and new scenarios defined for transferability analysis (D3.3)

Scenario	Scenario defined in D1.1	New scenario defined in D4.2
Regional	Mantua (Italy)	Sussundenga (Africa)
National	Northwest Iberian Peninsula, Spain and Portugal	Southern Balkans, Greece and Bulgaria
International	Asia_Europe	Serbia (No EU) to Germany (EU)

2 Transferability of the *SARIL General Methodology for Green Resilience Assessment*

The *SARIL General Methodology for Green Resilience Assessment* is proposed for evaluating and assessing the resilience of infrastructures and logistics networks when exposed to disruptive hazards. This methodology is structured around four key components, shown in *Figure 2-1*. The evaluation begins by defining the network and the hazards to be analysed. Then, a resilience assessment of the network is conducted by evaluating the outcomes of traffic simulations reflecting several scenarios, such as i) a standard situation where no disruption has taken place, ii) a disrupted situation where some sections of the network have been affected, and iii) a disrupted situation where resilience measures have been implemented. By incorporating resilience measures into the assessment, this methodology is as well proposed for evaluating the effectiveness of these measures in enhancing the system's resilience.

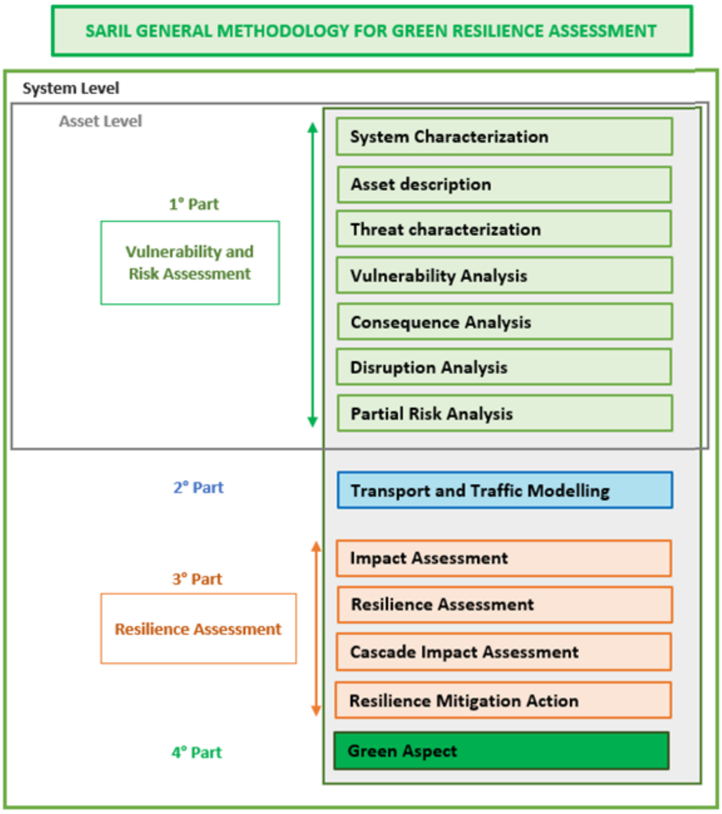

Figure 2-1: SARIL General Methodology for Green Resilience Assessment (Adapted from D2.2).

2.1 Transferability analysis of the methodology

The *SARIL General Methodology for Green Resilience Assessment* has been designed to be applicable to any system or logistics network. This framework, therefore, is not limited to specific geographical areas, networks, or hazards. However, several factors should be considered when implementing the methodology:

Part 1: Vulnerability and risk assessment

The methodology begins by identifying which system is being analysed. Once the extent to be evaluated is specified, a vulnerability analysis is conducted by recognising the main hazards that can disrupt the system. A detailed evaluation can be achieved by establishing disruption functions for various threat scenarios and by conducting consequence, disruption, and partial risk analyses. However, only acknowledging which system and hazards are analysed is required to apply the methodology. Given that these aspects are inherent to the analysed area and context, the transferability of this component is guaranteed.

Part 2: Transport and traffic modelling

Traffic models are used to simulate the network under different scenarios. The main aim of this component is to replicate the network and analyse how it behaves under standard and disrupted scenarios. This component relies on using software or programs that can model traffic. This modelling includes the following input data:

- **Network data** to describe road and rail infrastructure through links, nodes, capacities, speed limits, signal timings, etc.
- **Travel demand data** through Origin-Destination (O-D) matrices, trip generation rates, and modal split.
- **Disruptive data** to represent the impact of the hazard on the system.

Measures can be implemented to enhance the system's resilience based on its reaction to disruptive events. Therefore, additional traffic models can be conducted to evaluate the effectiveness of these measures by comparing the system's responses.

The transferability of this component relies on the availability of software and programs to model traffic, the skills required to employ them, and knowledge of network data. Although some data, such as O-D matrices or signal timings, may not be acknowledged, representative conclusions can be determined. The transferability of this component is guaranteed, as it is the user who defines disruptive data based on which hazard is analysed.

Part 3: Resilience assessment

The third component evaluates the system's resilience by comparing the outputs of the traffic models. It begins by comparing the outputs from the standard scenario with those from the disrupted scenarios. To assess the effectiveness of resilience measures, traffic model outputs from the latter are then compared with those of the standard and disrupted scenarios.

The resilience assessment can be conducted through several approaches. Therefore, the user chooses the most suitable approach by considering the analysed event and the aspects of the system that they consider critical. Consequently, the transferability of this component is guaranteed as it is only limited by which aspects the user intends to examine.

Part 4: Green aspect

The last component incorporates sustainability analysis into the methodology. It analyses the impact that disruption events have on socio-economic aspects, such as population, employment, and economic activity, as well as environmental elements, including emissions and noise levels. Whenever measures have been implemented to enhance the system's resilience, their effectiveness is also analysed by considering their effect on socio-economic and environmental aspects.

As in the resilience assessment, several approaches can be implemented to incorporate the green aspect component. Therefore, its transferability is only limited by the aspects the user intends to examine.

2.2 Transferability summary

The transferability of the *SARIL General Methodology for Green Resilience Assessment* is guaranteed as it is not restricted to any geographical area, network, or hazard. Its implementation depends on the availability of software and programs to model traffic, skills in employing them, knowledge of network data, and which aspects the user intends to examine in terms of resilience and sustainability. *Figure 2-2* illustrates a successful implementation of the *SARIL General Methodology for Green Resilience Assessment* in [1], demonstrating that not all steps are required to conduct the assessment.

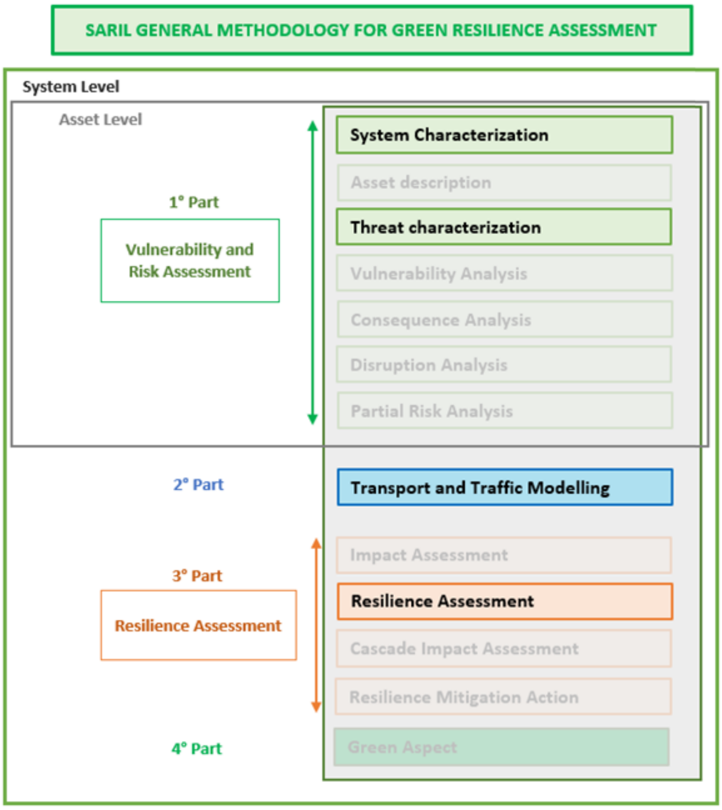

Figure 2-2: Example of the implementation of the SARIL General Methodology for Green Resilience Assessment shown in D3.3.

3 Transferability of Green Resilience tools

As described in the documents delivered in WP3, "*D3.1 Improved models and tools", "D3.2 Models and tools covering gaps",* and *"D3.3 Results of the ecological resilience assessment"*., green resilience models incorporate a set of tools used to evaluate the resilience of the network under disruptive events and the effectiveness of mitigation measures when applied to logistics networks. This section first highlights the potential and inadequacies of the transferability of each tool, followed by a summary of the transferability for the entire set.

Table 3-1 summarises the Green Resilience tools and for which SARIL roles (among the following) they are relevant.

- **Role 1:** Developing and Maintaining Transport Infrastructures
- **Role 2:** Configuring Transport and Logistics Networks
- **Role 3:** Managing Logistics Operations

Table 3-1: Relevant roles for each Green Resilience tool.

Green Resilience tools	Relevant roles
Natural hazard map	R1
Traffic simulation	R1
Scour monitoring for decision support	R1
Vulnerability and traffic tool	R1, R3
Route attributes (Energy module)	R3
Route planning	R3
Transport simulations (ASTROIT)	R2
Disruption information interface	R3

Transferability refers to the ease with which a tool can be applied in various contexts or regions. In order to evaluate this transferability, the following aspects are considered:

- **License type:** Open-source tools are generally more transferable as they allow modifications and do not rely on proprietary licenses. On the other hand, closed sources complicate transferability due to their high cost.
- **Data diversity:** The need to use different data and formats compromises the transferability of tools.
- **Data volume:** Tools that require smaller data volumes are more transferable, as they can be deployed in environments with limited data resources.
- **Data availability:** The greater the availability of relevant data, the easier it is to implement the tool in different scenarios.
- **Confidentiality level:** The lower the sensitivity of the required data, the easier the tool's implementation, as it avoids legal and security restrictions.

3.1 Methodology for assessing transferability

The transferability of tools is evaluated through the transferability score (T), which indicates how easily a tool can be applied in different scenarios. This score is calculated according to *Equation 1*, which combines coefficients related to transferability aspects (*License type*, *Data diversity*, *Data* *volume*, *Data availability*, and *Confidentiality level*). Each transferability aspect is ranked from 0 to 20 based on data properties summarised in *Table 3-2*.

$$T = \mathrm{C}_{Licence\ type} + \mathrm{C}_{Data\ diversity} + \mathrm{C}_{Data\ volume} + \mathrm{C}_{Licence\ type} + \mathrm{C}_{Licence\ type} \qquad \textit{Equation 1}$$

Table 3-2: Coefficient values based on transferability aspects.

Transferability aspect	Definition	Coefficient value
License type	Depends on private software	0
	Does not depend on private software	20
Data diversity	More than 20 data files and formats are involved	0
	Up to 10 data files and formats are involved	10
	Up to 5 data files and formats are involved	20
Data volume	Above a terabyte	0
	Below a terabyte	10
	Below a gigabyte	20
Data availability	Data is private and difficult to obtain	0
	Data is private and easy to obtain Data is public and difficult to obtain	10
	Data is public and easy to obtain	20
Confidentiality level	Involves private-governmental information	0
	Involves public information	20

The transferability of each tool is categorised based on its transferability score. Tools are grouped into three distinct categories: **Low Transferability** (0–50), **Moderate Transferability** (51–70), and **High Transferability** (71–100). Tools with High Transferability, indicating strong potential for application across various contexts. Those falling into the Moderate Transferability range demonstrate some adaptability but may be more limited in scope. Finally, tools from the Low Transferability category, reflecting minimal potential for practical use beyond their original context.

Table 3-3: Transferability categorisation based on transferability score.

Low Transferability	Moderate Transferability	High Transferability
0 – 50	51 – 70	71 - 100

3.2 Transferability analysis of tools

Natural hazard map – Role 1

The *Natural Hazard Map* tool is designed to predict areas at risk of disruptive events through the development of fire risk maps (using QGIS), fire spread simulations (using the Flammap software), as well as extreme wind and rainfall prediction maps based on satellite imagery and weather data. The tool requires access to satellite and meteorological data related to forest fires, wind, and rain events in the studied areas.

To simulate fire spreading, geospatial layer data are required, including elevation, slope, aspect, fuel models, and canopy models. Higher accuracy can be achieved optionally by including layer data covering stand height, canopy base height, and canopy bulk density. This data for the North American region is available on Flammap; however, for other countries, this data must be acquired and manually uploaded to the software.

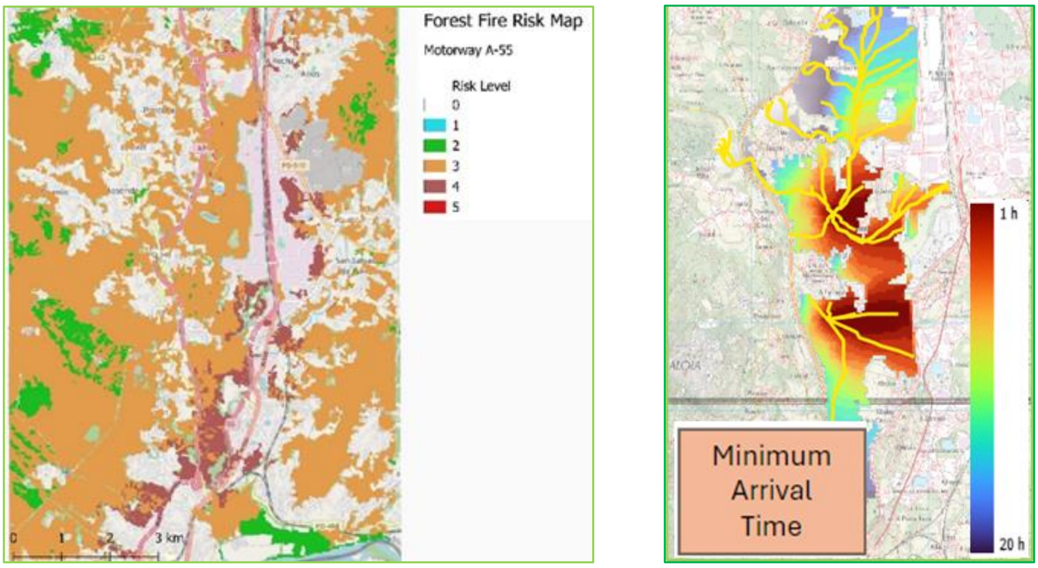

Figure 3-1: Demonstration of the Natural hazard map tool: forest fire risk map (left) and fire spread map (right).

The transferability of the *Natural Hazard Map* tool regarding the used software is guaranteed, as it utilises open-source QGIS and Flammap software. Data diversity is not so extensive that it compromises its transferability. On the other hand, data volume only relies on the geographical extent that the user defines for analysis. **Data availability** and **confidentiality** can be limiting factors, to a lesser extent within regions in a country, but more significantly when several countries are being studied, even within the EU. Consequently, the *License type, Data diversity, Data volume, Data availability,* and *Confidentiality level* parameters are set to 20, 10, 20, 10, and 20, respectively, providing a transferability score of 80, indicating high transferability.

Traffic simulation – Role 1

The *traffic simulation* tool is a framework to assess the impact of disruptive events on transportation. The tool consists of three components, shown in *Figure 3-2*. The first component, the Hazard translator, see *Figure 3-3*, is a GIS-based software that translates hazard occurrences, e.g. fire and flooding, into transportation disruptions, i.e. speed reductions or complete closure of routes. This data is used in the second component, the open-source software *Simulation of Urban Mobility* (SUMO), to simulate network behaviour including congestion, queuing, delays, and vehicle rerouting. The last component involves analysing the results by evaluating the impact caused by disruptions (including hazard events) and assessing the network's resilience.

The transferability of the Hazard translator in this tool is high due to its open-source development in Python and use of standard GIS libraries, which makes it easier to adapt to other contexts. Since the Python script is provided to translate hazard impacts into traffic disruptions, its logic depends on the type of hazard being modelled. Although it requires georeferenced hazard data and a spatial traffic network as input, these are typically available or can be prepared for most regions. The structure of the translator is flexible, allowing users to define their own hazard-impact rules, which facilitates its application in different geographic settings.

SUMO's transferability is supported by its open-source nature, which allows for modification and deployment without licensing restrictions. It requires specific input data, including network layout, lane counts, speed limits, road capacity, and origin-destination matrices. While access to traffic control data improves accuracy, SUMO can generate these inputs if they are unavailable, thereby enhancing adaptability in data-limited environments.

In conclusion, the transferability of the *Traffic simulation* tool is high, as it utilises open-source software and is limited by the aspects the user intends to examine. Its applicability is limited only to data acquisition. Consequently, the *License type*, *Data diversity*, *Data volume*, *Data availability*, and *Confidentiality level* parameters are set to 20, 10, 10, 10, and 20, respectively, providing a transferability score of 70, indicating moderate transferability.

Figure 3-2: Traffic simulation tool framework.

Figure 3-3: Hazard translator tool framework.

Scour monitoring for decision support – Role 1

The *Scour monitoring for decision support* tool is designed for emergency management of bridge networks impacted by flood events. It is used to infer and update the scour depth at bridge piers in real-time, thereby updating the structural reliability of the bridges. It then integrates this data with analyses of both direct and indirect costs associated with all possible management alternatives to compute the risk for each alternative. *Figure 3-4* illustrates the workflow of the tool.

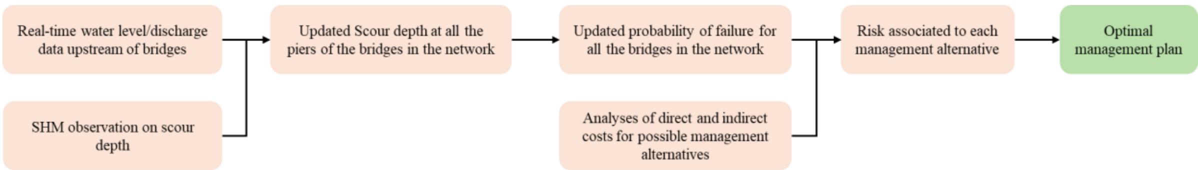

Figure 3-4: Scour monitoring for decision support workflow.

The flow discharge (or water level) and the scour depth are computed using Monte Carlo Simulation (MCS). Estimating the flow discharge (or water level) requires knowledge of Manning's coefficient, the river's width and slope, and the upstream water level (or discharge) upstream of the bridge. To estimate scour depth, it is necessary to know the pier width, the mean flow velocity upstream of the pier, and correction factors that account for the pier nose shape, the flow's angle of attack, and the bed conditions.

The scour depth model, along with its corresponding estimates, is updated using observations from Structural health monitoring (SHM) sensors installed on one of the piers in the network. This updating process is carried out using Bayes' theorem. [2]

The probability of failure is then defined through a limit state function, which considers the difference between the estimated scour depth at the bridge pier and the depth of the pier's foundation. Each infrastructure in a network exhibits a specific state depending on the flood event. This state reflects the component's condition or level of functionality. Based on these states and the indirect utility contribution due to network-wide effects, global utility (risk) is computed for a given strategy.

Following the Principle of Maximum Utility, the optimal management strategy is the one that maximises the total expected utility.

Since the framework is model-driven rather than site-specific, it can be applied to any bridge infrastructure, with adjustments made according to the specific characteristics of the bridge. Its successful application primarily depends on the availability of relevant input data. Additionally, any bridge can be equipped with SHM sensors to supply real-time information on its structural condition, further enhancing the tool's effectiveness. Consequently, the *License type*, *Data diversity*, *Data volume*, *Data availability*, and *Confidentiality level* parameters are set to 20, 10, 20, 10, and 20, respectively, providing a transferability score of 80, indicating high transferability.

Vulnerability and traffic tool – Role 1 and Role 3

The *Vulnerability and traffic tool* is used to analyse the risk and resilience of transport infrastructures and networks. It comprises a primary vulnerability assessment of the assets (e.g. bridges), a traffic simulation of the network, and a resilience assessment, as illustrated in *Figure 3-5*.

Figure 3-5: Vulnerability and traffic tool workflow.

To use the tool, hazard data is required, as well as structural data of the analysed infrastructures. This data must include the location, as well as the geometrical and mechanical parameters of the assets. Critical assets within the network are identified based on hazard and structural data. These critical assets are then used to represent disruption events, enabling adjustments to the traffic capacity of routes.

The tool incorporates a traffic module to evaluate the impact of disruptions on transport networks. This step requires shapefiles containing the traffic network layout and traffic distribution (expressed in Average Daily Traffic (ADT)). The traffic module consists of the software "TRANSCAD", which is not open-source and requires a private licence for use.

The resilience assessment involves a set of equations used to compare traffic simulation results, which do not depend on the input data.

The simple transferability of the *Vulnerability and traffic tool* is not guaranteed due to the cost of the private-source TRANSCAD software. From a data diversity perspective, its applicability is limited due to nontrivial data acquisition. In addition, data availability might be complicated as specific network data is required, and some might interfere with confidentiality (but not necessarily have to). The volume of data is not a concern, as the selected size and scope of the study area determine it. However, larger areas might increase problems regarding data availability and confidentiality. Consequently, the *License type*, *Data diversity*, *Data volume*, *Data availability*, and *Confidentiality level* parameters are set to 0, 10, 20, 10, and 20, providing a transferability score of 20, which indicates low transferability.

Route attributes (Energy module) – Role 3

The *Energy module* tool calculates vehicle fuel consumption and emissions along a specified route. This tool can be accessed through an API or a web interface. Input data, including origin, destination, and vehicle type, is needed to estimate fuel consumption. Although the tool offers pre-defined vehicle types such as "private vehicle" and "large goods vehicles", the user can customise their vehicles by providing physical characteristics, powertrain configuration, and fuel type. Other information, such as driving style, can be specified by the user or set as a default by the tool.

The tool covers Europe´s network data (i.e., infrastructure coordinates, speed limits, road width, and number of lanes, as well as infrastructure restrictions for transport modes or goods types) from OpenStreetMaps (OSM). However, this can be expanded to other regions as OSM is an open-source database. The tool sets route choice via the *Route planning* tool, which is currently based on the shortest travel time.

The transferability of the *Energy module* tool is high, as it only requires setting the origin, destination, and vehicle type. The tool allows optional efficacy enhancement by users customising vehicles, providing network data, and defining route choice. However, this information is not a requirement.

Consequently, the *License type*, *Data diversity*, *Data volume*, *Data availability*, and *Confidentiality level* parameters are set to 20, 10, 20, 10, and 20, providing a transferability score of 80, indicating high transferability.

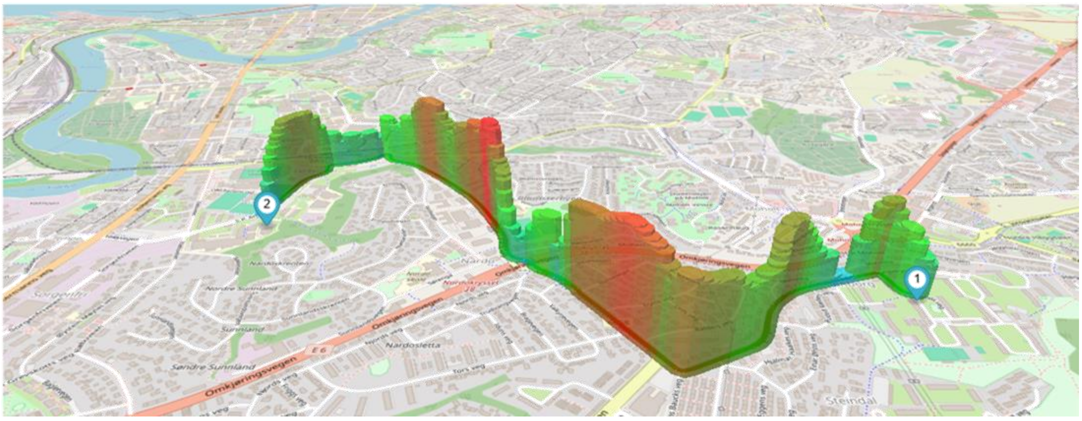

Figure 3-6: Demonstration of the Route attribute tool applicability.

Route planning – Role 3

The *Route planning* tool estimates the best route between coordinates based on the Open-Source Routing Machine (OSRM). Currently, it estimates the route based on minimum travel time. However, the tool offers alternative approaches for route estimation, incorporating considerations of resilience and sustainability.

This tool utilises data from OpenStreetMap (OSM) and can be accessed through its API or web interface. Therefore, the transferability of the *Route planning* tool is guaranteed as it only requires setting the origin and destination coordinates. Consequently, the *License type, Data diversity*, *Data volume*, *Data availability*, and *Confidentiality level* parameters are set to 20, 10, 20, 10, and 20, providing a transferability score of 80, indicating high transferability.

Transport simulations (ASTROIT) – Role 2

The *ASTROIT* tool simulates cargo transportation within a network. It models the transloading time in warehouses and changes in transportation modes. Each cargo and good is represented as an agent capable of finding the optimal path from origin to destination based on which type of cost should be minimised, and by using several vehicles and transportation modes.

The tool can be accessed through the ASTROIT app website, where the user needs to define the network, identifies which nodes and edges are disrupted and when, determines the origin-destination of agents, and enters vehicle schedules and properties.

The tool enables the impact evaluation of disruptive events by modifying the network's characteristics (e.g., decreasing capacity at nodes or edges) and assessing the consequences by comparing performance to standard situations. Outputs are then used to identify bottlenecks and determine mitigating measures.

The tool enables resilience assessment by testing various mitigation measures and evaluating their impact on the network's performance.

To use the ASTROIT tool, the coordinates of the nodes and edges of the network must be defined, as well as the sections and vehicles being disrupted. The transferability of the tool regarding **data diversity** is high as attributes are defined in the user interface. The **data volume** aspect of transferability depends on which network the user is analysing and its extent. However, transferability is jeopardised since data such as route schedules, vehicle volume, node capacity, and transloading time are generally **inaccessible**, as logistics companies do not share their data openly due to confidentiality concerns. Still, publicly available information on local transport infrastructure combined with informed estimates of logistics dynamics is sufficient to build an initial model of the network under study, which can later be refined with the company-internal data. Consequently, the *License type*, *Data diversity*, *Data volume*, *Data availability*, and *Confidentiality level* parameters are set to 20, 20, 10, 10, and 20, respectively, providing a transferability score of 80, indicating high transferability.

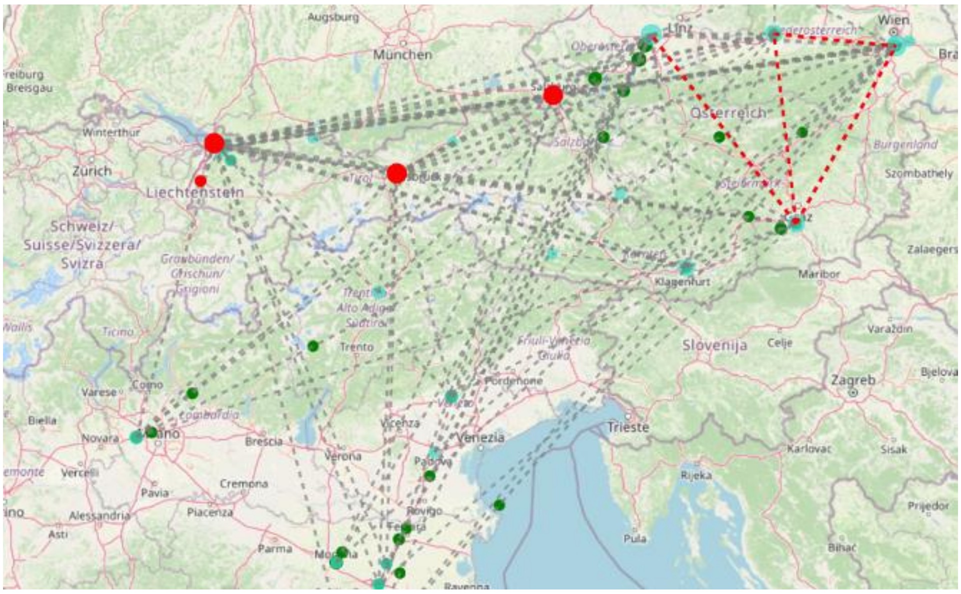

Figure 3-7: Example of a simulated transportation network displayed in the ASTROIT-app between Austria and Italy with impacted nodes and edges in red.

Disruption information interface –Role 3

The *Disruption information interface* tool is used for collecting and displaying information about disruptions in road, rail, and maritime transport modes. Records are obtained by scraping data received from local authorities responsible for traffic disruption information, as well as websites providing disruption data. Moreover, users can request the inclusion of additional disruption data.

The tool provides the location of the disruption or hazard, its type, description, and estimated end time. The tool's accuracy is improved through data verification and the identification of problematic inputs.

The disruption information interface retrieves all information from the internet; therefore, only one data format is used. Additionally, it does not use any private source information or software. The transferability of the tool is limited by data availability and volume. It may not function effectively in regions where data transparency is lacking, local authorities do not cooperate, or available data is outdated. Consequently, the *License type, Data diversity, Data volume*, *Data availability*, and *Confidentiality level* parameters are set to 20, 20, 10, 10, and 20, respectively, providing a transferability score of 80, indicating high transferability.

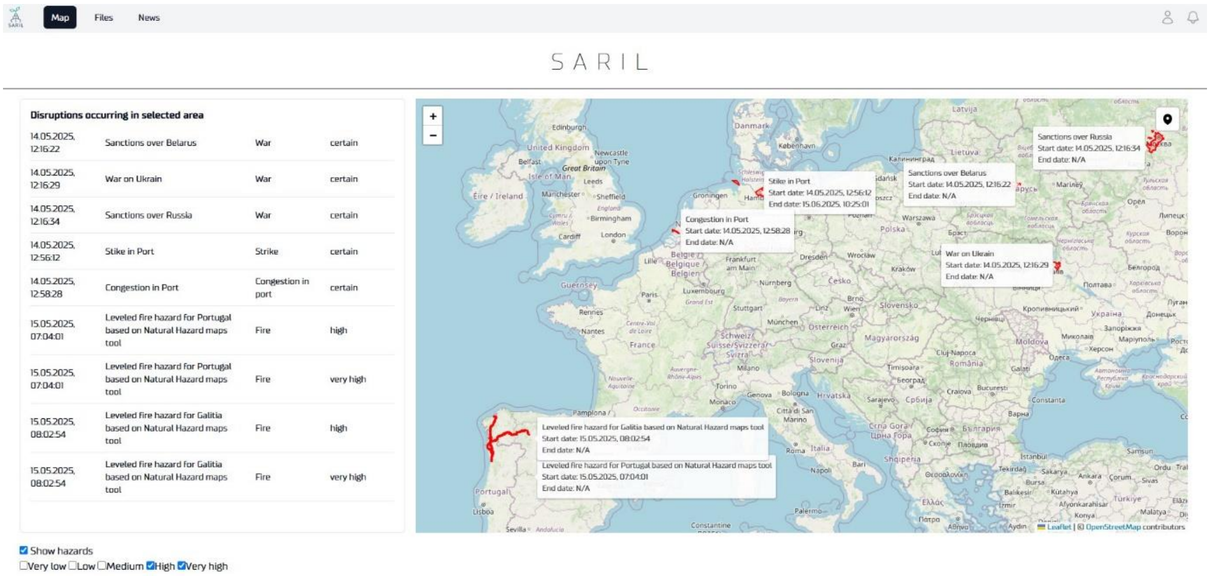

Figure 3-8: Disruption information interface applied in Europe.

3.3 Transferability summary

Tool transferability depends on several aspects, including whether source codes are publicly available, whether different data files are required, and the volume, availability, and confidentiality level of these files. It should be acknowledged that the lack of input data implies an immediate inapplicability of any tool. *Table 3-4* summarises the scoring of each tool where red colours indicate low transferability, blue moderate transferability, and green high transferability.

Table 3-4: Transferability score by tool.

Tool	License type	Data diversity	Data volume	Data availability	Confid. level	Total
Natural hazard map	20	10	20	10	20	80
Traffic simulation	20	10	10	10	20	70
Scour monitoring for decision	20	10	20	10	20	80
Vulnerability and traffic tool	0	10	20	10	20	60
Route attributes (Energy module)	20	10	20	10	20	80
Route planning	20	10	20	10	20	80
Transport simulations (ASTROIT)	20	20	10	10	20	80
Disruption information interface	20	20	10	10	20	80

Table 3-5 summarises the required data for the tool to be applicable and the optional data that enhances its performance.

Table 3-5: Required and optional data for transferability.

Name	Required data	Optional data
Natural hazard map	- Satellite images - Meteorological data	- Meteorological data hazard
Traffic simulation	- Georeferenced hazard data - Layout of the road network - Road lane count, speed limits, and capacity - Origin-Destination matrices	- Traffic control data - Traffic demand temporal variations
Scour monitoring for decision support	- Manning´s coefficient - Width and slope of the channel - Bed condition and sediment gradation - Flow depth and velocity - Pier shape - Depth of the pier's foundation	- Install monitoring devices (for updating data based on measures) - Expected costs caused by a failure (for calculating risk)
Vulnerability and traffic tool	- Localisation and identification of assets - Asset description through geometrical and mechanical parameters - Number of exposed people and goods - Data about the capacity and the service proposed by the asset - Hazard data - Traffic network layout - Traffic distribution	
Route attributes (Energy module)	- Origin and destination coordinates - Vehicle type	- Specific route - Driving style - Vehicles' physical characteristics, powertrain configuration, and fuel type
Route planning	- Origin and destination coordinates	
Transport simulations (ASTROIT)	- Node coordinates - Edge coordinates - Impacted node and edge - Impacted vehicle type on edges	- Node name - Node id - Node capacity - Node transloading time - Edge ID - Edge allowed velocity - Edge vehicle type - Impact curve defining the performance per timestep - Route schedule - Route vehicle type

		- Number of vehicles per route - Agent spawn timestep - Agent origin - Agent destination - Agent weight - Agent volume - Total amount of created agent - Agent routing weights - Agent rerouting reaction time - Vehicle max volume - Vehicle max weight - Vehicle velocity - Vehicle co2 per km - Vehicle cost per km - Vehicle name/type
Disruption information interface	- Data transparency - Accessible local authorities' data - Updated data	- Verification approaches - Identification of problematic inputs

4 Transferability of mitigation measures

A set of mitigation measures to address disruptive events and reduce their effects on the logistic network was presented in D3.3 (2025), as summarised in *Table 4-1*.

This section evaluates the potential of implementing these mitigation measures in other contexts. To achieve this, new scenarios were developed by considering zones with varying configurations in the transportation network, as well as geographical and socio-economic characteristics.

Table 4-1: Mitigation measures implemented in the SARIL scenarios.

Mitigation measure	SARIL Scenario
Scour monitoring for decision support tool	Regional
Mitigation of cyber threats	Regional
Firebreak	National
Forest mass management	National
Early warning digital system	National
Introducing E-trucks	European
Replacing trucks with trains	European
Higher percentage of deliveries which can shift to another mode	European

4.1 Characterisation of new scenarios

To better understand how different socio-economic conditions influence the capacity to respond to unforeseen disruptions, new 3 scenarios with contrasting characteristics have been selected. The choice seeks to represent a wide range of contexts: from regions with high institutional fragility and dependence on basic resources, to countries with consolidated structures but exposed to new vulnerabilities. In this way, the aim is to analyse not only the differences in risk management, but also how logistical, economic, and social factors shape the resilience of each territory.

- **Regional Scenario_Sussundenga (Manica, Mozambique)** illustrates extreme dependence on subsistence agriculture and natural resources, where any environmental disruption directly threatens food security and social stability, with cross-border effects due to its location near Zimbabwe.
- **National Scenario_ Greece–Bulgaria cross-border** case represents an intermediate situation within the EU: two peripheral economies with constrained resources that must coordinate in shared territories, where disruptions affect strategic sectors like tourism, agriculture, and regional mobility.
- **International Scenario_Serbia–Germany** highlights contrast between a transition economy with limited institutional capacity and a highly developed country with strong systems, yet increasingly vulnerable to climate change and rigid production models.

4.1.1 Regional: Sussundenga, Manica (Mozambique)

An analogous **Regional Scenario** has been derived in the district of Sussundenga in Manica, Mozambique, whose location is illustrated in *Figure 4-1*. In this context, a single road connects Assicante and Sussundenga with Chimoio, the capital of Manica. Adjacent paths are mainly dirt roads, which become difficult or impassable during rainy seasons. Local transport consists of 4WDs, bicycles, motorbikes, and animal carts, as the region lacks a railway line.

Local life is organised by community structures led by traditional authorities, where economic growth is constrained due to limited access to credit, technology and broader markets. [3]

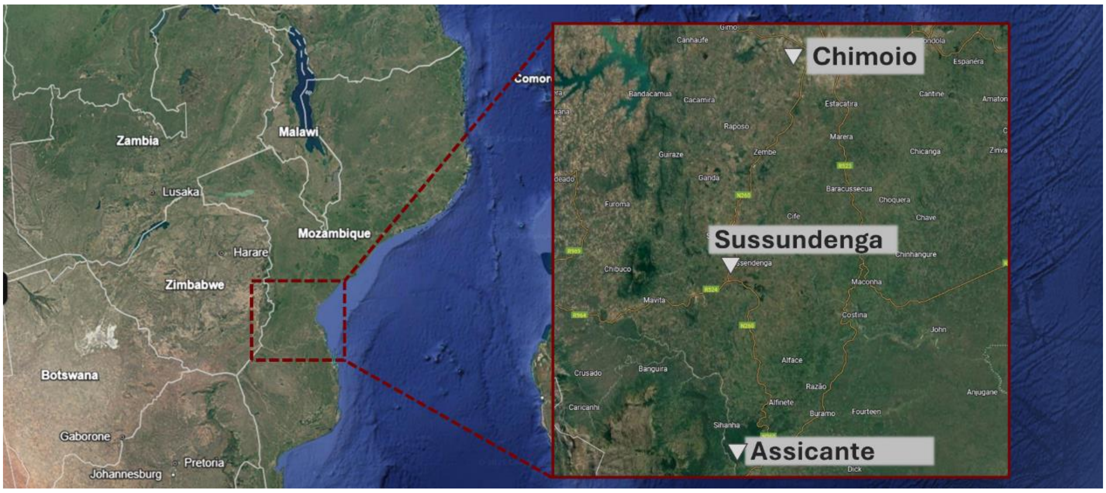

Figure 4-1: Location of the Sussundenga district.

Figure 4-2 illustrates the analysed infrastructures in the region, which have been observed on the maps, including [4]:

- Dirt tracks and communal roads.
- **N260,** which connects Assicante and Chimoio through Sussundenga.
- **Bridge over the Revue River** on the **N260** above Sussundenga.
- **Bridge** on the **N260** below Sussundenga.
- **EN6** running east-west across the country from the port of Beira to Chimoio and Machipanda.
- **R524** connecting Sussundenga to the vicinity of the Chimanimani nature park.

The Sussundenga landscape comprises farmland, grasslands and extensive miombo forests. It borders the Chimanimani National Park, which, although bringing ecological value, creates tensions between conservative and traditional approaches since the area between Assicante and Sussundenga is categorised with a high conservation value (shown in light red) [5]. The climate combines a long dry season, which heightens fire and drought risk, with heavy rains that cause erosion and damage infrastructure.

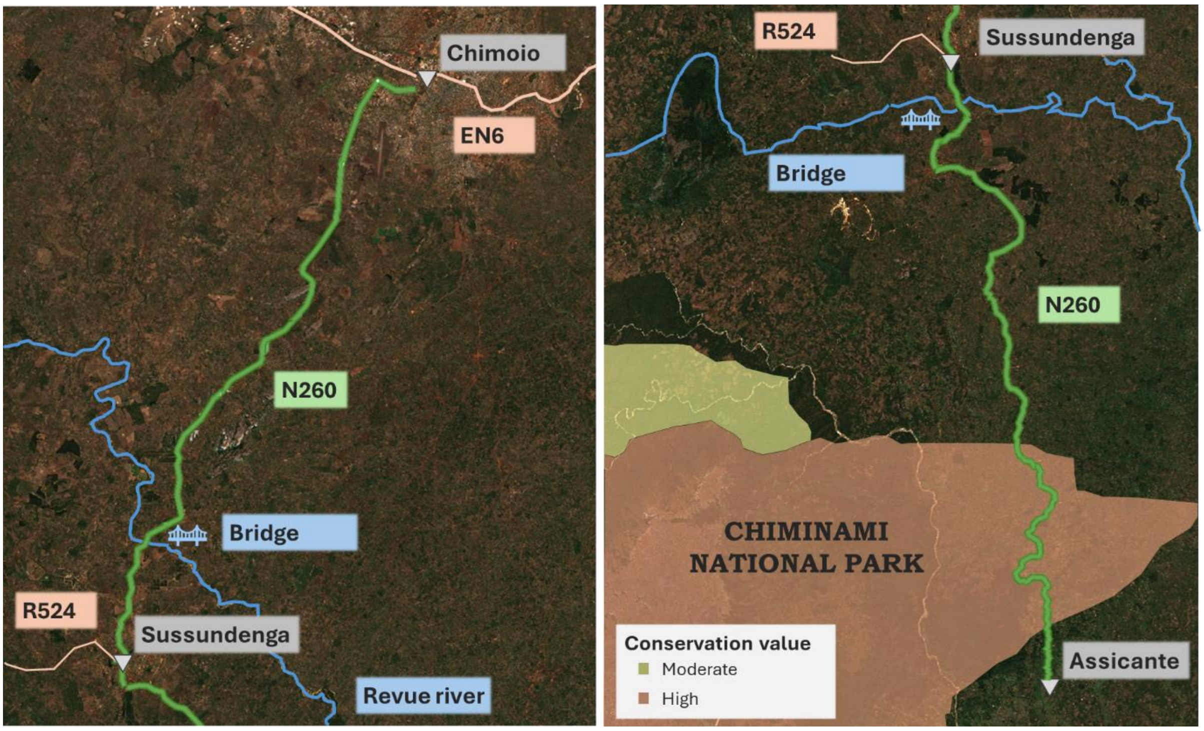

Figure 4-2: Main infrastructures within Sussundenga and Chimoio (left) and Assicante (right) [4].

4.1.2 National: Bulgaria – Greece (coastal countries)

The new **National scenario** covers the region between Greece and Bulgaria, a strategic axis connecting the Aegean Sea with central and northern Europe. These countries are linked by the **Baltic Sea-Black Sea-Aegean Sea Corridor (BBA Corridor)**, see *Figure 4-3*, a European corridor comprising railways, roads, highways, airports, seaports, and multimodal terminals.

Bulgaria and Greece are two cross-border EU countries that, despite their strategic role, face limitations in certain road sections and significant congestion at the Kulata/Promachonas border crossing. Compared to other European countries, their railway infrastructure, digitalization processes, and integrated customs management systems are less developed, which affects their logistical competitiveness. These weaknesses are further compounded by the additional pressure of the war in Ukraine, which is diverting greater volumes of traffic towards this corridor. [6]

In this context, Greece acts as a maritime gateway through Piraeus and Thessaloniki. Bulgaria then ensures the connection to Romania, Hungary, Slovakia, Poland, Lithuania, Latvia, and Estonia, facilitating the transit of goods along the European axis. Main infrastructures observed in the map in the scenario include [7]:

- **Motorway E79 / Struma Corridor (TEN-T):** axis connecting Sofia (Bulgaria) and Thessaloniki (Greece) through Blagoevgrad and Sandanski in Bulgaria.
- Several **bridges** throughout the Motorway E79.
- **Thessaloniki-Kulata-Sofia** Railway Line.
- **Port of Thessaloniki (Greece):** one of the main ports in Northern Greece.
- **Egnatia Odos (A2) motorway** that runs through northern Greece from west to east, connecting the port of Igoumenitsa and Turkey.

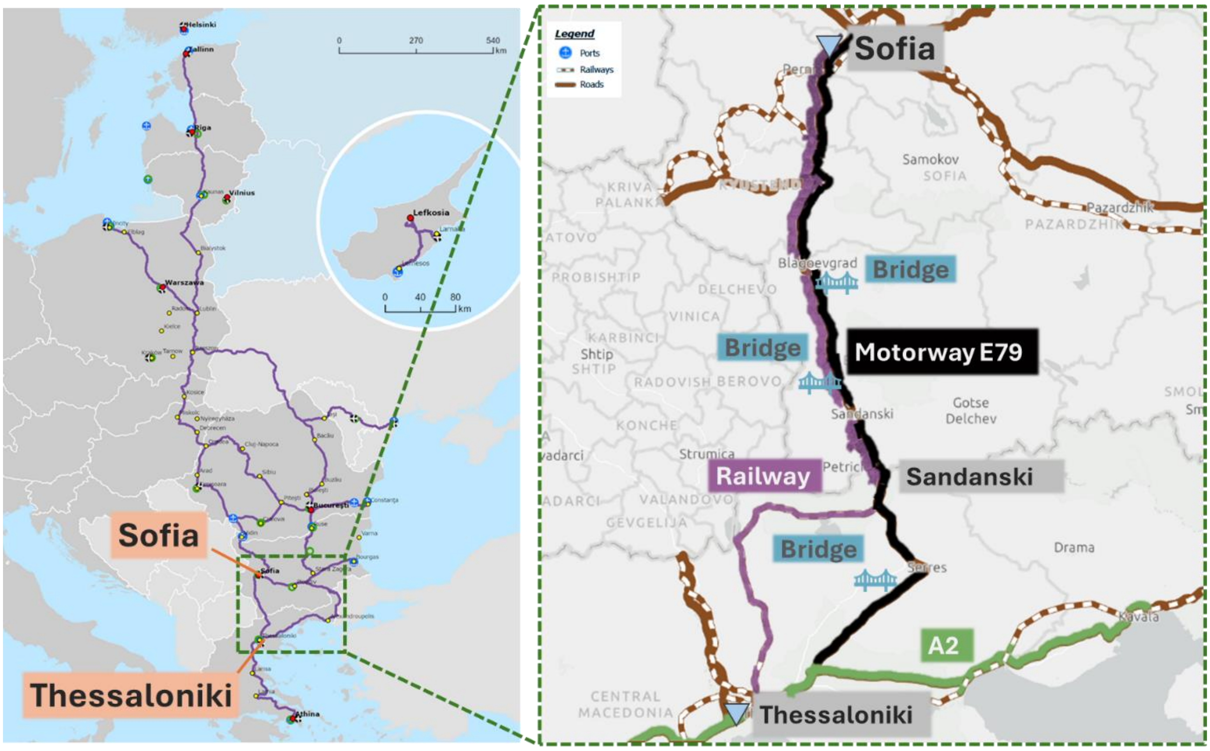

Figure 4-3: Main infrastructures considered in the National scenario [7].

4.1.3 International: Serbia (non-EU) - Germany

The new **International scenario**, see *Figure 4-4*, considers the European **Rhine-Danube Corridor (blue)**, which combines river and rail routes along the Danube, and the **Western Balkans/Eastern-Mediterranean Corridor (brown)**, which links Serbia with Austria and Hungary.

Serbia, located at the heart of the Balkans, is an EU candidate country that depends on land corridors and the Danube River for access to seaports. Germany is one of Serbia's main trading partners, exporting machinery, automobiles and chemicals, and importing mainly agricultural materials and light manufactures. Most of its exports/imports to Germany enter or leave via ports on the Adriatic (Koper, Rijeka) or the Mediterranean (Thessaloniki, Piraeus) and continue by road or rail. The main domestic distribution centres are in Belgrade and Novi Sad, Serbia, and the main destinations for goods from the Balkans are Munich, Nuremberg, and Stuttgart. [8]

This scenario faces challenges stemming from Serbia being a non-EU member country, which implies additional customs controls, specific regulatory differences, and an infrastructure that is still being modernised to fully comply with European standards. These factors can lead to delays and additional costs in the transit of goods. [8]

Main infrastructures observed in this international scenario include:

- **Western Balkans/Eastern-Mediterranean Corridor (brown colour):** E75 Motorway connecting Thessaloniki, Skopje, Niš, and Belgrade.
- **Rhine-Danube Corridor (blue colour):** Comprising the E75 Motorway that connects Belgrade and Budapest, passing through Hungary at Horgoš / Röszke, and the E60 Motorway, which links Budapest with the German network (A1/A8 motorway via Vienna, Salzburg and Munich).

- **RFC10 rail Corridor Alpine western Balkan:** Rail corridor connecting Sofia and Salzburg, see *Figure 4-5*.
- **Rhine-Main-Danube Canal:** Crosses Serbia from east to west and connects Belgrade with Germany, see *Figure 4-6*.

Figure 4-4: Rhine-Danube and Western Balkans/Eastern-Mediterranean Corridor. [7]

Figure 4-5: RFC10 rail Corridor Alpine Western Balkan. [9]

Figure 4-6: Rhine-Danube (only logistic river). [7]

4.2 Transferability analysis of mitigation measures

This section evaluates the transferability of mitigation measures derived in D3.3 (2025) to other contexts especially to the new scenarios derived in *Section 4.1*. *Table 4-3* summarises the considered mitigation measures and for which SARIL roles they are relevant.

Table 4-2: Relevant roles for each mitigation measure.

Mitigation measure	Relevant roles
Implementation of Scour monitoring for decision support tool	R1
Mitigation of cyber threats	R1, R3
Implementation of Firebreak	R1
Implementation of Forest Mass Management	R1
Early warning digital system	R1, R3
Introducing E-trucks	R2, R3
Replacing trucks with trains	R2, R3
Higher percentage of deliveries which can shift to another mode	R2, R3

4.2.1 Implementation of Scour monitoring for decision support tool – Role 1

The *Scour monitoring for decision support* tool helps decision-making processes when the closure of bridges is considered during flooding events. It can be applied to any location since it is constructed on analytical equations. Its performance can be enhanced when SHM sensors or real-time water level and discharge recordings are installed. However, their deployment and installation pose some challenges.

Installing sensors in **remote or rural** bridge sites can be logistically challenging due to poor access, a lack of power supply, and limited technical capacity for installation and maintenance. Similarly, the **geographic spread of river** systems, particularly in mountainous or heavily forested terrain, can make sensor deployment expensive and technically complex.

In **cold regions** where rivers freeze seasonally, sensor hardware may be subject to ice damage or reduced accuracy due to snow cover. Conversely, **tropical areas** with sediment-heavy or debris-laden rivers may face issues with sensor fouling or short lifespans.

Adaptation to the new scenarios

Regional scenario

The *Scour Monitoring for Decision Support Tool* is only partially applicable in the context of the Sussundenga district. While its analytical foundation can be applied without advanced infrastructure, the enhanced version, which relies on real-time data and sensors, is not feasible. This is due to significant limitations in the region, including the lack of reliable electricity, poor access to remote bridge sites, limited technical capacity for sensor installation and maintenance, and inadequate transport infrastructure. As such, only a basic version of the tool could be realistically applied under current conditions.

National scenario

The corridor between Greece and Bulgaria features modern transportation infrastructure, including highways, railways, and bridges. The reliable power supply and technical capacity allow for the installation and maintenance of real-time monitoring systems and sensors. Furthermore, access to bridge sites is generally good, reducing logistical challenges. Therefore, both the basic and sensor-enhanced versions of the tool can be effectively deployed in this context, making the implementation of the *Scour Monitoring for Decision Support Tool* feasible within the alternative National scenario.

International scenario

The effective implementation of the Scour Monitoring for Decision Support tool in the alternative International scenario depends on addressing certain regional constraints. In Serbia, infrastructure modernisation is ongoing, and while this provides opportunities to integrate such monitoring systems during upgrades, limitations in technical capacity and funding could hinder widespread deployment. Moreover, since much of the corridor traverses transboundary and multi-jurisdictional areas, coordination between national authorities would be essential to ensure data compatibility and effective decision-making.

4.2.2 Mitigation of cyber threats – Role 1 and Role 3

This mitigation measure detects cyber threats to ensure the reliability of the outputs of the *Scour monitoring for decision support* tool. The tool analyses historical recordings (training data) to identify trends and define thresholds to trigger threat alarm systems. It can be employed for any dynamic data type, such as water discharge levels or scour depths.

Due to its digital properties, this measure is not limited to any geographical or socio-economic context. However, its performance can be reduced if historical data are incomplete or unreliable, as thresholds will be poorly calibrated.

Considering this, the mitigation measure for detecting cyber threats can be applied to any of the “new scenarios”.

Adaptation to the new scenarios

Regional scenario

The mitigation measure for detecting cyber threats to support the *Scour Monitoring for Decision Support Tool* is theoretically applicable in the context of the Sussundenga district, as it is not restricted by geographical or socio-economic conditions. However, its effectiveness relies heavily on the availability and quality of historical data to accurately calibrate alarm thresholds. Given the likely absence of consistent and reliable historical data in Sussundenga, the performance of this cyber threat detection system would be significantly limited. Therefore, while the measure can technically be applied, its reliability and usefulness in this specific context would be low.

National scenario

The mitigation measure is fully applicable in the alternative National scenario. The region has well-established digital infrastructure, institutional capacity, and access to reliable historical data, enabling accurate system calibration and continuous performance. Additionally, both Greece and Bulgaria have the necessary technological and regulatory frameworks to support cybersecurity measures across their infrastructure systems. As such, this measure can be effectively implemented without significant constraints.

International scenario

Applying the cyber threat detection measure in the alternative International scenario could strengthen the reliability of monitoring systems. Its effectiveness in this context would depend on the availability and quality of historical hydrological and infrastructure data, particularly on the Serbian side, where data records may be less comprehensive or standardised compared to EU member states. Additionally, cross-border data-sharing protocols and cybersecurity frameworks may differ, posing challenges for coordination and integration.

4.2.3 Implementation of Firebreak – Role 1

A forest firebreak is a strip of land, artificially or naturally created, with little or no vegetation, that acts as a barrier to stop or slow the spread of forest fires. Its primary function is to prevent fire from spreading from one area to another, protecting forest areas, properties and communities.

The implementation of forest firebreaks depends on multiple socio-economic and environmental factors that determine their viability, sustainability, and effectiveness. First, **Climate and level of fire risk** are essential determinants: in dry regions with long, hot summers, firebreaks are indispensable and tend to be designed wider and more continuous. In contrast, in temperate and humid climates, the risk of large-scale fires is lower, so firebreaks are more often used to facilitate conservation work or pest control rather than stopping catastrophic fires.

The **structure of the territory** and the settlement pattern have a direct influence: in areas with scattered villages surrounded by forests, the firebreak network needs to be much denser to protect each settlement, significantly increasing costs and planning requirements, whereas in dense peri-urban environments, there is a priority on integrating firebreaks into the landscape and local functions, combining them with parks, trails, and recreational areas.

Economic capacity determines the technical quality of firebreaks (width, continuity, and frequency of clearing) and the ability to utilise specialised machinery. Regions with high budgets can ensure well-designed and maintained firebreaks, whereas in areas with economic constraints, firebreaks tend to be narrower and not maintained as frequently.

The degree of dependence on **agroforestry activities** also positively influences the sustainability of firebreaks when they are integrated into pastures or agricultural lands that are kept clear through their own economic use, thus reducing public expenditure. In contrast, in regions suffering from rural abandonment, keeping these strips open requires direct subsidies or agreements with forestry companies.

Areas with existing **infrastructure**, such as forest tracks, rural roads, and access for machinery, are more prepared to establish and maintain firebreaks. However, costs may increase rapidly in areas with complex terrain or inadequate road networks.

Social perception and cultural acceptance play a critical role: in regions historically affected by wildfires communities generally regard firebreaks as a necessary measure, even if they alter the landscape. In contrast, in areas with a high aesthetic sensitivity or where continuous forest is culturally valued, there may be greater resistance to opening wide strips, requiring participatory processes or designs that minimise visual impact.

Adaptation to the new scenarios

Regional scenario

Firebreaks in the Sussundenga region can be implemented by burning specific sections of the forest. Therefore, this measure should be implemented before the dry season, due to the risk of fire. In the Natural Park surroundings, the measure should be applied under institutional supervision, avoiding the use of forest burning. However, when the administration is not taking responsibility for implementing this measure, it can be carried out through community or voluntary action, where the community decides on the priority areas (e.g., near villages or to protect crops).

In short, the firebreak measure is crucial in these less developed environments, although it would be more effective if implemented in a more integrated and coordinated manner between communities and authorities.

National scenario

In the border area between Greece and Bulgaria (Blagoevgrad region), crossed by the Baltic Sea-Black Sea-Aegean Sea corridor, the implementation of the 'firebreak' measure is common and regularly applied in both countries as a preventive measure against forest fires. The measure is legislated and well-defined in both Greece and Bulgaria and is regularly applied by national and municipal authorities.

The size and maintenance of firebreaks is a key differential factor between Greece and Bulgaria. In Greece, wildfire prevention policies explicitly include the creation and upkeep of firebreaks, supported by heavy machinery and specialised brigades such as EMODE, which increases the efficiency of this measure. In contrast, in Bulgaria the implementation is less efficient due to narrower firebreaks and a stronger dependence on local forestry services and limited resources, even though prevention policies formally provide for vegetation clearance and the establishment of firebreaks. [10] [11]

The management of these cross-border zones or protected areas poses a challenge in deploying the measure, as coordination with projects of the same type (Interreg or RED Natura) is necessary to ensure that the implementation of the measure is effective.

International scenario

Firebreaks can only be implemented individually in each country. The implementation in Serbia depends on the resources allocated. Serbia has potential need for application due to its drier climate and the fact that this country is still heavily dependent on traditional practices such as burning **[12]**.

Although having some barriers, such as a lack of social acceptance (which prefers actions such as preventive forest management), the measure can also be applied in Germany. However, recent climate change and the forecast of extreme heatwaves mean that this measure is gaining social acceptance in Germany, also due to its proven effectiveness. [13]

4.2.4 Implementation of Forest Mass Management – Role 1

Forest management is defined by silviculture, the science and practice of cultivating, caring for, and using forests and woodlands. Silviculture, in the context of forest management for fire prevention, refers to practices and techniques used to modify the structure and composition of forests with the aim of reducing vulnerability to wildfire and improving forest resilience. This is achieved through vegetation manipulation, such as reducing the amount of vegetation fuel, creating discontinuities in the vegetation, and improving the health and vitality of trees.

In order to carry out effective preventive management, it is essential to have continuous monitoring and observation of the forest mass before applying any vegetation control measures. For this purpose, various administrations rely on satellite data, which, combined with the use of different GIS tools, allow the creation of a solid and up-to-date database. This database is crucial for both preventive management and decision-making during emergencies.

Forest management for fire prevention focuses on reducing the amount of combustible material, making it more difficult for fires to spread. This includes techniques such as clearing, pruning, creating firebreaks (discussed above), and using more fire-resistant species. Additionally, it is crucial to maintain a mosaic landscape with open areas that can serve as natural barriers and facilitate access for firefighting equipment.

Preventive silvicultural management varies widely from country to country: instead of pruning and the choice of low-flammable species, prescribed burning and the use of heavy machinery for clearing are employed. In some regions, defence lines and undergrowth clearance are required, but with little regulation on pruning or species selection; in others, clearance in 10-30 m strips and pruning of low trunks are required, encouraging an agroforestry mosaic, but often on a voluntary or subsidised basis. In some places, the mosaic landscape concept, rather than preventive planning based on the use of firebreaks, is implemented through rotational cycles of controlled burning and periodic clearing, as opposed to firebreaks, which offer great flexibility but are highly dependent on local technical and financial capacity.

Adaptation to the new scenarios

Regional scenario

Forest Mass Management is a measure that can be highly effective in the context of Sussundenga, where forest fires, unplanned agricultural expansion and lack of technical forest management increase environmental and social vulnerability. However, although practices such as clearing and a fragmented landscape could facilitate implementation, they cannot be applied for prevention purposes or under a structured approach, as there are no resources or institutional technical support in these underdeveloped areas. [14]

National scenario

In the National scenario, the implementation of the Forest Mass Management measure is feasible due to the increase in extreme forest fires in recent decades, which has been aggravated by climate change and the abandonment of rural areas. Currently, despite the existence of forest plans and specialised bodies in this context, the measure may be more necessary if used for controlling high-risk forest biomass. Measures such as planned clearing, preventive tree pruning, planting more fire-resistant species, and redesigning the landscape with open areas can be implemented in a more systematic and coordinated manner.

Applying this measure in an integrated manner can break the vegetation fuel continuum, facilitating fire control and restoring resilient landscapes. Forest Mass Management is therefore a highly effective measure in this context.

International scenario

In Serbia, where forest fires are less frequent but are increasing due to climate change and rural land abandonment, this measure represents a key preventive tool to reduce the accumulation of hazardous biomass. However, its implementation is very limited, as it depends on further planning, technical training and community participation, especially in mountainous regions and secondary forests. [15]

In Germany, the measure can be applied in an advanced forest management mode, which faces new challenges from droughts, emerging fires and pests associated with water stress. In Germany, the Forest Mass Management measure is essential for evolving existing forest systems, promoting selective pruning practices, introducing more heat-resilient species, and diversifying the forest landscape. In both countries, this measure is effective in fire prevention and as a basis for more sustainable and climate-adapted forests.

4.2.5 Early warning digital system – Role 1 and Role 3

A **Digital Early Warning System (DEWS)** for disruptive events on traffic routes is a system that uses digital technologies to identify and notify about potential hazards or incidents on roadways, with the aim of preventing accidents, minimising delays and improving road safety. This system combines sensors, data analysis, and communication systems to alert drivers, authorities, and other road users about situations such as accidents, adverse weather conditions, traffic jams, roadworks, or the presence of obstacles.

The most important factors for the development of the measure are an adequate **technological infrastructure** (including sensors, communication networks, and data analysis), effective institutional coordination between authorities and services, sustainable financing, social acceptance, adequate training, and a legal framework regulating the use of data and protocols for action. In addition to the above factors, geography, climate, and technological interoperability also play a crucial role. The combination and alignment of these elements are critical to ensuring the system's success and improving road safety through early and effective responses to potential incidents.

Adaptation to the new scenarios

Regional scenario

The use of this digital early warning measure in this Sussundenga scenario is limited and conditioned by existing technological and financial constraints. There is a lack of adequate infrastructure, access to advanced technologies and sufficient financial resources, without which it isn't easy to implement such comprehensive solutions. Additionally, the lack of institutional capacity to manage and maintain these systems in the long term is currently a significant barrier.

National scenario

The implementation of the early-warning measure in Bulgaria is applicable, although the Bulgaria Alert system still requires upgrades to strengthen its digital technology and coverage. In contrast, Greece has developed more consolidated civil-protection alert infrastructures, supported by national investment in public warning channels and emergency management. Both countries operate their own systems but are linked through interoperable European platforms, which enable the exchange of early-warning information across borders. This highlights the need for further intra-EU cooperation and technological investment to ensure joint effectiveness. [16]

International scenario

The early warning system in Serbia's logistics network can be applied, although it is subject to technological capabilities and institutional integration. Serbia has initiated the development of an end-to-end early warning system, focusing on enhancing institutional capacities in disaster risk identification, monitoring, and early warning systems. This project aims to strengthen response and preparedness capacities at national, municipal, and local levels, providing the national disaster risk management coordinating body with the necessary equipment to establish the front-end of the national early warning system. In the area of general risks, it is more viable due to the existing platform and government involvement. [17]

Germany can use this measure because it already employs multiple connected public-warning channels (location-based apps such as NINA (Notfall Informations und Nachrichten App) and

KATWARN (Katastrophen-Warnsystem), planned Cell Broadcast, sirens and media integration, enabling rapid and geographically targeted alerts. Moreover, German research and projects on cooperative perception/in-vehicle advisory warnings and road-safety early-detection (FeGiS and related work) illustrate avenues for vehicle integration and advanced road-risk management. In short, Germany can utilise the measure within a consolidated and specialised model, while Serbia has significant potential for applicability due to its need for support and institutional development. [18]

Both share the same principle of preventive protection, albeit with different levels of technological maturity, sectoral application, and response capacity.

4.2.6 Introducing E-trucks – Role 2 and Role 3

Electric trucks (E-trucks) are freight vehicles that use electric motors, which use influence costs delivery times and Co2 emissions. They offer a sustainable alternative to traditional combustion engines, which run on gasoline or diesel, by reducing emissions and noise pollution. However, their deployment poses infrastructure, economic, and social challenges.

E-trucks require charging infrastructure, as they use electric motors powered by batteries. This infrastructure may be viable in urban environments, as charging facilities can be easily installed and maintained. However, this measure may require a significant investment in rural or sparsely populated regions since the grid infrastructure is less reliable and charging stations may not be installed uniformly (infrastructure gaps). This creates a fragmented logistics system that may complicate operations for firms with extensive **geographic coverage**.

Areas with **extreme temperatures** require higher investments in technological adaptation since battery performance is sensitive to extremely cold or hot climates. Cold climates reduce battery efficiency and range, as energy is diverted for heating systems, while hot climates can strain battery cooling systems and shorten battery life. **Hilly or mountainous regions** also reduce battery range and increase battery drain, posing a challenge for long-haul logistics without adequate charging support.

In **low-income or fragile economies**, implementing E-trucks can be limited by a lack of investment in energy infrastructure, higher operational costs, affordability in terms of upfront costs and the ability to maintain specialised electric fleets.

Adaptation to the new scenarios

Regional scenario

Access to electricity in the new Regional scenario is extremely limited—only about 6.3% [19]. Electricity is largely confined to district headquarters, with only a few health centres and schools powered by solar energy [20]. Given these economic and infrastructural limitations, the introduction of electric trucks (E-trucks) is not currently feasible. A reliable grid would be required to support charging infrastructure, which is currently lacking.

National scenario

The introduction of E-trucks in the National scenario is feasible, given the relatively well-developed infrastructure and stable economic conditions in both Greece and Bulgaria. Urban centres such as Thessaloniki and Sofia are well-suited for the installation of charging infrastructure, and major transport corridors like the Motorway E79 offer strategic opportunities for developing a reliable network of charging stations. While some rural or mountainous areas along the corridor may pose challenges due to terrain and potential gaps in grid coverage, these can be addressed through infrastructure investments. Additionally, the temperate climate in the region mitigates the extremes that typically affect battery performance, further supporting the viability of E-trucks. Overall, with appropriate planning and investment, the deployment of E-trucks is both feasible and aligned with sustainable transportation goals.

International scenario

The deployment of E-trucks in the new International scenario presents a mixed feasibility outlook. On the German side, where infrastructure is advanced and environmental regulations support low-emission transport, E-trucks can be readily integrated into logistics operations, particularly in and around urban hubs like Munich and Stuttgart. However, challenges arise on the Serbian side. Although urban centres like Belgrade and Novi Sad offer potential starting points for E-truck adoption, the broader deployment across Serbia is constrained by uneven grid reliability, infrastructure gaps along key corridors, and limited investment capacity. Additionally, the mountainous and rural terrain in parts of the Western Balkans may reduce battery efficiency and increase logistical complexity for long-haul transport. Overall, the deployment of E-trucks in the International scenario may not be implementable on a short timescale. [21]

4.2.7 Replacing trucks with trains – Role 2 and Role 3

Trains are significantly more fuel-efficient and produce fewer greenhouse gas emissions per ton-mile compared to conventional trucks. Replacing trucks with trains becomes then a sustainability measure for reducing ecological impact. However, some drawbacks need to be highlighted.

Existing rail infrastructure is not designed to handle high-frequency **local cargo distribution** and cannot effectively compete with door-to-door transport, as rail lacks direct access. Trains typically connect large cities, industrial hubs, and ports, not warehouses, farms, or small towns. Therefore, trucks remain essential for the “first and last mile,” especially in urban and peri-urban logistics.

Rail coverage may not align with some supply chains. Therefore, redirecting cargo to rail is only possible when cargo partially shares the **same origin-destination** as the one covered by the rail infrastructure.

Replacing trucks with trains may not be applicable in dynamic delivery networks, which require on-demand responsiveness, operational agility, or real-time adaptability, as rail timetables may be infrequent, inconsistent, and inflexible.

In **less developed regions,** networks may be technically operational but practically unusable. Trains are slow, breakdown-prone, and disconnected from key economic centres, with little possibility of truck-to-train substitution.

This coordination becomes more complex when the network spans several countries, making it challenging to organise and implement, as there is a need to align with local trains.

Adaptation to the new scenarios

Regional scenario

This mitigation measure is not feasible, as there is no railway connection between Sussundenga and Chimoio.

National scenario

Goods transferred from Thessaloniki to Sofia can be transported through motorway and railway, see *Figure 4-3*, as both systems connect ports, cities, and logistics hubs. Consequently, replacing trucks with trains is a viable mitigation measure for this scenario.

Although trains cannot fully replace trucks (especially for first and last mile deliveries or dynamic, time-sensitive logistics), they can significantly reduce truck usage for long-haul freight transport along the corridor. Additionally, the interoperability between Greece and Bulgaria's rail systems, supported by European Union transport policies, facilitates cross-border coordination. Therefore, although complete replacement is not practical, a hybrid rail-truck logistics system is achievable.

International scenario

Limitations arise when implementing this measure due to Serbia's non-EU status, which introduces customs procedures and coordination challenges at border crossings, as well as infrastructure constraints that limit rail's flexibility and reliability. Additionally, the absence of direct rail access to many warehouses or rural production zones means trucks remain necessary for first and last mile deliveries. While complete modal replacement is not practical, a hybrid logistics system using rail for mainline transport and trucks for distribution could offer meaningful environmental and efficiency gains.

4.2.8 Higher percentage of deliveries which can shift to another mode – Role 2 and Role 3

Not all freight can be shifted from one mode of transport to another due to constraints, including cargo type, volume, timing, and packaging format. However, a significant percentage of deliveries, particularly those involving standardised cargo, predictable routes, and non-perishable goods, can be adapted to several modes.

Deliveries involving parcels, packaged goods, or standardised pallets within city boundaries are highly compatible with trucks. Goods transported in containers, bulk commodities, or freight with low urgency (e.g., raw materials, construction materials, or industrial goods) are well-suited for rail. In regions with robust intermodal systems, a significant portion of port-to-city or city-to-city transport can be shifted to rail, particularly when supplemented by trucks for first and last mile deliveries.

However, certain types of cargo cannot be easily shifted between modes of transportation. Shipments requiring **specific temperature** control, **irregular-sized goods**, or very small, **urgent**, or scattered deliveries often rely on trucks for their flexibility. Palletised cargo with non-standard dimensions may not fit within rail containers or be compatible with truck **weight limits**. Additionally, dynamic just-in-time (JIT) supply chains, emergency deliveries, or sectors with highly responsive logistics requirements (e.g., medical supplies or electronics) often require the speed and route adaptability of trucks. Consequently, some deliveries, due to technical, operational, or customer-specific requirements, will remain anchored to conventional trucks for the foreseeable future.

Adaptation to the new scenarios

Regional scenario

Transport modes in the Sussundenga district include four-wheel drive vehicles (4WDs), bicycles, motorbikes, and animal-drawn carts. As a result, this mitigation measure can only be applied within the scope of these existing modes. A higher proportion of deliveries (particularly small-sized and lightweight cargo) can potentially be shifted among these local transport options. However, shifting deliveries to other transport modes such as rail or maritime transport is not possible, as there is no railway or waterway connection between Sussundenga and Chimoio.

National scenario

In the new National scenario, a higher percentage of deliveries can feasibly be shifted to alternative transport modes, particularly rail. The region features intermodal infrastructure, including seaports (e.g., Thessaloniki), a rail network (e.g., the Thessaloniki–Kulata–Sofia line), and roadways (e.g., the Motorway E79). Standardised cargo, such as containers, bulk goods, and industrial materials (commonly transported along this corridor), is well-suited for a modal shift. However, this shift may not be possible across borders due to a lack of infrastructure for this purpose. Therefore, shifts in modes may only be implemented in Thessaloniki and Sofia.

Rail can serve as the backbone for long-haul transport, complemented by trucks for first and last mile deliveries. While certain cargo types (e.g., perishable, urgent, or irregular-sized goods) will still require truck transport due to logistical constraints, the overall infrastructure and freight profile of the region allow for a substantial portion of deliveries to be shifted away from road transport. This measure is therefore both applicable and potentially impactful in reducing emissions and congestion along the corridor.

International scenario

Germany already possesses an intermodal network that integrates rail and road freight, making modal shift a practical option for long-haul transport. Serbia, while still in the process of modernising its infrastructure, offers potential for rail connectivity. However, cross-border modal shift may be constrained by infrastructure discontinuities and border controls from Serbia’s non-EU status. Other constraints may include differing rail standards, which do not characterise this International scenario, but should be considered in others. Additionally, first and last mile logistics in Serbia may still rely heavily on trucks due to less developed rail access in rural or industrial zones. Nevertheless, as Serbia progresses with EU-aligned transport upgrades and intermodal facilities near urban centres like Belgrade and Novi Sad, this measure could become increasingly effective in reducing road freight volumes and improving logistical efficiency across the corridor.

4.3 Transferability summary

Table 4-3 collects the mitigation measures employed in the SARIL scenarios and indicates their potential and inadequacies for transferability. These can be distinguished by:

Highly transferable measures: Mitigation of cyber threats and early warning digital systems show complete transferability across all levels—regional, national, and international. These measures are technology-driven, largely infrastructure-independent, and rely on data-sharing, which can be standardised across borders.

Partially transferable measures: Several measures demonstrate partial international transferability, although they are fully applicable at national and/or regional levels. Scour monitoring for decision support tools, for instance, is highly relevant locally and nationally where consistent infrastructure conditions and management authorities exist. However, its international applicability is limited by the variability in river systems, infrastructure standards, and data availability. Forest mass management, replacing trucks with trains, and increasing the share of deliveries shifting to other modes also show partial international transferability.

National-only measures: Some measures, such as introducing E-trucks, are transferable solely at the national level. This is primarily due to differences in infrastructure readiness (e.g., charging networks), regulatory frameworks, and vehicle standards, which vary significantly across borders. At the regional level, such technologies may lack economic viability or adequate infrastructure support, while international implementation faces challenges related to cross-border compatibility, emissions regulations, and supply chain management.

Regionally Constrained Measures: Forest mass management and the three transport-related measures (E-trucks, train substitution, and modal shift in deliveries) show no regional transferability. This suggests that at smaller scales, either the economies of scale, administrative capacity, or infrastructure do not support the effectiveness of these measures.

In conclusion, while digital and cyber-based solutions exhibit the greatest flexibility across all scales, infrastructure-heavy and land-management measures face increasing complexity and diminished feasibility as the scope expands from local to international levels. Successful implementation, therefore, depends not only on the intrinsic qualities of each measure but also on governance structures, institutional cooperation, and the harmonisation of technical standards. The effectiveness of these measures is also influenced by the economic conditions of the region where they are applied, see *Table 4-4*.

Table 4-3: Potential and inadequacies for transferability of tools.

Mitigation measure	Regional	National	International
Scour monitoring for decision support tool	Yes	Yes	Partially
Mitigation of cyber threats	Yes	Yes	Yes
Firebreak	Yes	yes	Partially
Forest mass management	No	Yes	Partially
Early warning digital system	Yes	Yes	Partially
Introducing E-trucks	No	Yes	No
Replacing trucks with trains	No	Yes	Partially
Higher percentage of deliveries which can shift to another mode	No	Yes	Partially

Table 4-4: Potential and inadequacies for transferability of tools.

Mitigation measure	Developing	Developed
Scour monitoring for decision support tool	No	Yes
Mitigation of cyber threats	Yes	Yes
Firebreak	Yes	Yes
Forest mass management	No	Yes
Early warning digital system	Yes	Yes
Introducing E-trucks	No	Yes
Replacing trucks with trains	Partially	Yes
Higher percentage of deliveries which can shift to another mode	Partially	Yes

Conclusions

This deliverable analysed the transferability capacity of the SARIL General Methodology, the Green resilience tools, and the mitigation measures developed in D3.3 to other socio-economic contexts.

The transferability of the SARIL General Methodology for Green Resilience Assessment is high as it is not restricted to any geographical area, network, or hazard. Its implementation depends on the availability of software and programs to model traffic, skills in employing them, knowledge of network data, and which aspects the user intends to examine in terms of resilience and sustainability.

The transferability of the green resilience tools was analysed considering several factors, such as the license type needed to use it, the diversity of data, its volume and availability, and whether it contains confidential information. A transferability score was given to each tool, where 0 indicated low transferability and 100 indicated high transferability.

The Transport Simulations (ASTROIT), the Natural Hazard Map, Scour Monitoring for Decision Support, Route Attributes (Energy Module), the Disruption Information Interface and Route Planning each scored 80, showing strong potential for adaptation in various settings with moderate adjustments. Traffic Simulation and the Vulnerability and Traffic Tool and scored 70 and 60, suggesting moderate transferability—useful in multiple contexts but potentially reliant on local infrastructure or data.

A series of mitigation measures were proposed in D3.3 to address disruptive events and minimise their impact on the logistics network. The transferability of these measures was analysed in various contexts by developing new scenarios that reflect different transportation network configurations, as well as diverse geographical and socio-economic conditions.

The new Regional Scenario was in the district of Sussundenga in Manica, Mozambique. The new National scenario covered the region between Greece and Bulgaria, linked by the Baltic Sea-Black Sea-Aegean Sea Corridor (BBA Corridor). The new International scenario comprised the European Rhine-Danube Corridor and the Western Balkans/Eastern-Mediterranean Corridor.

The transferability analysis revealed distinct patterns of applicability and scalability. Measures such as cyber threat mitigation and early warning digital systems demonstrate high transferability, being feasible and effective at all three levels. Scour monitoring for decision support tools and firebreaks are transferable regionally and nationally, but only partially at the international scale, mostly due to differing environmental and infrastructural contexts. Forest mass management, replacing trucks with trains, and promoting modal shifts in freight delivery exhibit limited regional applicability but gain relevance nationally and partially internationally, reflecting the need for broader policy frameworks and cross-border coordination. Meanwhile, the introduction of E-trucks is limited to the national level, indicating technological or regulatory barriers at both regional and international scales. This analysis highlights the importance of aligning mitigation strategies with the appropriate scale to ensure effective implementation and impact.

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