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Sustainability And Resilience For Infrastructure And Logistic Networks

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Abstract

Worldwide fright transportation has faced major unprecedented disruptions in recent years (pandemic, block of the Suez Canal, war in Ukraine), while climate change increases the occurrence rate of extreme weather events such as flood and wildfires. In order to address these challenges, a research plan is presented towards a holistic approach for green and resilient freight transport networks, which are quickly adaptable to diverse disruptive scenarios while minimizing the ecological costs. This includes the design of three operational environments (scenarios) different in geographical scale and focus. Their assessment aims to develop a methodology for green resilience logistics management. A final goal of the presented project are recommendations for business models, infrastructure developers, providers shippers and logistics operators. This work presents the identified gaps in the fright transportation and logistics network towards green resilience, which the project aims to close. The applied methodology such as stakeholder involvement and identification of key performance indicators relevant for a resilient and sustainable logistics network will be briefly described. Furthermore, an overview of the to be used support tools is given. Overall, this paper presents the planned work within the project SARIL funded by the European Commission.

Keywords: sustainability, resilience, multi-modal, fright transport, logistic networks

1. Introduction

In recent years the worldwide freight transportation was under huge pressure due to several huge and unprecedented events. The Covid-19 pandemic, the block of the Suez Canal in 2021 and the war in Ukraine following 2022 and lasting until now have resulted in disruptions of the international logistics network felt

worldwide (March et al., 2021). Furthermore, extreme weather events such as floods and wildfires pressured the logistic network and their occurrence frequency is expected to increase due to climate change (Nova, 2022). Especially sensitive to such disruptions are "just-in-time" supply chains. The vulnerability they portray also effects the delivery of critical goods such as medication and food. To maintain the continuity of critical societal operations and to support economic stability, it is absolutely necessary to increase the resilience and sustainability of the transportation network.

The project SARIL (Sustainability And Resilience for Infrastructure and Logistics networks) aims to address these challenges. The consortium consists of 15 partners from Belgium, Italy, Spain, Portugal, Norway, Poland, Germany, and Austria. The project is funded by the European Commission under the call 'HORIZON-CL5-2022-D6-02-07' over a duration of three years starting in June 2023. The scope of the project is to develop a roadmap towards a holistic approach for green and resilient freight transport networks, which are quickly adaptable to diverse disruptive scenarios while minimizing the ecological costs.

Eventually this approach should enable logistic stakeholders and infrastructure managers to assess the resilience of logistic networks and make the right decisions when moving cargo. The sustainability of a selected solution will also be accounted for, e.g. when expanding infrastructure or choosing a transportation mode.

Synchro-modal solutions in freight transportation, for example, can minimize the impact of transportation network disruptions. However, to account for sustainability, the redirection of cargo flows should follow the principles described in (ALICE, 2019).

The final result of the development sketched in this paper is a methodology for a "resilient, green logistics management", a combination of resilient and green logistics management capabilities.

For that, three operational environments (scenarios) will be designed, different in geographical scale and focus. A set of relevant and observable key performance indicators (KPIs) will be identified from past works and new findings during the development (Smart Fright Centre, 2023). Available simulation models and tools are then adapted to the scenarios to analyze the effects of disruptions and the effectiveness of adaptation and mitigation measures.

Finally, recommendations will be given

- for business models, balancing cost-efficient, green and resilient operations;
- for regulatory measures, that make green solutions more attractive;
- to achieve 'resilience by design', both regarding infrastructure and logistics operations.

A strong stakeholder engagement throughout the whole development process ensures the relevance and applicability of the final methodology and delivers the necessary information for the scenario design and model development.

This paper is structured as follows: First, in Chapter 2 the project concept of SARIL and the collaboration with the sister project ReMuNet [https://remunet-project.eu/] is presented. Chapter 3 describes the methodology and implementation of the work. Finally, in Chapter 4 conclusion and outlook are provided.

2. Project Goals

The overall aim is to develop a holistic approach to green resilience management. The resulting methodologies and tool should enable industrial stakeholders and policymakers to maximize the resilience and sustainability of the freight transport network and logistic operations.

2.1. Current gaps and project goals

In the context of the most recent hazards, the logistics sector had to face, we identified the following shortcomings that need to be addressed if we want to improve the system's resilience and be better prepared for future hazards:

- End-to-end services, which are very common in the logistic sector, are not too flexible when they are faced with a sudden change of conditions. Logistics operators usually don't perceive the effects such disruption will have on their operations. Instead, significant efforts are undertaken to deal with the deviations;
- Real-time data on infrastructure conditions as well as early warnings on possible disruptions is currently barely available or insufficient. Information as early and as comprehensive as possible would support the decision-making of logistics operators and other stakeholders (Tubaldi. et al., 2022);
- Logistic operations are increasingly dependent on reliable real-time information. This enhances the risks cyber-attacks pose on logistic networks;
- Sustainability and resilience in logistics are so far considered independently. To achieve a sustainable and resilient logistic network these considerations need to be joined;

- Currently the resilience analysis is not performed for multiple interconnected systems of different scale in a quantitative manner. A holistic approach would be beneficial for improving the performance regarding both long-term and short-term disruptions.

To address the listed shortcomings and archive a green and resilient logistic freight transportation system, the following steps will be taken (aspects will be discussed):

- A holistic concept of the European transportation network will be developed, which visualises disruptions and their consequences. It reaches over different regions and scales from European to a local level and includes different modes of operation. In this context three scenarios of different geographical scales and with a different focus on operation modes are designed and investigated. A close exchange with relevant stakeholders ensures the applicability of the results;
- Another important step is to develop a "green resilience" management methodology, which makes it possible to increase the resilience and sustainability of the European fright transportation and logistics network. Resilience and sustainability will be quantified with the help of a "green resilience" metric, where key performance indicators (KPIs) are identified for the different scales and modes in the logistic network;
- Under the premise of the "green resilience" metric, simulations are used for different elements of the network to identify the mitigation measures, which will show the biggest effect in case of different types of current and future disruptions. The investigated measures include the implementation of synchro-modal approaches in freight transportation, structural monitoring, forecast and early detection abilities as well as an increase in cyber security, which aim at a resilient-by-design solution;
- The conduction of the "green resilience" management will result in green business models and recommendations, that balance green, resilient and economic demands.

2.2. Concept for developing a green resilience management in freight transportation

The overall concept to develop a holistic approach to green resilience management and its dissemination is depicted in Figure 1.

Three scenarios will be set up and investigated regarding disruptions, their effects and mitigation possibilities. The setup of the scenarios is done in close cooperation with relevant logistics and transportation network stakeholders for the specific scenario. In general, a strong stakeholder involvement planned throughout the whole development to ensure realistic and relevant results.

Each scenario covers a different geographical area, scale and threat type, to ensure a comprehensive picture of the European freight transportation and logistics network. The discussed threat types include:

- natural hazards (floods, wildfires, snowstorms, heavy rain, pandemics) and
- man-made disruptions (war-related disturbances of freight transport and cyber-attacks).

Based on the scenarios a methodology for green resilience management is developed. The methodology includes the definition of a holistic set of green resilience metrics. Its respective KPIs cover resilience and sustainability, and by that allowing a trade-off between both.

Models and simulation tools are needed for the implementation of the green resilience management, to investigate disruptions and the effects of adaptation and mitigation measures as well as resilient-by-design approaches under current and future boundary conditions. More details to the used models and tools can be found in section 3. The available tools are supposed to fully cover the scenario and mitigation measures, they are used for. Therefore, they will be further developed for the specific needs when adding sustainability issues and monitoring information. The interoperability of the different tool outputs must be guaranteed.

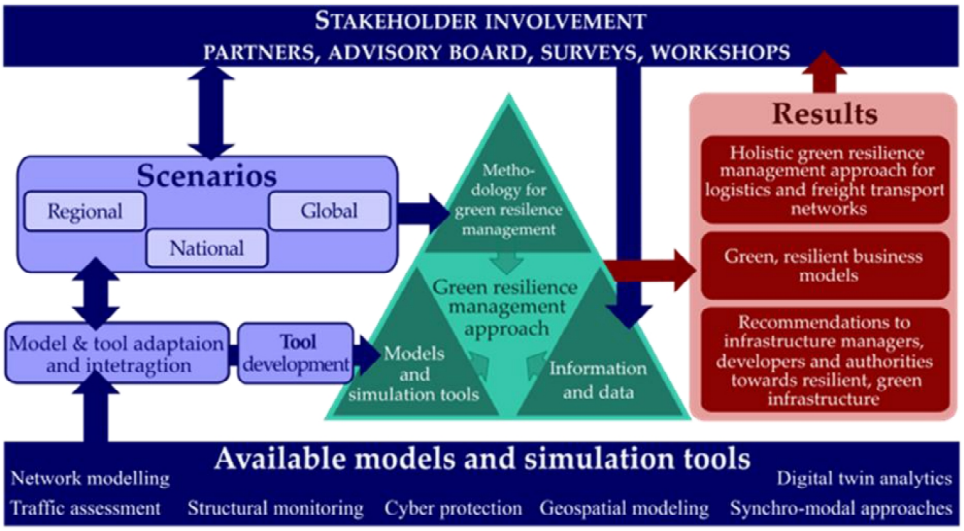

Fig. 1. SARIL concept.

The freight network models need data and general information on the network they wish to depict. A strong stakeholder engagement allows to gain this information through historical data and survey results among relevant stakeholders.

Finally, the main results of this development will be:

- a holistic green resilience management approach for freight transport and logistics networks;
- attractive green and resilient business models;
- recommendations to infrastructure managers, developers and authorities for greener and more resilient infrastructure.

The results will then eventually be fed back to the stakeholders.

2.3. Scenarios

In the SARIL project, three scenarios are studied that live on different geographical scales. The regional scenario is located in Italy, in the city of Mantua where during a flooding event a cyber-attack happens and monitoring systems of bridges are disabled. This leads to a catastrophic impact on the road and transportation system in the city. The national scenario, which actually should be called cross-border scenario, is located on the Iberian Peninsula. The climate change is currently leading to extreme weather events ranging from extreme heat and bush fires to unexpected cold and heavy snowfall. Finally, the global or EU-wide scenario is focused on transportation via the ‘silk road’ which has faced severe impacts due to the Covid pandemic and the war in Ukraine.

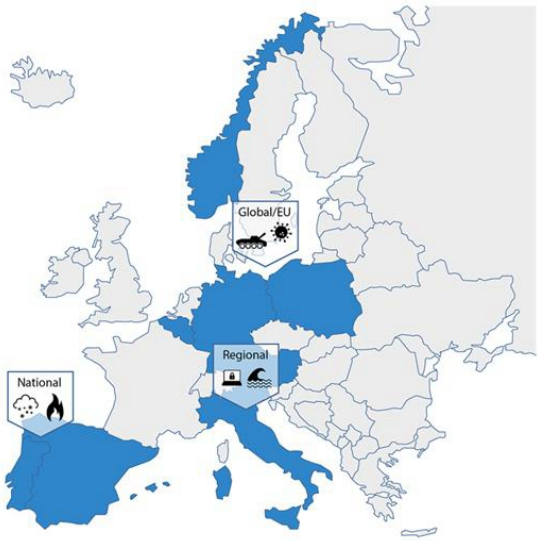

Fig. 2. Three scenarios in the project SARIL taken from (SARIL,2023).

2.4. Short description of the stakeholder involvement

For the development of meaningful decision support tools and recommendations for resilient and sustainable transport networks, it is crucial to involve stakeholders in the project (P. D. Andersen et al., 2021). To this end, the whole implementation of the project starts with the detailed definition of the scenarios comprising stakeholder interviews and a close collaboration with the end-users involved in the project, namely Rangel Logistics Solutions, the Port of Vigo, CSL Group and Gebrüder Weiss.

Further, the SARIL project teams up with the sister project ReMuNet to provide a joint questionnaire survey to stakeholders containing questions about the daily business in transportation but also about the impacts of potential disruptions, solutions to handle disruptions and resilience However, the survey does not only target those that work with logistics or transport infrastructure. To discern relevant stakeholders to reach, we defined stakeholders here as any actors (organization level) or groups of people being affected by or responding to disruptions in logistics chains. So, both users and providers. This means we are interested in the perspective also from the public sector, such as municipalities, counties, goods owners and in general commercial companies as well as interest organizations. This provides us with a broader approach for understanding the scope of disruptions and their consequences, and then also the grounds for finding solutions that are more likely to be applied at later stages.

The collaborative approach with the sister project strengthens the cooperation between the two EU projects, which will be followed up during the project implementation with e.g. common dissemination events.

For SARIL, the survey will be sent in a second round (made possible by the requirement of login) for those that wishes. This is part of a so-called Delphi survey method (H. A. Linstone und M. Turoff, 1975; C. Markmann et al., 2013). The goal is to catch a variety in answers in the first round. The second round will give the chance to answer modified questions from the first round, based on the others' responses. In the second round one will be able to see the aggregated answers to several questions. The findings from the survey will be applied in workshops with a core group of stakeholders connected to the three scenarios of the project. This is to provide grounds for discussions and new ideas to the further developments of the project and modelling. Finally, the knowledge platform by ALICE is used to making project results available to stakeholders and an external advisory board supports us to ensure the quality of the project results.

3. Methodology and Implementation

Based on the strong involvement of stakeholders (see Section 2.4), the methodology for a sustainable/green and resilient transport system is developed. To do so, the findings and KPIs from the stakeholder involvement will be compared to existing resilience assessment methods. Existing and future mitigation and adaptation measures are

collected to cope with a selection of potential disruptions. For the quantification of resilience and sustainability, KPIs, monitoring systems and the corresponding data collection are designed.

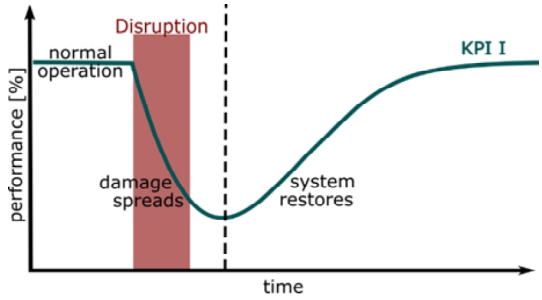

Fig. 3. Exemplary KPI evolution before, during and after a disruptive event.

These activities are followed by the modelling of transportation networks and the development of decision support tools. The tools are then used in performing a green resilience assessment of the fright transportation and logistics network. Finally, the results are exploited to generate recommendations for stakeholders. In the following the identification of KPIs, the used support tools and the assessment and management process are described in some more detail.

3.1. Key Performance Indicators

In order to perform a quantitative green resilience assessment, one needs credible and measurable indicators for both the green and resilience aspects of the discussed system (C. Nan, 2017). Key performance indicators are identified with the help of strong stakeholder involvement in form of interviews, workshops and surveys as described in section 2.4. They are compared with existing resilience assessment methods. To ensure that the identified KPIs map the resilience of the fright transportation network comprehensively, the resilience concepts in (M. Bruneau et al., 2003; I. Häring et al., 2021; K. Thoma, 2016) are applied.

The sustainability of boundary conditions and discussed mitigation measures in the fright transportation and logistics network are often neglected. Therefore, the introduction of "green" KPIs, such as CO_2-emissions, to the system assessment is a key aspect of the project.

The effects of changed boundary conditions and the effectiveness of mitigation measures can be evaluated through simulations. By calculating the identified relevant KPIs, one can follow their course before during and after a disruptive event. An exemplary course is plotted in Figure 3. Mitigation measures will shorten the decay time, reduce the maximal performance drop and/or speed up the recovery.

With the multi-level character of the planned green resilience assessment of the logistics network in mind, one goal is to identify KPIs which are maximally general. This means that they ideally account for all SARIL scenarios and a maximal number of stakeholders. Due to the stakeholder roles ranging from shippers to infrastructure operators to local authorities, it is to be expected, that certain KPIs will be more relevant to one stakeholder role than to another.

3.2. Support Tools

The modelling of the fright transportation and logistics networks is undertaken by the (further) development of decision support tools (see Figure 4). The main tools are:

- Remote sensing and GIS for weather and land-cover data;
- Agent-based model for fright transport;
- Vulnerability and Traffic Model tool;
- AI-based digital twin for predicting disruptions in logistics processes;
- Route selection for logistics operations;
- Monitoring-based decision support tool for emergency management of civil infrastructure;
- Dynamic mesoscopic traffic model for analysis of extreme events and aftermath including multi-agent conditions.

These tools will be employed to simulate disruption scenarios and to assess the resilience of the transportation network under consideration. The relevance and applicability of the results will be assessed in the defined

scenarios. Further, the interrelation of tools will be analyzed to ensure the collaboration between tools and a useful data exchange under the lead of the technical management.

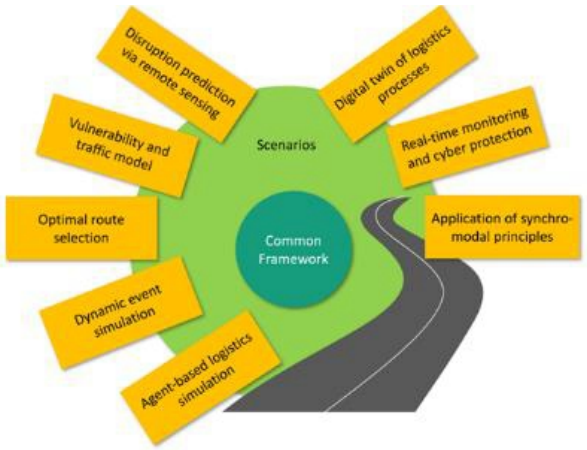

Fig. 4. Support tool overview.

3.3. Green Resilience Assessment and Management

The quantitative evaluation of the resilience models and sustainability will be performed with different datasets provided by the project stakeholders, based on measurable historical events and considering the different threats under study. The transferability of tools to other historical scenarios is tested. An impact assessment (environmental, social, and economic) will be performed using state-of-the art methods such as life cycle assessment and environmentally extended input-output analysis. This enables to test for impacts that exceed the system boundaries of the affected infrastructure or mode of transport. Finally, the results are demonstrated and applied to synchro-modal fright transport.

Based on the findings of the resilience and sustainability model evaluation, recommendations are prepared. These recommendations are addressed to infrastructure managers and developers, to shippers and logistics operators and to authorities. The aim is to provide insights to make infrastructure more resilient and to propose means to quantify the resilience. Further, mitigation measures are proposed to make the transport infrastructure resilient towards immediate disruptions such as accidents and natural hazards, but also towards disruptions with a longer time span such as pandemics and political unrest. Also, green alternatives must become more competitive in the future. Thus, business models will be developed based on the project results to be attractive for potential users and to provide acceptable profitability.

To maximize the impact of the project results, target groups and stakeholders are defined and communication objectives for overall communication are established. The relevant stakeholder groups for the project are the business community, technology providers, policy makers and public authorities, research and education, and civil society, as well as media, press and the general public. The core group of stakeholders comprises logistic service providers, transport infrastructure operators, shippers and authorities.

3.4. Project Structure

The work in the SARIL project is divided into six work packages, which contain the working steps that were just described. The work packages are named as follows:

WP 1: Co-creation of Scenario Cases and Sustainability and Resilience Evaluation Framework;
WP 2: Methodology for the Green Resilience Management;
WP 3: Modelling and Demonstration of Resilience Solutions;
WP 4: Validation and Impact Assessment;
WP 5: Recommendations, Business Models, Dissemination and Exploitation;
WP 6: Management.

The sustainability and resilience evaluation framework is performed in WP 1. This includes the stakeholder involvement throughout the whole project, the scenario set up and KPI identification. The Methodology of the green resilience management is developed in WP 2. It is supplied through the stakeholder engagement in WP 1 with KPIs and metrices, current and future disruptions and mitigation measures and optional measures to assess sustainability. A special focus lies on the inclusion of sustainability and expected future developments into the methodology development.

The tool development and green resilience assessment will be performed in WP 3. This includes the identification, where the developed tools can collaborate and exchange data. Resilience patterns will be identified and the results, their relevance and applicability compared.

The results from green resilience assessment are validated in WP 4. Furthermore, the results will be discussed regarding their transferability to other, broader context to address the holistic aim of the project. In an impact assessment the found results will be further assessed regarding their environmental, economic and social impact, using state-of-the art methods such as life cycle assessment (LCA) and environmentally extended input-output (IO) analysis. A close communication with stakeholders will be essential here as well. Finally, synchro-modal fright transport will be investigated in how to be optimized under the simulated disruptions and found results. Accurate predictions – especially in a holistic manor – allow stakeholders to improve their fright transportation by an optimized usage of the logistics network.

From the performed green resilience and impact assessment, recommendations are prepared for infrastructure operators and developers, authorities, shippers and logistic operators and business models are built in WP 5. Dissemination, communication and exploitation of the project results are also planned in WP 5.

Finally, the project management is located in WP 6.

4. Conclusion

The fright transportation and logistics networks have faced several major challenges in the last years. With climate change threatening to increase the issue, it is important to increase the not only the resilience but also the sustainability of the network. Here, a project plan is presented to develop a methodology for a green, resilient logistics management.

Gaps towards a resilient and sustainable logistics network, which we aim to tackle are presented and their alliance with the project goals. The overall project concept is presented, as well as the methodology, which is currently used or is going to be used in the project in future. This includes the stakeholder involvement, the three-scenario approach, the KPI identification for green resilience in the fright transportation and logistics networks, the support tools, which are going to be used in the project, as well as our plan for a resilience and impact assessment. To this point, the stakeholder involvement started with first interviews and a survey setup and an initial set of KPIs has been identified.

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