Pan-European Analysis of Flood-Induced Supply Chain Disruptions

***Fernandez-Perez, A[1]; Pant, R[1] ; Li, Y[1]; Raj, S[2]; Koks, E.E[2]; Hall, J[1]**
***alberto.fernandezperez@ouce.ox.ac.uk**
1. Environmental Change Institute, University of Oxford
2. Instituut voor Milieuvraagstukken (IVM) – Vrije University of Amsterdam

Abstract

Flooding is among the most disruptive natural hazards in Europe, not only damaging physical infrastructure but also triggering cascading disruptions across industrial supply chains. While existing research has largely focused on direct impacts on assets, the indirect consequences for interconnected production and trade systems remain underexplored. This study develops a Europe-wide assessment of flood-induced disruptions to industrial supply chains by integrating industrial output localization, transport lifeline connections, and commodity flow mapping. Using Eurostat Supply-Use Tables, facility-scale industrial data, and multi-modal freight network modeling, we construct a geospatially explicit representation of production and trade dependencies across Europe. Flood hazard maps from the Joint Research Centre are then overlaid to evaluate damages under baseline and future climate scenarios (SSP2-4.5 and SSP5-8.5). Initial results highlight significant damages to rail assets from river flooding in the central European countries.

Keywords: Flooding disruptions, Supply chain, multi-modal transport.

Introduction

Floods are among the most frequent and costly natural hazards in Europe, causing billions of euros in damages each year and severely disrupting communities, businesses, and national economies (Paprotny et al. 2018). Recent events such as the 2021 Central European floods and recurrent flooding of river basins like the Danube, Rhine, and Po have demonstrated that flooding not only damages infrastructure but also disrupts critical services and industrial production across wide regions (Koks et al. 2021).

While existing research has provided valuable insights into flood risk for physical assets (van Ginkel et al. 2021), less attention has been devoted to the indirect and cascading effects of flooding on industrial supply chains. Industrial clusters, transport lifelines, and commodity flows are tightly interconnected; localized flooding of ports, rail junctions, or inland waterways can ripple across national borders and trigger systemic impacts.

This work develops a Europe-wide analysis of flood-induced disruptions to industrial supply chains by mapping: (1) the localization of industrial output, (2) lifeline connections to ports, airports, and rail stations, and (3) commodity flows across Europe by transport mode.

By using flood maps for present and future scenarios, and their disruption to transport infrastructure, we estimate cascading impacts on industrial continuity. The analysis highlights critical bottlenecks and systemic vulnerabilities, providing insights into how resilience strategies may be designed to protect Europe's economy from flood-related risks.

Methodology

The study adopts a three-step methodology tailored to flood impacts:

Localization of industrial output

Industrial production (in tonnes/year) mapped at the NUTS-2 level using Eurostat Supply-Use tables (SUT) (García-Rodríguez et al., 2025) provides the baseline of industrial activity across Europe. This is downscaled to geolocated industrial locations using EPRTS (European Pollutant Release and Transfer Register) footprint maps, enabling industrial input and output flows from regional to facility level. Industrial activity is categorized into key industry/commodity groups: metals, chemicals, intensive livestock, food, and paper/wood, commercial and mining.

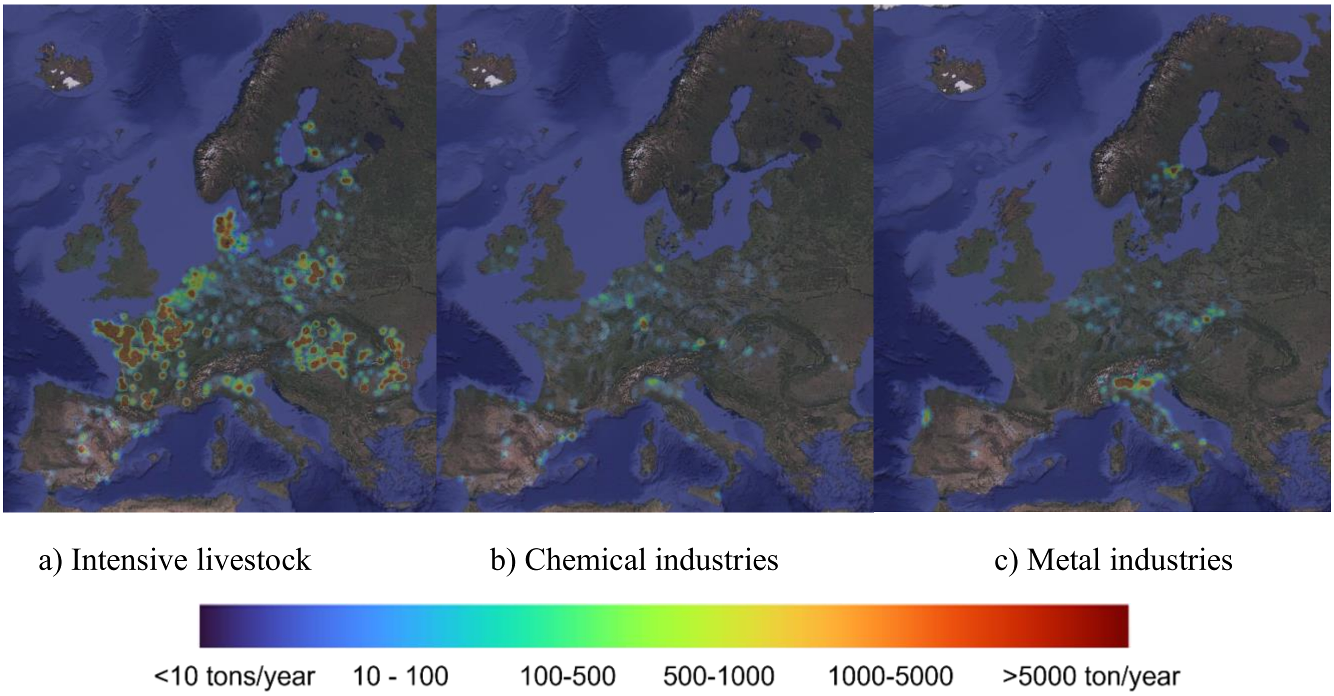

Figure 1. Localization of industrial output at pan-European scale for three different commodity types.

Trade flow downscaling and lifelines analysis

The location specific downscaling of the SUT helps to generate a geospatially explicit network of inter-sectorial trade at the facility level. Then, each facility is linked to its nearest ports, airports, rail stations and road junctions. Downscaled commodity trade flows between industrial locations are assigned to air, maritime, rail and road connections between the facilities, using Eurostat statistics for port, airport and inland waterways as capacity constraints of the flows. Thus, the multi-modal Origin-Destination matrices are created at pan European scale, which are then fed into a flow allocation model (Li et al., 2025). The left panel of Figure 2 provides a representation of the multi-modal transport flow allocation.

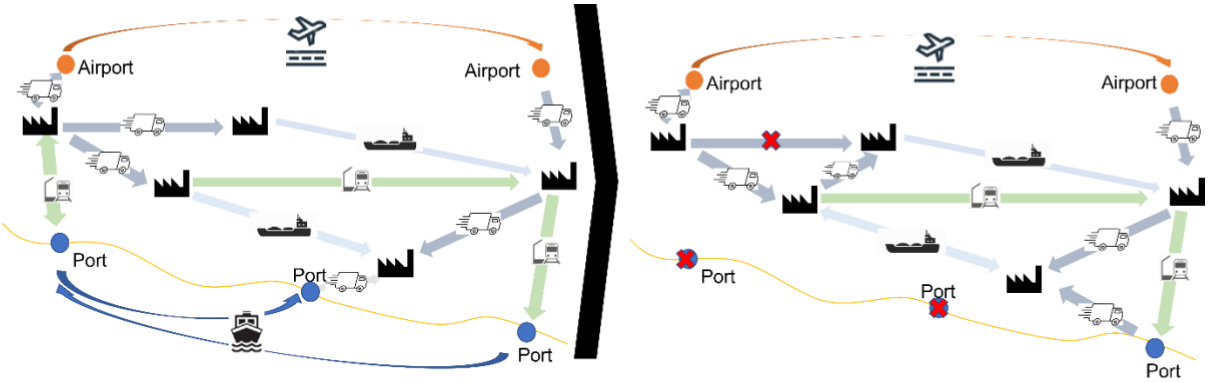

Figure 2. Assumed supply chain structure and disruption-rerouting analysis

Flood disruption analysis

Flood hazard return period maps from the JRC (Baugh et al., 2024) are overlaid to identify exposed and disrupted transport assets and estimate potential service interruptions in transportation networks (see Figure 2 right panel). A baseline scenario plus two future ones (SSP2 4.5 and SSP5 8.5) are considered for mid and end of century. Then, commodity flows are re-computed based on the multi-modal network flow re-routing costs (Li et al., 2025). Thus, disruptions from flood-exposed assets enable to trace cascading impacts through industrial supply chains. Both direct effects (damages on assets) and indirect effects (lost connectivity of commodity flows) are quantified.

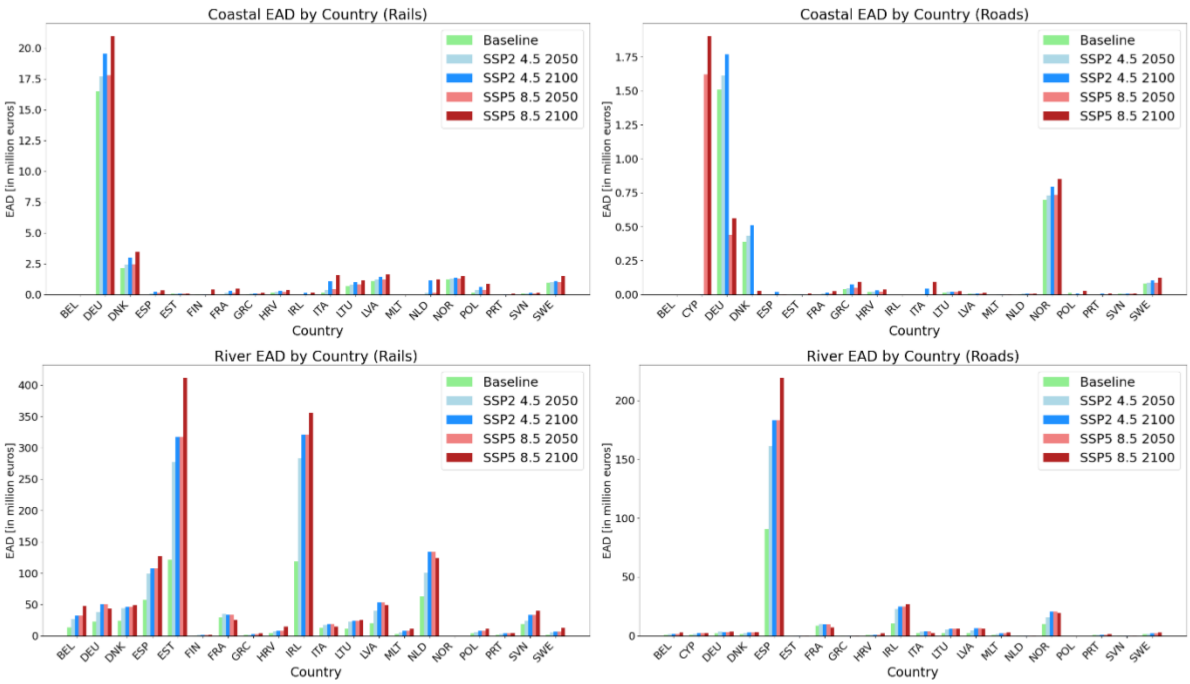

Figure 3. Expected Annual Damage from direct damages caused coastal and river flooding for baseline and future scenarios

In Figure 3, preliminary results of the Expected Annual Damage (EAD) due to coastal and river flooding events are highlighted for each European country. The results show the increase in disruptions on transportation assets due to Sea Level Rise and the changes in the extreme events patterns. These effects are more prominent when evaluating river flooding, specially affecting central European railways.

Conclusion

This study aims to demonstrate that both coastal and river flooding in Europe have the potential to generate widespread and cascading disruptions far beyond the directly affected areas. Preliminary analysis shows that these effects, which are presently significant for the European transport assets, will further increase in frequency and intensity of extreme floods.

By combining industrial production data, facility-level footprints, and multi-modal freight flow modeling with present and future flood scenarios, we aim to identify critical vulnerabilities in Europe's industrial and transport networks. In next steps of the work, we aim to show the critical linkages across flood-exposed transport networks whose failures can trigger cascading impacts on industrial continuity and cross-border supply chains. Such disruptions compound the direct damages to physical assets, amplifying economic losses and threatening the stability of key sectors across Europe.

References

Baugh, Calum; Colonese, Juan; D'Angelo, Claudia; Dottori, Francesco; Neal, Jeffrey; Prudhomme, Christel; Salamon, Peter (2024): River flood hazard maps for Europe and the Mediterranean Basin region. European Commission, Joint Research Centre (JRC) [Dataset] doi: 10.2905/1D128B6C-A4EE-4858-9E34-6210707F3C81 PID: http://data.europa.eu/89h/1d128b6c-a4ee-4858-9e34-6210707f3c81

https://www.eea.europa.eu/data-and-maps/data/member-states-reporting-art-7-under-the-european-pollutant-release-and-transfer-register-e-prtr-regulation-23/european-pollutant-release-and-transfer-register-e-prtr-data-base

https://ec.europa.eu/eurostat/en/

García-Rodríguez, A., Lazarou, N., Mandras, G., Salotti, S., Thissen, M., & Kalvelagen, E. (2025). Constructing interregional social accounting matrices for the EU: Unfolding trade patterns and wages by education level. Spatial Economic Analysis, 1–24. https://doi.org/10.1080/17421772.2025.2461051

Koks, E., Van Ginkel, K., Van Marle, M., & Lemnitzer, A. (2021). Brief communication: Critical infrastructure impacts of the 2021 mid-July western European flood event. Natural Hazards and Earth System Sciences Discussions, 2021, 1-11.

Li, Yue, Pant, Raghav, Russell, Tom, Thomas, Fred and Hall, Jim, Oldham, Philip, Lamb, Rob and Young, Paul J., Stress-Testing Road Network in Great Britain with Historical Flood Events between 1953-2024.

Paprotny, D., Sebastian, A., Morales-Nápoles, O., & Jonkman, S. N. (2018). Trends in flood losses in Europe over the past 150 years. Nature communications, 9(1), 1985.

Van Ginkel, K. C., Dottori, F., Alfieri, L., Feyen, L., & Koks, E. E. (2021). Flood risk assessment of the European road network. Natural Hazards and Earth System Sciences, 21(3), 1011-1027.