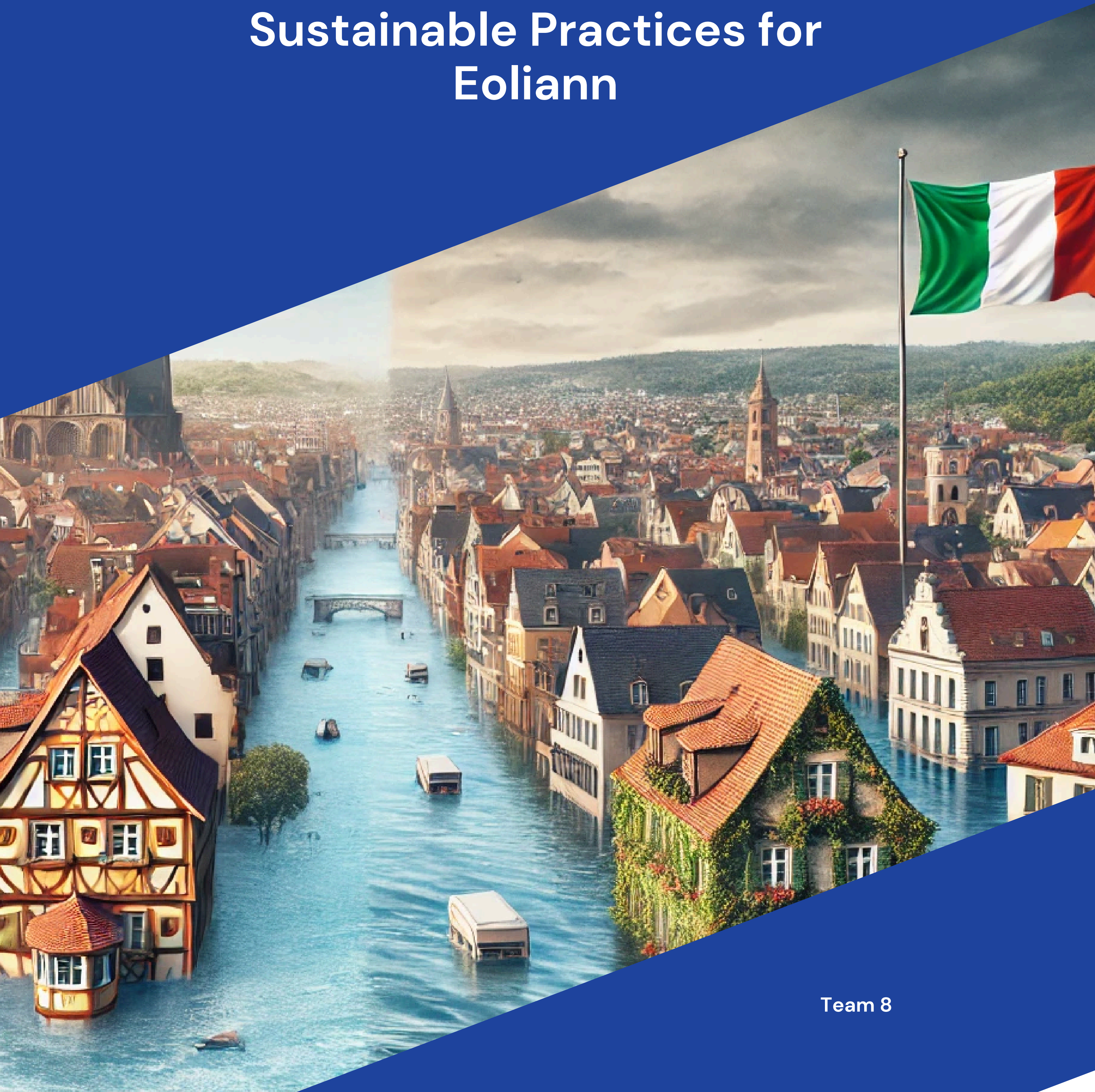
FEBRUARY 2025

Flood risk and resilience in Italy and Germany

Sustainable Practices for Eoliann



Team 8

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Introduction

Critical infrastructure is seriously threatened by floods, which also cause significant long-term structural damage, operational disturbances, and financial losses. Rising frequency and intensity of extreme weather events brought on by climate change have made resilient infrastructure increasingly important to governments, companies, and investors. Now safeguarding assets, guaranteeing company continuity, and reducing financial losses depend on the capacity to forecast and control these risks.

Eoliann, an Italian climate risk modeling company, seeks to enhance its analytical tools to provide accurate flood risk assessments for infrastructure owners, policymakers, and insurers. By leveraging data-driven insights, Eoliann aims to support better decision-making in flood defense investments, helping stakeholders allocate resources effectively, reduce vulnerability, and strengthen long-term resilience.

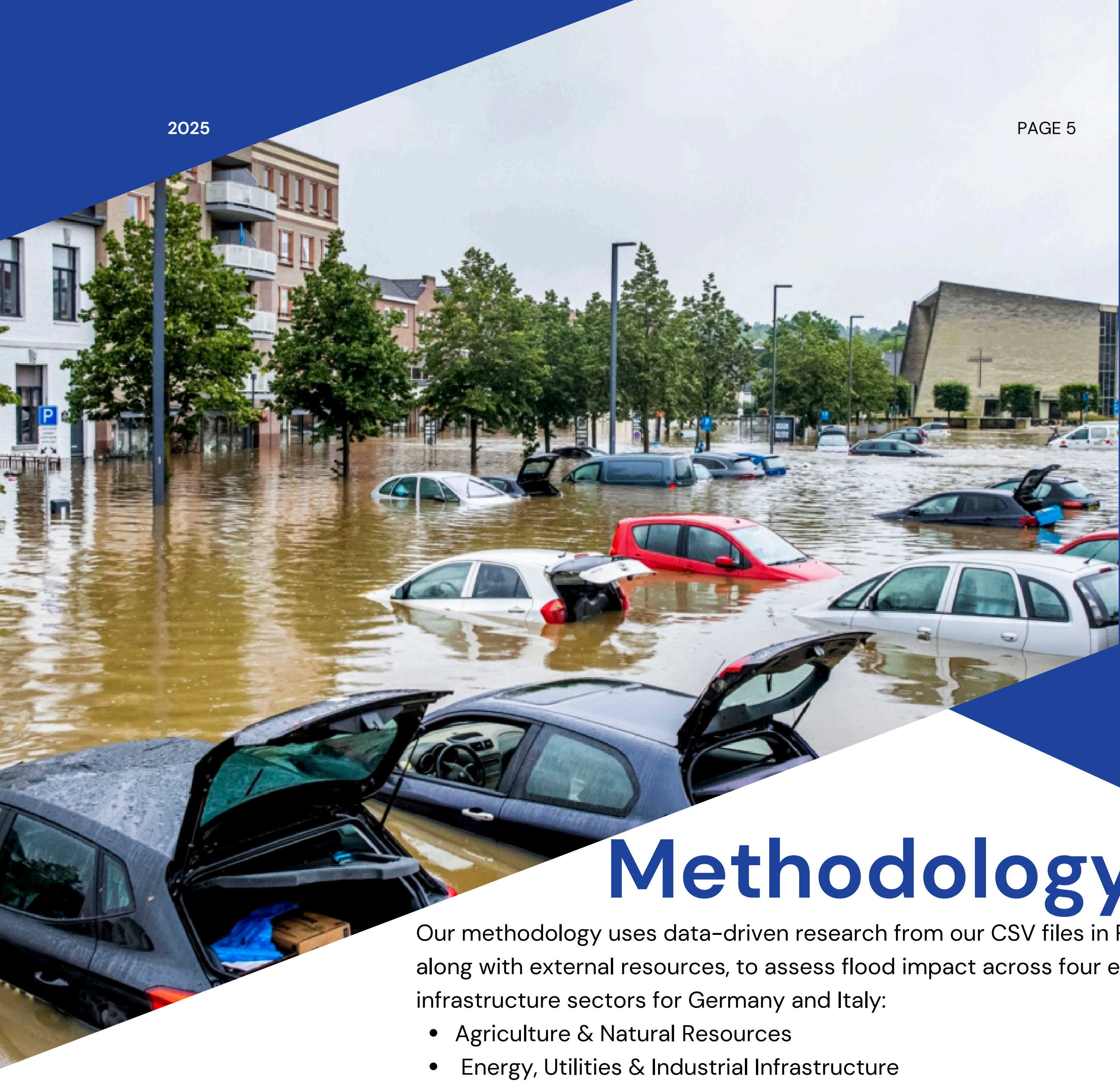
This report provides a comprehensive analysis of flood hazards in Italy and Germany, identifying the most and least at-risk infrastructure types, the key factors influencing flood damage, and the socio-economic considerations that shape investment in flood resilience. By exploring these critical aspects, we aim to contribute valuable insights that will improve Eoliann's predictive modeling and enable more informed climate risk management strategies.

Research scope

This analysis examines flood hazards in Italy (2023–2024) and Germany (2024), focusing on infrastructure vulnerability, resilience, and recovery. The report aims to provide a data-driven understanding of flood impacts, incorporating geospatial assessments, disaster records, and economic analysis to support better decision-making in climate resilience and infrastructure investment.

Key Areas of Exploration

- Impact of Flooding on Infrastructure Types: Identifying which assets are most and least affected, using flood impact data and damage assessments from sources like Copernicus Rapid Mapping and EMDAT.
- Comparative Damage Patterns Between Italy and Germany: Analyzing geographical, structural, and economic factors that influence flood severity, infrastructure damage, and recovery efforts.
- Physical & Socio-Economic Risk Drivers: Investigating how building materials, construction age, land use, and economic conditions contribute to flood vulnerability and resilience.
- Land Valuation & Willingness to Pay (WTP): Assessing how property values, financial exposure, and risk perception influence investment decisions in flood protection and resilience measures.



Methodology

Our methodology uses data-driven research from our CSV files in Python, along with external resources, to assess flood impact across four essential infrastructure sectors for Germany and Italy:

- Agriculture & Natural Resources
- Energy, Utilities & Industrial Infrastructure
- Real Estate & Urban Development
- Transportation & Mobility

Infrastructure resilience is based on three key physical factors:

- Building Material (flood resilience of materials like concrete, steel, or soil-based structures).
- Year of Construction (compliance with modern-day flood resilience standards).
- Structural Design (flat, elevated, drained, or reinforced structures).

Also, socio-economic factors such as economic development, insurance coverage, and government policies affecting flood damage recovery and resilience were discussed. To sum up the research answering the last part, Insurance Market Trends, Financial Exposure, Land Valuation and Functional Usage and valuation-based approach to determine the infrastructure owners' willingness to pay for flood protection, thus giving Eoliann key insights into sector-specific investment priorities for climate risk predictive modeling.

Business Logic & Model Integration

Justification for Research Scope

Eoliann uses climate risk models to analyze a range of hazards, which include floods, storms, wildfires, heat stress among others, but this report focused on doing an extensive analysis regarding flood for reasons below.

Why Floods?

Flooding is one of the most frequent and costly climate perils, triggering widespread damage and long-term economic disruption across many sectors, including transport, energy, real estate, and agriculture. Recent history, including Ahr Valley (2021), Emilia-Romagna (2023), and Southern Germany (2024) floods, demonstrates how increased flood risks due to climate change, urban development, and high-intensity rainfalls have manifested. Apart from direct damage, floods interrupt supply chains, bring businesses to a standstill, and cost heavily in recovery efforts, and thus become a priority for risk assessment and resilience planning. Their increasing scale and economic impact render them the most important hazard for infrastructure modeling and investment planning.

Why Germany & Italy?

Germany has implemented an elaborate, developed flood resilience system with strict infrastructure policy and government-funded reconstruction initiatives. In contrast, Italy faces a higher degree of climate-driven threat from flooding, along with urban planning issues and varying resilience in infrastructure across different regions. There have been quite a number of recent floods in both these countries that are well documented. This gives a good data setup to serve Eoliann's needs in the further development of its predictive model.

Why 2023-2024?

The most recent available flood data is used in this analysis to be as closely relevant as possible in the risk modeling context. Recent floods in Emilia-Romagna (Italy) and Southern Germany in 2023-2024 provide useful case studies in the context of analyzing damage patterns or recovery actions and preparedness aspects. The research is aimed at providing Eoliann with useful, immediate data for their climate risk model by addressing flooding issues into their occurrence in 2023-2024 in Germany and Italy.

How Eoliann Can Use This Data in Their Risk Models:

Our analysis helps Eoliann enhance its flood risk estimation models by providing:

- Sector-Based Risk Scoring: Identification of the high-risk category of infrastructure and level of anticipated flood damage.

- Geographic Variability Analysis: Insight into regional differences in levels of resilience across Germany and Italy.

- Policy & Investment Insights: Supporting policymakers and infrastructure owners to prioritize allocating flood protection investment based on economic impact.

Improving Climate Risk Insights for Infrastructure Owners:

- Eoliann's clients, including government agencies, insurers, and asset managers, need evidence based on flood risk data to help with their investment planning. Our analysis is implemented to:
- Better Flood Risk Prediction → Better probability and severity models for infrastructure.
- Investment Prioritization: Identifying where investments in resilience are most needed.
- Risk-Adjustment Pricing of Insurance → Allowing insurers to build better price models for flood-risk assets.

Infrastructure Damage Analysis

Most impacted and least impacted infrastructure assets

Country Specific differences

Severity of damage and Sector-Specific Vulnerabilities

Most At-Risk

- Highways, Streets, and Roads (634 Assets) - Roads are more susceptible to being damaged by floods because they have low ground profiles, cross over rivers and streams, and are reliant on drainage systems that could be flooded.

- Non-Residential Buildings (603 Assets) - Urban flood-risk areas are commonly used for commercial, industrial, and public structures, especially leading to high exposure to damage.

- Agricultural Areas (376 Assets) - Agricultural lands are commonly located in productive floodplains and therefore have high exposure to floods which can cause soil erosion and waterlogging.

- Harbors, Waterways, and Dams (205 Assets) - Water facilities are directly exposed to flooding and are at risk of damage to ports, embankments, and hydroelectric dams.

Least At-Risk

- Bridges, Overpasses, Tunnels, and Subways (2 Assets): These are flood-resistant and designed using elevation, waterproofing, and supporting materials.

- Wetlands (59 Assets): Wetlands naturally absorb floodwaters, which act as flood buffers rather than vulnerable assets.

Country-Specific Differences (Germany vs. Italy):

While exposed to extreme flood events, Italy and Germany present contrasting levels of damage due to infrastructure resilience, urban planning, and policy interventions.

Italy: Higher Damage Intensity:

- More infrastructure in flood-risk zones → Urbanization & poor zoning regulations increase risk exposure.
- Medium to high level of damage noted in transport & real estate industries.
- Energy & industrial infrastructure are under threat too, as seen during the Emilia-Romagna 2023 floods (Schnebele et al., 2023).

Germany: More Resilient, But Not Immune:

- Enhanced flood control measures, i.e., engineered flood defenses and land-use planning, reduce impact.
- Most impacted sectors include agriculture & transport, especially in low-lying regions.
- Shortcomings in early warning systems and disaster response (Kreibich et al., 2025).

Severity of Damage & Sector-Specific Vulnerabilities:

The extent of damage varies significantly across industries due to differences in structural strength, material durability, and disaster preparedness.

Transportation & Mobility

- Roads and highways suffer extensive flood damage, particularly from waterlogging, erosion, and bridge collapse.
- Railways are less impacted but experience service disruptions due to flooding of railway-lines.
- Bridges and tunnels are least impacted as they are elevated and supported.

Real Estate & Urban Development

- Commercial and residential constructions in low-lying urban areas suffer medium to high flood loss.
- Older structures (pre-2000 constructions) were the more susceptible, whereas recent high-rise structures are considered lowly affected.

Energy, Utilities & Industrial Infrastructure

- Industrial sites and power plants are greatly impacted by flood-caused electrical failure and erosion of structure.
- Pipes and communications infrastructure are moderately impacted, based on height and flood defenses.

Agriculture & Natural Resources

- The farmlands and natural parks are highly vulnerable to water stagnation, crop losses, and land erosion.
- Forest and wetland areas act as natural flood regulators, reducing cumulative damage.

Physical and Socio-Economic Factors

To ensure a structured analysis, we mapped physical factors to 12 infrastructure categories across four sectors. A Python script was developed to generate a dataframe, classifying each infrastructure by sector, material, year of construction, and design. This process was done by research from external resources such as Rossetto et al. (2013), Kelman & Spence (2004), and Fink et al. (2023).

To quantify socio-economic impacts, a second Python script was used to map each infrastructure category with relevant socio-economic factors. Data sources included: AGU Publications (2024), European Central Bank (2025), Financial Times (2024), Marsh McLennan (2021)

Physical Factors

Building Material:

- Concrete/Steel (e.g., bridges, power plants, roads) → More flood-resistant due to structural integrity.
- Asphalt/Concrete (e.g., roads) → Fairly durable but susceptible to long-duration submersion.
- Soil/Natural Land (e.g., arable land, wetlands) → Very prone to erosion and water saturation.
- Natural vegetation/wood (e.g., forests, older buildings) → Prone to deterioration in flood conditions.

Example:
Steel/plastic pipes and concrete/steel power plants suffered less damage, while soil-based agricultural land encountered high erosion.

Year of Construction:

- Post-2000 infrastructure → More resistant to floods due to following newer building codes & waterproof designs.
- Pre-2000 infrastructure: → More vulnerable due to outdated drainage, elevation, and reinforcement.

Example:
New bridges (post-2000) had high resilience, while older wholesale/retail buildings (pre-2000) had high damage due to a lack of flood-resistant designs.

Structural Design:

- Raised, drained, strengthened structures (e.g., bridges, newer industrial buildings) → More resistant to flood injury.
- Low, undrained, or flat assets (e.g., roads, older structures, arable land) → More susceptible from water pooling and erosion.

Example:
Drained/higher power plants survived, but open/flat agricultural land suffered heavy flood losses.

Socio-Economic Factors

Economic Development & Income Levels:

- More developed sectors (e.g., Industry, Energy) → More investment in flood protection & faster recovery.
- Less developed sectors (e.g., Agriculture, Small Businesses) → More exposure to flood losses & reliance on public aid.

Example:
Power plants (insured, well-funded) recovered quickly, while forests & agricultural land suffered prolonged damage due to a lack of funds.

Insurance Coverage & Public Funding:

- Better-insured assets (e.g., power plants, hotels) → Recovered faster through financial compensation.
- Underinsured assets (e.g., small retail buildings, agricultural land) → Longer economic recoveries & increased financial burdens.

Example:
Hospitals that were covered quickly recovered economically, while small agricultural land had prolonged economic losses.

Government Policies & Investment:

- Government investment in flood avoidance (e.g., roads, bridges) → Lower risks of damage.
- Uncollected land-use planning (e.g., urbanization in floodplains) → Increased infrastructure exposure.

Example:
Germany's flood protection policies reduced damage severity, whereas Italy's urbanization of flood-prone areas increased flood exposure (Schnebele et al., 2023).

Urban Planning & Land Use Policies:

- Deforestation & bad zoning → Increased flood risks.
- Wise land-use & wetland conservation policies → Increased flood resilience.

Example:
Urban areas in Emilia-Romagna (Italy) suffered severe flood damage, whereas wetland regions experienced natural flood mitigation (Kreibich et al., 2025).

Social Inequality & Marginalized Communities,

- Poorer or vulnerable societies have poorer infrastructure & fewer recovery resources.

Example:
Germany's response to the flood was quicker in richer communities, but rural communities were behind because they had lower resilience funding.

Key findings

- Concrete/steel structures (bridges, power plants) showed lower flood vulnerability, while soil-based and wooden structures (arable land, forests) suffered severe damage.
- Post-2000 infrastructure performed significantly better than pre-2000 assets, highlighting the importance of modern flood-resistant construction.
- Elevated, drained, and reinforced designs (e.g., modern pipelines, bridges) reduced damage, whereas flat/undrained designs (e.g., roads, agricultural land) suffered high erosion & water saturation.
- Higher-income sectors (Industry, Energy) invested more in flood defenses, while lower-income sectors (Agriculture, Retail) struggled with recovery.
- Well-insured infrastructure assets (hotels, power plants) recovered faster, while underinsured properties (farmland, small businesses) faced long-term damage.
- Germany’s stronger flood policies helped minimize economic impact, while Italy’s urban expansion in flood-prone areas increased damage risks.

Willingness To Pay (WTP)

Insurance Market Trends: Principal Driver of WTP

- Insurance premiums represent a principal driver of WTP since higher premiums and increased coverage needs force infrastructure owners to reconsider their long-term financial risks.

- Germany: Following the 2021 and 2024 floods, building insurance premiums in flood-prone areas increased by 15%, which had a considerable impact on WTP (German Insurance Association [GDV], 2024). Certain insurers now exclude coverage unless flood protection measures (e.g., flood barriers, waterproof foundations) are implemented. This has motivated companies to invest in flood resilience, increasing WTP.
- Italy: On the other hand, only 20% of firms are insured against floods, and premiums have not risen as much as in Germany (Italian Insurance Association, 2024). The majority of firms rely on government support for recovery from floods, reducing the perceived need for proactive investment. In the absence of economic pressure from insurers, WTP is low.

Land Value & Functional Use as WTP Drivers:

- WTP for flood resilience investments is driven directly by the economic value and use of land.
- Higher-Value, Higher-Usage Properties (Higher WTP) → Commercial properties, industrial estates, and transport facilities have higher WTP due to the possibility of financial loss and operational interruption (World Bank, 2023).

Example: A luxury hotel chain in Milan, Italy, has real estate valued at €5,000 per m². Basement flooding occurred after the recent storms (e.g., Seveso River Flood, May 2024), leading to a loss of €500/m² (Global Property Guide, 2024; McKinsey & Company, 2023). To protect business and property value, the hotel chain identifies flood resilience as a matter of investment necessity (European Central Bank [ECB], 2024).

- Low-Value, Passive-Use Land (Lower WTP) → Wetlands and conservation areas lack economic justification for flood resilience investments.

Example: A Lower Saxony, Germany, conservation group has €3 per m² value wetlands (Eurostat, 2023). Since wetlands naturally absorb floods and suffer no property depreciation, WTP for flood protection is low (OECD, 2023).

Financial Exposure & Cost-Benefit Equation

Infrastructure owners must decide whether it is cheaper to invest in flood resilience now or in future financial losses.

High-Risk Sectors (Higher WTP) → Operators with a high financial risk (e.g., transport operators, commercial property) will be more likely to invest in flood resilience.
Example: The 2024 Bavarian floods hit 120 km of highways with a repair cost of €2 billion (GDV, 2024). The cost of elevating highways and installing high-tech drainage is €500,000/km, while flood repair can cost up to €10 million/km (OECD, 2023). The benefit-cost ratio supports investment in resilience, leading to significant WTP by highway operators (McKinsey & Company, 2023).

Low-Risk Sectors (Lower WTP) → Low-risk asset owners (e.g., arable land, forests) can avoid resilience costs since they have less financial exposure.
Example: A vineyard owner in the Po Valley, Italy, has much less financial risk. The land itself is priced at €1.50 per m², which has to endure regular flooding, but crop damage is normally offset by government subsidies (Italian Ministry of Agriculture, 2023). Sump-proof irrigation systems are €50,000 per hectare to install, while annual crop loss averages only €20,000. With government subsidies offsetting financial risks, WTP for flood resilience remains low (World Bank, 2022; European Commission, 2024).

Conclusions & Recommendations

Conclusions:

Flood hazards represent a significant threat for the infrastructure of Germany and Italy and the effects vary across sectors. Our analysis includes some high-risk assets such as highways, agricultural land, and non-residential buildings, while reinforced structures (bridges and elevated highways, in particular) tend to show higher resilience against floods. The most relevant physical factors—modeling design, construction year, and building materials—determine the resistance of an asset to flooding, whereas socio-economic factors, such as financial resilience, insurance coverage, and government investment, govern the speed of recovery.
Further funding decisions will to some extent vary depending on the ability to pay for flood resilience through the willingness to pay (WTP), where commercial and industrial assets are expected to prioritize investments through subsidies, and agriculture or conservation land will depend much more on government aid. This will provide the scale for Eoliann to do further work towards establishing robust climate models in assessing climate risks and guiding data-driven flood mitigation strategies for policymakers, insurers, and infrastructure owners.

Recommendations:

Incorporate Infrastructure-specific Resilience Scores into Risk Modeling

- Develop sector-friendly flood scores in Eoliann's models that will differentiate some high-risk assets (roads, agricultural land) from those showing lower risk (bridges, reinforced structures).
- Factor in historical flood damages, e.g., Emilia-Romagna 2023, Bavaria 2024, to disentangle risk assessment.

Create an Economic Risk Indicator for Willingness-to-pay (WTP)

- Land valuation metrics expose value-related exposures that can further shed light on the following sectors indicating WTP.
- Divert the investment gaps of under-researched sectors—like agriculture and small businesses—which government policy measures might further help improve resilience.

Assist in Policy & Investment Prioritization for Flood Resilience

- Recommending flood-dependent policies for protection in a vulnerable region backed by damage patterns established in Germany and Italy.
- Work together with insurers to assess flood-proofing of infrastructure carried out as an incentive, in which owners will have a good case to make for investments in mitigation strategies.

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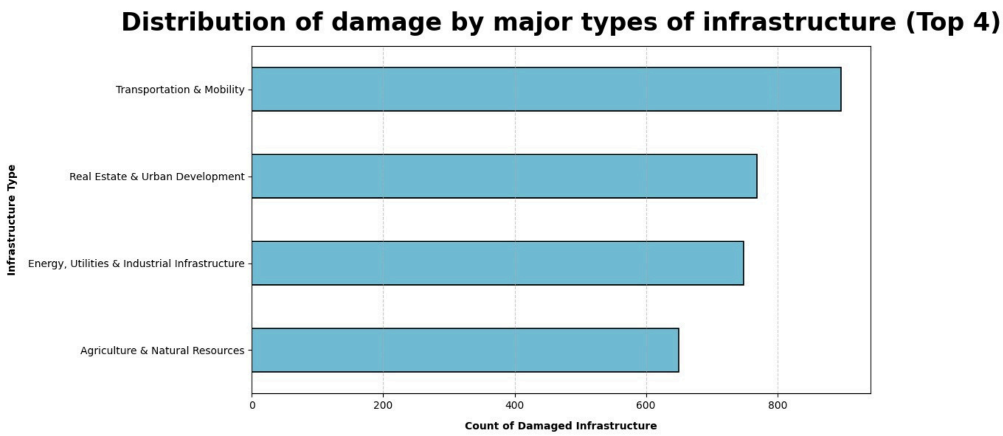
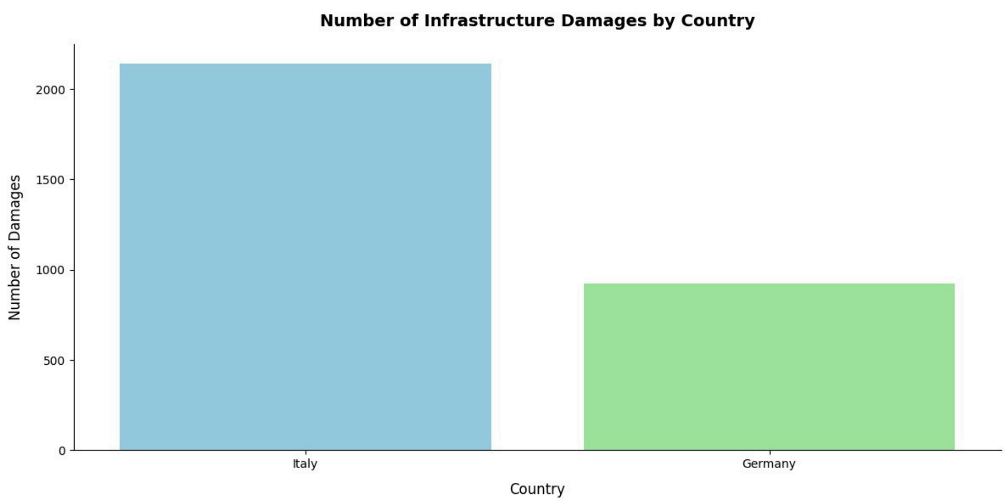
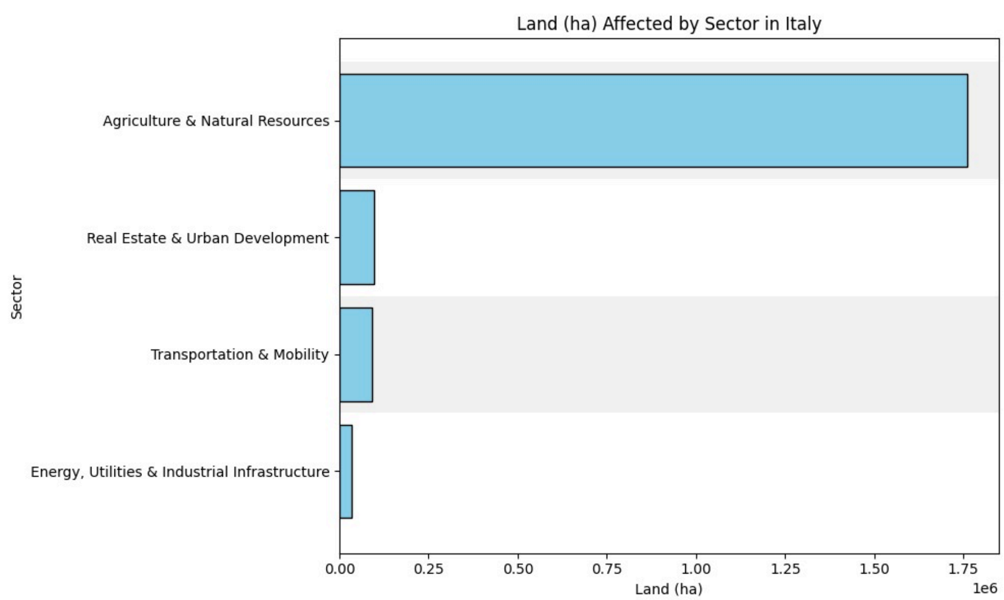
Appendix


Distribution of damage by major types of infrastructure (Top 4)
Transportation & Mobility
Real Estate & Urban Development
Energy, Utilities & Industrial Infrastructure
Agriculture & Natural Resources
Infrastructure Type
0
200
400
600
800
Count of Damaged Infrastructure


Number of Infrastructure Damages by Country
2000
1500
1000
500
0
Number of Damages
Italy
Germany
Country


Land (ha) Affected by Sector in Italy
Agriculture & Natural Resources
Real Estate & Urban Development
Transportation & Mobility
Energy, Utilities & Industrial Infrastructure
Sector
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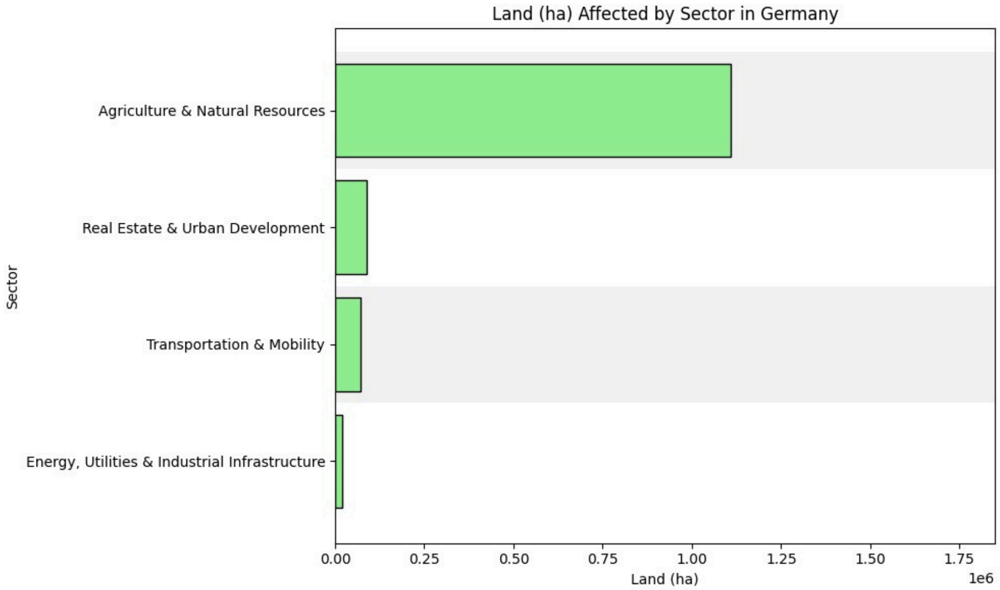
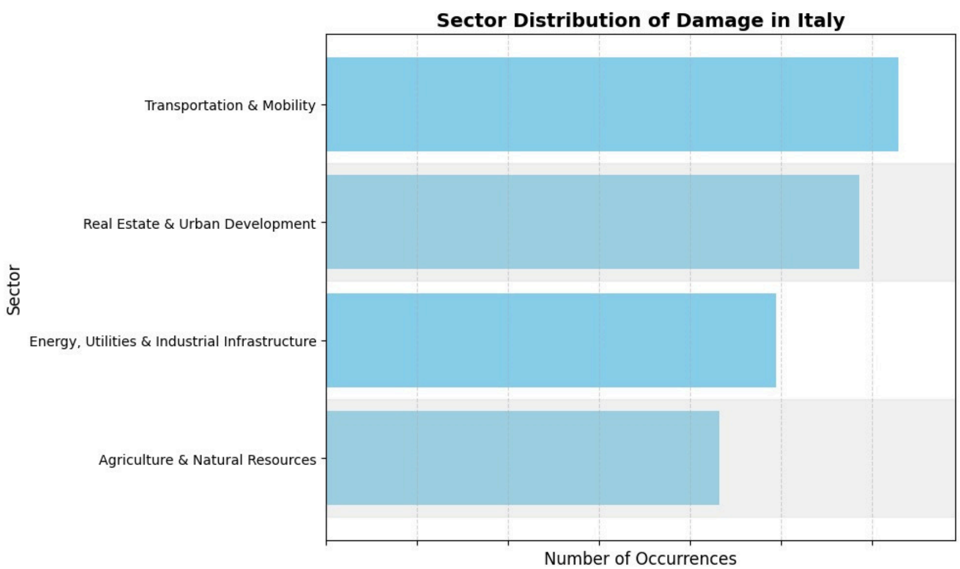
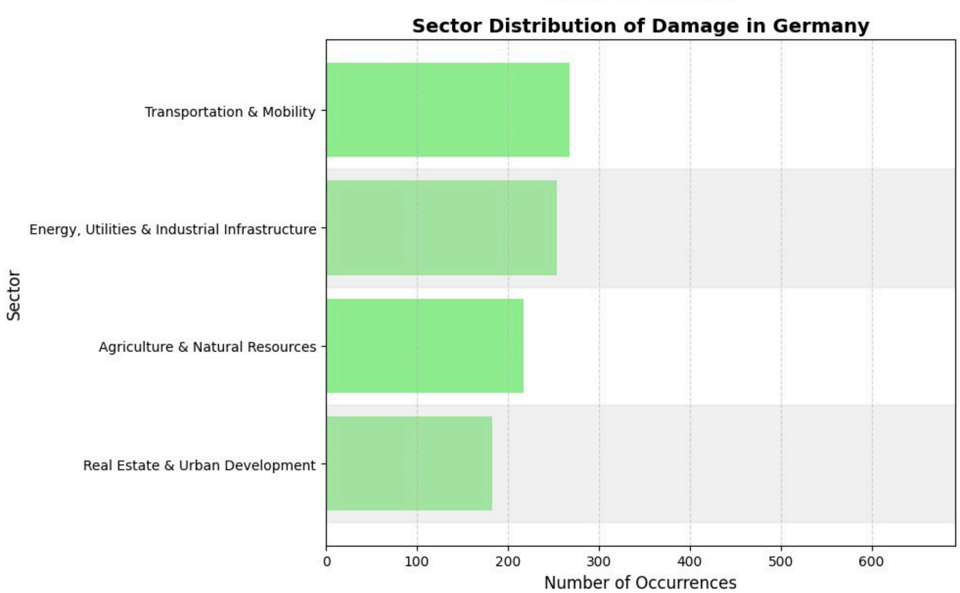
0.25
0.50
0.75
1.00
1.25
1.50
1.75
Land (ha)
1e6


Land (ha) Affected by Sector in Germany
Agriculture & Natural Resources
Real Estate & Urban Development
Transportation & Mobility
Energy, Utilities & Industrial Infrastructure
Sector
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
Land (ha)
1e6


Sector Distribution of Damage in Italy
Transportation & Mobility
Real Estate & Urban Development
Energy, Utilities & Industrial Infrastructure
Agriculture & Natural Resources
Sector
Number of Occurrences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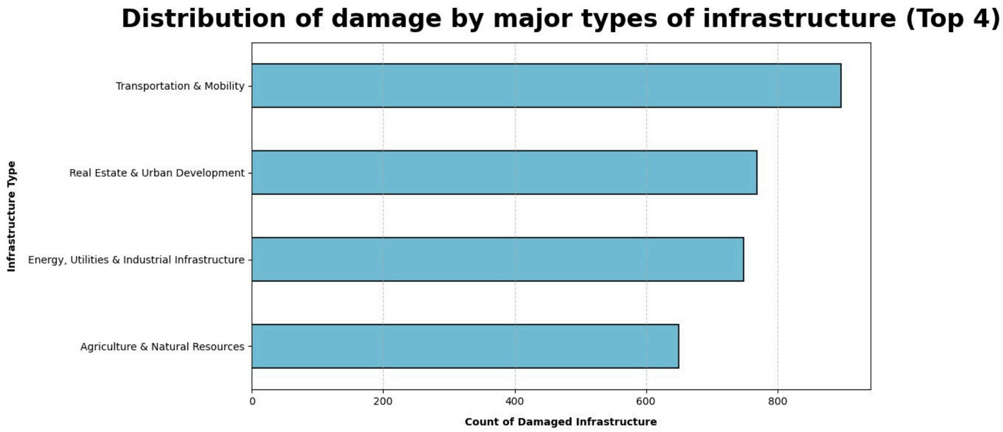
Transportation & Mobility
Energy, Utilities & Industrial Infrastructure
Agriculture & Natural Resources
Real Estate & Urban Development
Sector
0
100
200
300
400
500
600
Number of Occurrences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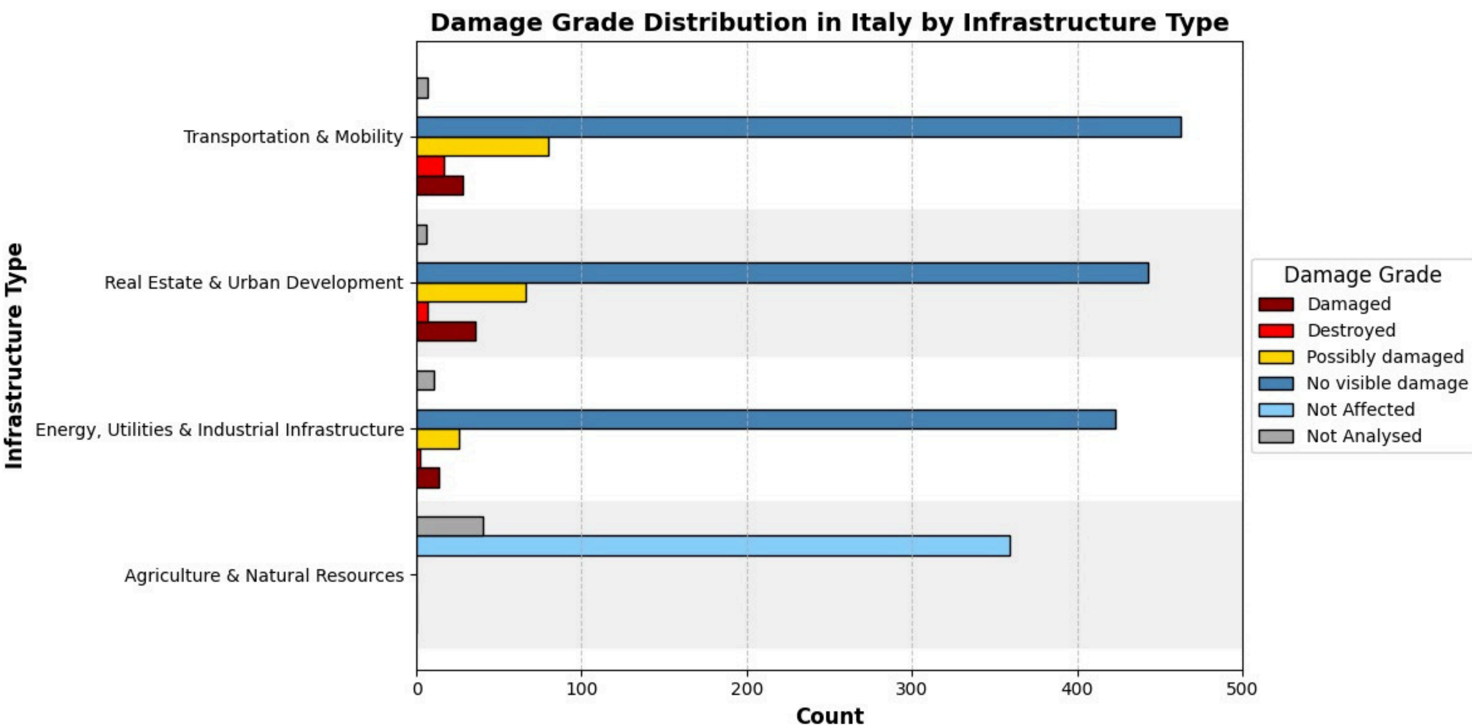
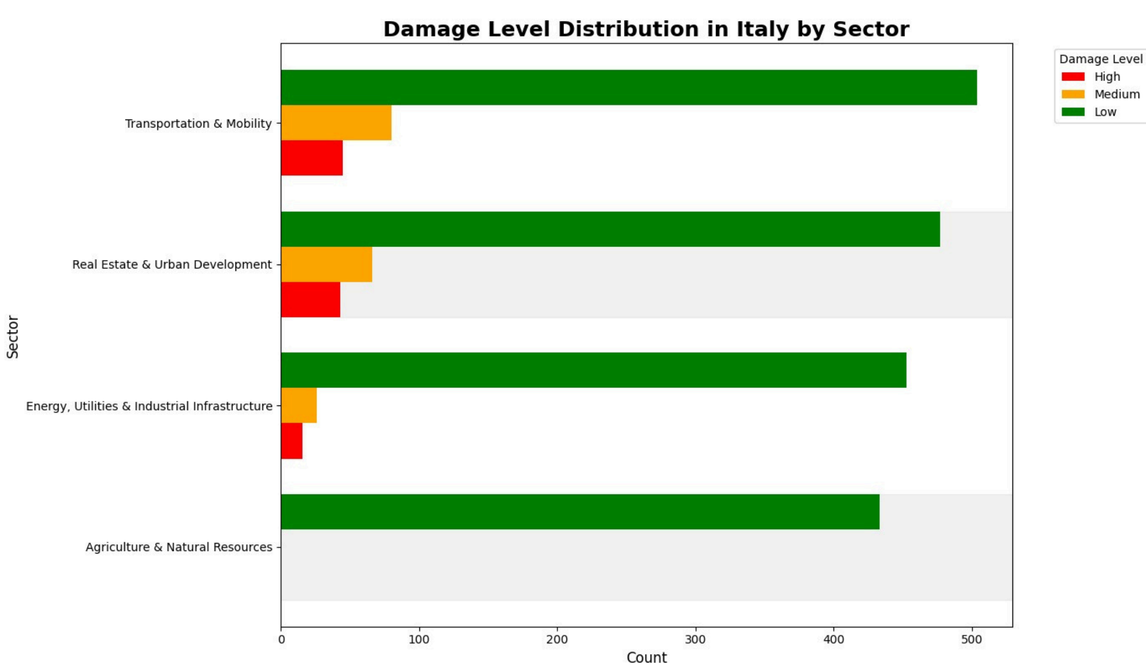
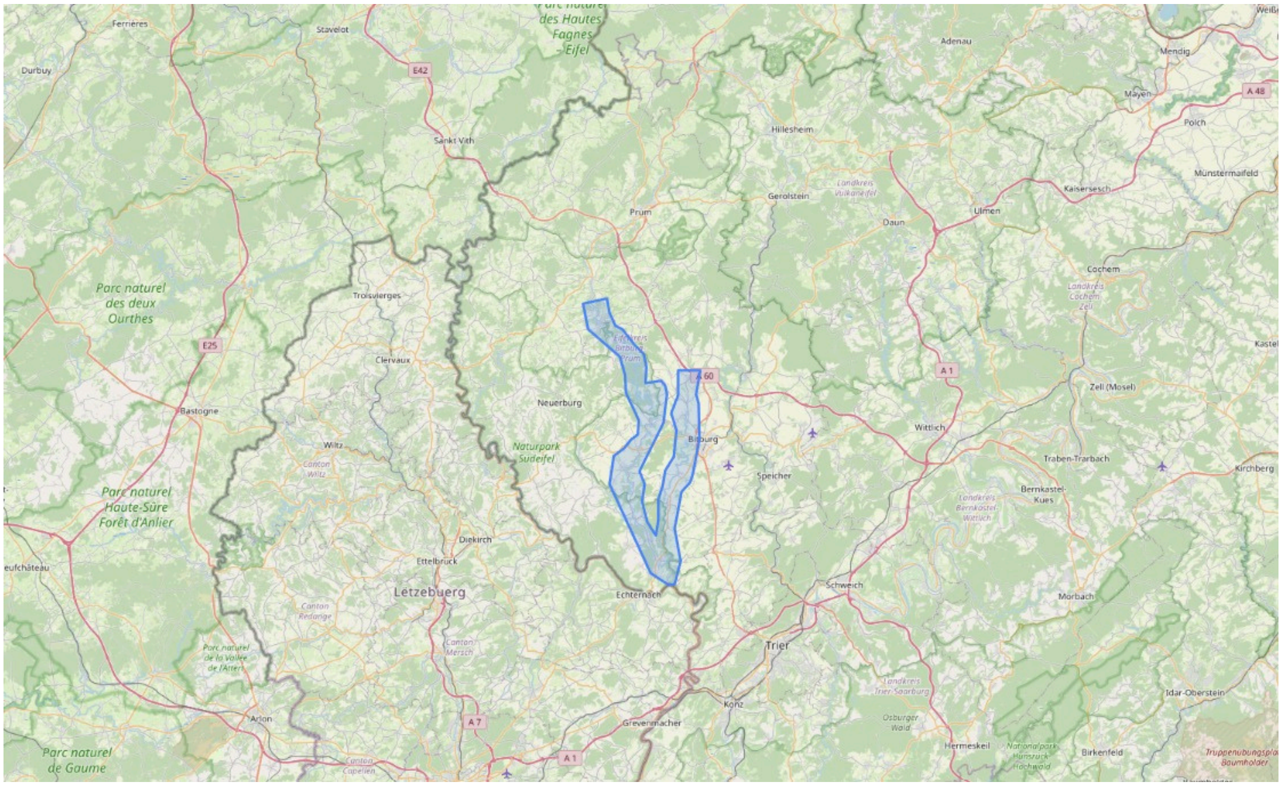
Real Estate & Urban Development
Energy, Utilities & Industrial Infrastructure
Agriculture & Natural Resources
0
200
400
600
800
Count of Damaged Infrastructure


Damage Grade Distribution in Italy by Infrastructure Type
Infrastructure Type
Transportation & Mobility
Real Estate & Urban Development
Energy, Utilities & Industrial Infrastructure
Agriculture & Natural Resources
0
100
200
300
400
500
Count
Damage Grade
Damaged
Destroyed
Possibly damaged
No visible damage
Not Affected
Not Analysed


Damage Level Distribution in Italy by Sector
Sector
Transportation & Mobility
Real Estate & Urban Development
Energy, Utilities & Industrial Infrastructure
Agriculture & Natural Resources
0
100
200
300
400
500
Count
Damage Level
High
Medium
Low

Geospatial Mapping of flood affected areas in Germany,



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