



D.2.4.1

Selection of appropriate coastal flood damage algorithms



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Executive Summary

This report assesses two candidate approaches for coastal flood damage assessment. The algorithms were developed within the ECFAS Horizon 2020 EU project and MOVIDA, an Italian national initiative financed by ADBPO. The algorithms were reviewed in relation to the STRENGTH project's coastal focus on Ravenna and Kaštela and its wider objective of strengthening resilience to sea-level rise, saltwater intrusion, flash floods, coastal floods, and related impacts. Based on this assessment, ECFAS is recommended as the primary cross-border coastal flood damage algorithm for STRENGTH. It is designed for European coastal applications, supports user-defined study areas, relies on pan-European public datasets, includes Adriatic/Croatian coastal coverage, and produces probabilistic outputs for affected population, buildings, and roads. Its open release on Zenodo, including MATLAB source code, a Windows executable, and a GNU GPL v2.0-or-later license, further supports implementation (Duo et al., 2025). MOVIDA is considered a valuable secondary framework for local refinement, particularly for Italian sites such as Ravenna. However, its reliance on Italian institutional datasets and Po River District planning workflows limits its immediate transferability to Kaštela without substantial adaptation.



1. Introduction

STRENGTH is a cross-border Italy–Croatia project focused on climate adaptation and disaster-risk reduction in coastal and urban ecosystems. Its coastal application domain includes the study sites of Ravenna (Italy) and Kaštela (Croatia). The objective of deliverable 2.4.1 is to assess which approach would be the most appropriate for coastal flood damage evaluation in these case studies. Two approaches developed by previous projects were taken into account: ECFAS (European Coastal Flood Awareness System) and MOVIDA (Modello per la Valutazione Integrata del Danno Alluvionale). ECFAS was a Horizon 2020 project financed by the European Union (<https://www.ecfas.eu>) while MOVIDA was financed by the National Po River Agency-ADBPO (<https://sites.google.com/view/movida-project>).

The ECFAS approach was designed for European-scale coastal zones, accepts user-defined study cases, uses pan-European public datasets for exposure and vulnerability support, includes the Adriatic/Croatia area in its coastal dataset, and produces probabilistic outputs for affected population, buildings, and roads. Its toolchain and licensing are also strong for implementation: the Impact Tool is openly released on Zenodo, with MATLAB source code, a Windows standalone executable, and a GNU GPL v2.0-or-later license (Duo et al., 2025).

MOVIDA, on the other side, is deeply structured, semi-automatic through the ISYDE GIS environment, tested in pilot areas of the Emilia-Romagna coast, implemented in the Po River District, and deliberately aligned with institutional planning workflows. In the context of MOVIDA Leone et al. (2025) reconstructed two Adriatic storm events, combining meteorological data, field surveys in the Rimini province, stakeholder interviews, GIS flood and impact maps, and simple versus numerical inundation modelling. The authors tried to derive direct depth–damage curves from questionnaires but the output was limited in the number of information, and it was difficult to establish a robust and statistically valid function. This is an important progress for the southern Emilia-Romagna coastal contexts but it difficult to be exported elsewhere.

It is important to take into account that damage algorithms are not full coastal hazard models. Both ECFAS and MOVIDA require externally produced inundation information or hazard mapping, so their performance depends directly on whether surge, wave setup, tide, morphology, defences, and local topography have been represented adequately in the hazard layer (Duo et al., 2025).

The scientific purpose of this report is to document the technical characteristics of ECFAS and MOVIDA, including inputs, outputs, assumptions, scales, damage functions, exposure needs, computational environment, validation, and licensing.



2. Summary of the approaches

2.1. ECFAS approach

ECFAS (European Coastal Flood Awareness System) was an Horizon 2020 project (<https://cordis.europa.eu/project/id/101004211>) and the impact framework was developed to support a proof-of-concept extension of the Copernicus Emergency Management Service toward coastal flood warning and mapping. Duo et al. (2025) defines its validated workflow around direct impacts on population, buildings, and roads, exploiting methods based on the presence of objects (where possible) considering uncertainty based on multiple input datasets, damage curves, or cost assumptions to generate a large number of possible impact scenarios. Results are therefore reported as percentile ranges rather than as single deterministic values. The ECFAS impact tool also includes railway damage and exposure layers for other sectors such as agriculture, ecosystems, power plants, points of interest, and NUTS areas (Duo et al., 2022).

A critical technical point is that ECFAS is an impact module, not a hazard model by itself. For the scope of the ECFAS project, coastal flood maps were generated with LISFLOOD-FP, using a 10 m DEM to build a 100 m hazard grid, and forcing the flood model with total water level time series that combine mean sea level, tide, storm surge, and empirical wave setup. Those flood maps were validated against satellite-based flood maps and in situ flood markers. Duo et al. (2021) describe that observed flooded areas were reliable, but modelled flood extent often showed overestimation.

For population, ECFAS uses a grid-based probabilistic method built from the Global Human Settlement - Residential population (GHS-POP) grid and the ENhancing ACTivity and population mapping (ENACT) grid. The method uses 25 layers in total—one static GHS layer plus 24 ENACT day/night monthly layers—and interpolates them to the flood-map grid, correcting for the mismatch in cell sizes. The probabilistic engine fits an empirical cumulative distribution function for each flooded cell and resamples 1000 scenarios, reporting the results as percentiles such as P2.5, P50, and P97.5. This is especially relevant for tourism-oriented coastal sites because ENACT introduces temporal population variability that is absent from many census approaches.

For buildings, ECFAS uses Open Street Map (OSM) footprints and the Copernicus Coastal Zone (CCZ) layer. OSM supplies geometry; the CCZ layer supplies the dominant land-



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use/land-cover class used to derive a building macro-classification of residential, commercial, industrial, mixed commercial/industrial, and other. Buildings smaller than 20 m² and places of worship are excluded. Flood depths lower than 0.1 m are disregarded, and the representative depth for each building is assigned by nearest-neighbour interpolation from the flood map to the building perimeter. Damage is computed using flood damage curves expressed as damage factors relative to maximum damage; ECFAS uses seven damage curves for residential building and four curves each for the commercial and industrial assets, with the mixed class receiving both commercial and industrial models. For absolute values, maximum damage follows the Huizinga database and is adjusted using country-level GDP information.

For roads, ECFAS again uses OSM road polylines and road-specific flood damage curves adapted from Van Ginkel et al. (2021). The method combines multiple road FDCs with probabilistic resampling of construction cost ranges using ECDFs, again generating 1000 scenarios. The documentation notes that the original road damage method adjusts cost by number of lanes, but in ECFAS default lane values were used for implementation for simplicity. This is a pragmatic large-scale choice, but it introduces a scale compromise that matters for local engineering applications.

Validation is one of ECFAS's strongest assets. Duo et al. (2025) report application to 16 European test cases and quantitative validation against three major coastal storms: Xynthia in La Faute-sur-Mer (France), Xaver in Norfolk (UK), and Emma in Cádiz (Spain). The validation used a database of georeferenced impact markers built from institutional, scientific, technical, media, and other sources, with quality indexing (Souto-Ceccon et al., 2025). The overall conclusion is that ECFAS provides useful affected-population estimates, reliable building and road damage estimates, and generally lower and more plausible values than coarse grid-based alternatives, especially for buildings and roads.

From an implementation perspective, ECFAS is unusually favourable. The Impact Tool bundle contains MATLAB 2021b scripts, a compiled Windows 10 executable, and the technical documentation. The software is licensed under GNU GPL v2.0 or later, while the technical document is under CC BY 4.0. As it relies on open source data, its application is straightforward for what concerns EU member states, such as Croatia.

2.2. MOVIDA approach

MOVIDA (<https://sites.google.com/view/movida-project>) is the Model for the Integrated Assessment of Flood Damage developed with the Po River District Authority (ADBPO) and



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seven universities (including the University of Ferrara) and the Italian National Research Council (CNR) to support the update of flood-risk maps and Flood Risk Management Plans (<https://www.adbpo.it/movida-modelli-e-strumenti-per-la-valutazione-integrata-del-danno/>). Its design is different from ECFAS. MOVIDA works on a higher resolution, focusing on small-scale planning and mitigation prioritization, and it deliberately assesses different asset categories with different levels of analytical maturity, rather than forcing the whole system into one homogeneous damage metric. The project's objective was to provide an information system able to perform an analytical evaluation and mapping of expected damage, replacing older qualitative practices (Ballio et al. 2022).

MOVIDA's methodology divided the damage assessment into five Floods Directive groups: population, infrastructures, economic activities, environmental and cultural heritage, and sites with risks of natural hazard. The process is structured around four steps: identifying available data that include hazard, exposure, and vulnerability, defining the scale of analysis and result representation, computing exposure, and then computing damage using the models available for that asset class. Depending on the asset category, MOVIDA outputs may be expressed as estimated economic damage, as other indicators such as exposed people or affected assets, or as qualitative damage classes.

The software stack is well structured and operational. ISYDE is described as an open-source GIS plugin or open information system developed using QGIS, Python, and SQL. The detailed ISYDE report describes a database built with PostgreSQL/PostGIS, managed through PgAdmin, and implemented in QGIS LTR 3.10.14, using the QGIS Graphical Modeler and integrated processing providers.

MOVIDA is focused on the exposure and qualitative damages of buildings, cultural heritage, and environmental assets rather than on quantification of economic loss. However, for residential buildings MOVIDA becomes much more quantitative. It estimates expected economic structural damage by averaging three models: Carisi et al. (2018), Simple-INSYDE (Galliani et al., 2020), and Arrighi et al. (2018). The analysis is done at single-building scale where a regional topographic database is available. Mean depth is assigned to each building, flooded floors are derived from water depth, and the final indicator is expressed as unit damage per flooded area (ADBPO, 2021).

Models were tested in six pilot areas, the procedure was then implemented in all Areas of Potential Significant Flood Risk (APSFR) in the Po District, and institutions were trained to use the tools (<https://www.adbpo.it/come-valutare-limpatto-delle-alluvioni-sul-sistema-antropico-corso-per-lutilizzo-dellapplicativo-isyde/>). Results are provided as tables, charts, and maps, including overall expected damage at APSFR level and spatial distribution of



impacts, and that the system has already supported damage-map updating and mitigation prioritization in the Po District (Simonelli et al., 2022).

3. Methodology for Comparative Assessment

The comparison framework applies six criteria. The first considers coastal process relevance, meaning whether the algorithm is designed for marine flooding and whether it can use hazard maps produced considering the tide, surge, wave setup, and local morphology. The second is geographic influence on applicability, since the sites of STRENGTH are from Italy and Croatia and therefore data availability might be different. The third is data dependence, therefore if the method is usable with widely available and consistent layers or instead requires national/regional institutional databases. The fourth is damage-model maturity, including depth–damage functions, asset coverage, and uncertainty treatment. The fifth is validation strength, with particular emphasis on coastal cases. The sixth is implementation readiness, including software architecture and licensing.

A second criterion considers whether the site conditions can be transferred to both sites in Ravenna and Kaštela. To notice that the coastal morphology of the two regions is quite different,: a low-gradient sandy barrier–lagoon coast (Ravenna) and an embayed urbanized coast with engineered shoreline segments (Kaštela).

4. Results

The review shows that ECFAS and MOVIDA are both reliable impact-assessment frameworks, but they solve different issues.

From an operational perspective, ECFAS offers a more immediately transferable baseline for STRENGTH. It was developed for large-scale European coastal flood impact assessment and can be applied to user-defined coastal cases, provided that suitable inundation maps are available in a consistent format. In addition, the ECFAS Impact Tool is distributed as a methodological and software package, including source code and a compiled executable, and is accompanied by explicit open licensing (Duo et al., 2022; Duo et al., 2025). This allows STRENGTH to treat ECFAS not only as a scientific reference, but also as a deployable and reproducible tool for cross-site comparison.

A particularly relevant feature for Ravenna is that ECFAS already addresses a classification problem typical of Adriatic beach environments. In Emilia-Romagna, some OpenStreetMap



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buildings located on beaches may fall within Copernicus Coastal Zone classes that are not explicitly labelled as commercial. To avoid underestimating tourism-related exposure, ECFAS includes beach-related classe within the commercial macro-class. This choice was made to better represent beach facilities and coastal tourism activities in sites such as Lido delle Nazioni, Lido di Dante and Rimini. For this reason, ECFAS is already relatively close to the Ravenna coastal context, where beach concessions, bathing establishments and seasonal tourism assets are important components of exposure.

MOVIDA has a different methodological approach. It was developed mainly to support Flood Risk Management Planning in the Po River District and is explicitly structured around different asset categories. This makes the framework flexible and rich from a public-planning perspective, but also less homogeneous than ECFAS if the objective is to produce one common economic loss indicator across different countries. MOVIDA can operate at micro-scale for some assets, for example individual buildings or infrastructure sections, but its planning outputs are often aggregated at small-scale. This is coherent with the original resolution of the local datasets.

The strongest added value of MOVIDA for STRENGTH could be local refinement, especially in Ravenna. However, the same aspect also highlights current limits of transferability. Its calibration is based on a limited number of Emilia-Romagna case studies, a small sample of interviewed establishments, and stakeholder-reported damage information. These data are valuable for improving damage estimates in the Emilia-Romagna coastal settings, but they are not yet sufficient to define a generic cross-border operational standard applicable without adaptation to Kaštela. In the Croatian site, MOVIDA would require the replacement or reconstruction of several Italian institutional inputs, including exposure datasets, cost assumptions, classification schemes and possibly vulnerability relationships.

MOVIDA is also strong in areas where ECFAS is less detailed, especially transport functionality. While ECFAS focuses mainly on direct physical damage and repair-cost estimation for roads, MOVIDA includes a functional damage approach for roads and railways. It classifies impacts as null, low, medium or high by combining hydraulic severity with the importance, uniqueness and role of the infrastructure section. Roads are differentiated by relevance and topography, including bridges, viaducts and tunnels, while railway lines and stations are also assigned functional impact classes. This makes MOVIDA particularly useful for emergency planning and network operability, even when it does not provide the same type of direct monetary estimate as ECFAS.

There are also practical implementation differences. MOVIDA avoids proprietary GIS software through the ISYDE environment, based on open-source GIS and database tools, but



it requires a more explicit GIS/database setup than the packaged ECFAS Impact Tool. Moreover, while MOVIDA materials describe ISYDE as open source, the publicly reviewed documentation does not expose a standalone software licence as clearly as the ECFAS tool documentation does. For formal operational reuse in STRENGTH, code access and licensing conditions for MOVIDA/ISYDE should therefore be clarified directly with the maintainers.

The role of coastal geomorphology is important for both methods as well. ECFAS explicitly includes tide, surge, and wave setup in the hazard evaluation, but its impact layer still assumes that flood depth at the asset is the principal driver of direct damage. MOVIDA, similarly, depends on flood-hazard inputs and uses sectoral vulnerability models that are mostly not based on coastal processes. Leone et al. (2025) improves this by linking damage curves to real storm reconstructions, but it still does not provide a self-evolving morphodynamic model. Consequently, both methods are most reliable when the hazard layer captures the effects of beach type, barrier or lagoon systems, local tidal range, storm surge, wave setup, and recent sediment-state changes such as beach narrowing or artificial dune crest lowering. The “artificial dune” is the result of beach scraping in winter performed on beaches of Emilia-Romagna and modelling by Harley and Ciavola (2013) has proved that an accurate design can be of support for flood defence. On a low-gradient sandy beach, a small vertical bias in total water level can cause a large horizontal flood-extent error; on an embayed urban shoreline, locally transformed wave runup, overtopping, seawalls, harbour geometry, and drainage backwater can dominate flood patterns. Those process differences matter directly for algorithm applicability because the same damage function can behave very differently under different hazard-generation mechanisms (Duo et al., 2025).

5. Discussion

On the evidence reviewed, ECFAS should be preferred to MOVIDA as the primary coastal flood damage algorithm for STRENGTH. The reasons are methodological, operational, and geographic.

Methodologically, ECFAS is the most coherent coastal algorithm. Its documented hazard-to-impact chain is explicitly marine in origin, combining total water level components and applying probabilistic impact estimation to coastal inundation scenarios. Leone et al (2025) makes MOVIDA more coastal than the original algorithm, developed for river and flash flooding (i.e. freshwater), but only for a narrow set of tourism-beach assets and only through a small number of Italian case studies.



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ECFAS was released with code in an executable format, its licensing is clear, and its baseline inputs can be assembled from harmonized sources. MOVIDA is effective inside its original study area of validation, but limited by its structure, meaning that it can be applied only in Ravenna and its applicability in Kaštela would require a large adaptation effort, not necessarily leading to success.

ECFAS was designed for European transfer and validated on multiple coastal cases. MOVIDA, by contrast, is demonstrably strong in the Po District and promising in Emilia-Romagna tourist-beach settings, but it is not yet demonstrated as a ready-to-run Croatian coastal solution.

Coastal geomorphology strengthens this conclusion. On a low-gradient sandy coast, beach width, dune crest elevation and recent sediment redistribution strongly affect inundation depth and extent. Ravenna is exactly the kind of site where event-specific hazard maps and locally calibrated tourism/beach curves can add discernible value. Kaštela, by contrast, likely requires careful treatment of embayment geometry, coastal structures, drainage, and local overtopping, all of which can be handled upstream in the hazard maps but are not currently embedded in MOVIDA’s coastal calibration. All features of the ECFAS and MOVIDA approaches are listed in table 1, combined with implications for STRENGTH.

Table 1 - Summary of the main technical differences between ECFAS and MOVIDA applied to the context of STRENGTH.

Attribute	ECFAS	MOVIDA	Implication for STRENGTH
Primary design objective	Pan-European coastal flood impact assessment and warning support, including user-defined study cases.	District-scale flood damage mapping for FRMPs and mitigation prioritization in the Po River District.	STRENGTH’s cross-border coastal framing aligns directly with ECFAS.
Hazard inputs	Requires external coastal flood maps; in the project, these came from LISFLOOD-FP with depth, extent, and velocity fields.	Requires hazard maps per scenario; ISYDE can work with raster depth maps or, when necessary, vector hazard bands.	Both need hazard inputs; neither removes the need for strong site hydrodynamics.
Geographic influence	The approach is built for European coastlines.	The approach is made for the Emilia-Romagna (Italy).	ECFAS for both Ravenna and Kaštela is a reliable method.



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Attribute	ECFAS	MOVIDA	Implication for STRENGTH
Spatial scale	Population on grids; takes into account buildings and roads; typical hazard grid 100 m.	Micro- to meso-scale analysis, but outputs often returned at census-section scale for district planning.	ECFAS is better for consistent cross-site application.
Temporal treatment	Event-based and scenario-based; population includes monthly/day-night variability through ENACT.	Scenario-based planning framework; resident population from census, not seasonal tourist dynamics.	ECFAS better captures seasonal population relevance in coastal tourism areas.
Asset coverage	Validated for population, buildings, roads; tool bundle also covers railways and other exposure sectors.	Population, roads/railways, strategic buildings, cultural/environmental assets, residential, commerce/industry, crops, livestock.	MOVIDA is broader in planning categories; ECFAS is more coherent in coastal environments.
Vulnerability and damage functions	Probabilistic ensemble using multiple building and road FDCs; 1000-scenario ECDF resampling; country-based maximum damage values.	Strong for residential buildings and crops; qualitative/functional or exposure-only for several other sectors; coastal extension adds local depth–damage curves for bathing establishments.	ECFAS is better as a quantitative baseline; MOVIDA is best for selective local refinement.
Validation	16 test cases, 3 detailed coastal reference cases, comparison against reported impact markers and grid-based methods.	Six pilot areas, district implementation in APSFRs, and operational uptake by regional authorities; coastal extension documented on two Emilia-Romagna storms only at a local level.	ECFAS has stronger publicly documented, peer-reviewed coastal validation for cross-site use.
Computational environment	MATLAB 2021b scripts plus Windows 10 executable.	QGIS/PostgreSQL/PostGIS/Python/SQL workflow, designed for semi-automatic use.	ECFAS is easier to package quickly; MOVIDA is more GIS-native and modular.
Licensing	Clear: GNU GPL v2.0-or-later for the tool; CC BY 4.0 for the technical document.	Public materials describe ISYDE as open/open-source, but reviewed public pages do not clearly expose a standalone software license in the same explicit way.	ECFAS is a lower-risk solution for formal project deployment and redistribution.



6. Conclusions

The comparison between the ECFAS and MOVIDA approaches was carried out to identify the most appropriate method for STRENGTH. ECFAS should be selected as the primary coastal flood damage algorithm for the project, while MOVIDA should be retained as a complementary local refinement framework for Ravenna. The ECFAS approach is designed for coastal environments, it uses normalized exposure datasets, produces probabilistic outputs, has stronger public coastal validation, can be adapted to Italian and Croatian study sites, and is openly released with clear licensing. MOVIDA is methodologically rich and highly valuable where Italian institutional datasets are available, especially for residential buildings, functional transport assessment, tourism and beach-concession assets. However, its current implementation remains strongly tied to Italian data structures and its coastal extension is not yet sufficiently generalized for immediate transfer to Kaštela.

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