GSEU GEOLOGICAL SERVICE FOR EUROPE

www.geologicalservice.eu

EGDI Multifunctional 2D/3D Decision-Support Module

Version: v1

Project	101075609 — GSEU — HORIZON-CL5-2021-D3-02
Deliverable Data	
Deliverable number:	**D5.7**
Dissemination level:	**Public**
Deliverable type:	**Report**
Work package:	**WP5 – Coastal vulnerability assessment & optimised offshore windfarm siting**
Lead WP/Deliverable beneficiary:	**HSGME/GEUS**
Deliverable status	
Verified (WP leader):	Eleftheria Poyiadji (HSGME)
Approved (Coordinator):	Julie Hollis (EGS)

Author(s): Isak Ring Larsen	Affiliation: GEUS
Verner Brandbyge Ernstsen	GEUS
Aurélie Maspataud	BRGM
Nicola Dakin	BGS
Sytze van Heteren	TNO
Anna Koutroulli	HSGME
Eleftheria Poyiadji	HSGME

Funded by the European Union

EuroGeoSurveys European Geoscience for Society
The Geological Surveys of Europe

Disclaimer

Copyright

Funded by the European Union

EuroGeoSurveys European Geoscience for Society
The Geological Surveys of Europe

Revision History		
Author(s):	**Description:**	**Date:**
Main Authors	1st Draft	31/01/2025
Jørgen Tulstrup (WP 7 lead)	1st Review (external WP7)	07/02/2025
Eleftheria Poyiadji (WP5 lead) and Anna Koutrouli (WP5)	2nd Review (internal WP5)	10/02/2025
Kris Piessens (T6.4 lead)	3rd Review (external WP6)	11/02/2025
Main Authors	2nd Draft	12/02/2025
Francesco Pizzocolo	4th Review	17/02/2025
Main Authors	3rd Draft	20/02/2025
Verner Brandbyge Ernstsen	Final Draft	21/02/2025
Francesco Pizzocolo	Final Version	23/02/2025

Funded by the European Union

EuroGeoSurveys European Geoscience for Society
The Geological Surveys of Europe

Executive Summary

The EGDI Multifunctional 2D/3D Decision Support Module plays a crucial role in improving decision-making for both coastal vulnerability assessment and offshore windfarm siting. This document provides an in-depth inventory of existing Decision Support Systems (DSSs), Decision Support Tools (DSTs), and Decision Support Indices (DSIs) used by Geological Survey Organisations (GSOs) across Europe. The study is based on a structured questionnaire circulated among GSOs to gather insights into their methodologies, tools, and outputs. By evaluating current practices and identifying gaps, this report lays the foundation for future improvements in decision-support frameworks.

Part 1: Decision Support Modules for Coastal Vulnerability

Coastal areas are under increasing pressure from human activities, climate change, and extreme weather events, making coastal vulnerability assessments a critical component of sustainable management. Decision Support Systems (DSSs) provide structured frameworks for evaluating these vulnerabilities, guiding stakeholders in risk mitigation and adaptation strategies. However, the application of DSSs varies across different GSOs, with some institutions using dedicated DSSs while others rely on standalone Decision Support Tools (DSTs) such as Geographic Information Systems (GIS) and numerical modelling tools. The Coastal Vulnerability Index (CVI) remains the most widely used Decision Support Index, though emerging methodologies incorporating Bayesian Networks and Artificial Neural Networks are beginning to improve predictive capabilities.

Decision Support Tools such as GIS-based platforms, numerical modelling software, and Multi-Criteria Decision Analysis (MCDA) are fundamental to coastal vulnerability assessments. These tools process diverse data sources, allowing for spatial analysis and predictive modelling of coastal zone dynamics. Key parameters considered in these assessments include topography, bathymetry, coastal behaviour, sediment composition, and metocean conditions, as well as socio-economic factors such as land use and population density. Despite the widespread use of these tools, a significant challenge remains in the standardisation of methodologies across different regions, as variations in terminology and assessment frameworks can hinder comparability.

The findings emphasise the need for enhanced cross-institutional collaboration to align methodologies and facilitate knowledge sharing among GSOs. The integration of machine learning techniques into decision-support workflows presents a promising avenue for improving accuracy and reliability. Moving forward, the development of best-practice decision-support models will be a key priority, ensuring that future coastal vulnerability assessments are more comprehensive and scientifically robust.

Part 2: Decision Support Modules for Offshore Windfarm Siting

With the rapid expansion of offshore wind energy, there is a growing need for informed decision-making to ensure the sustainable development of windfarm sites. Geological conditions, such as seabed stability, sediment composition, and metocean factors, play a crucial role in determining the feasibility of offshore wind projects. This section of the report examines the existing DSSs used for offshore windfarm siting, revealing that while some GSOs have developed dedicated decision-support frameworks, many rely on Marine Spatial Planning (MSP) tools and GIS-based assessments.

Compared to coastal vulnerability assessments, the field of offshore windfarm siting decision support remains less developed. Many existing tools prioritise economic and environmental considerations while overlooking detailed geological assessments. Nonetheless, some GSOs have begun integrating geodiversity indices and geo-assessment matrices into their site-selection processes. These

approaches provide a systematic way to evaluate geological suitability, ensuring that site assessments account for critical factors such as subsurface stability, bathymetric constraints, and infrastructure proximity.

GIS-based tools remain the primary decision-support instruments for offshore windfarm planning, with ArcGIS, QGIS, and Multi-Criteria Decision Analysis (MCDA) being widely used. In some instances, Bayesian Networks have been introduced to model uncertainties in seabed conditions and infrastructure placement. However, there remains a gap in the use of standardised geological indices that could improve comparability and facilitate cross-border collaboration. By integrating machine learning and probabilistic modelling approaches, decision-makers can refine their assessments and mitigate risks associated with offshore windfarm development.

The findings of this report highlight the need for greater emphasis on geological factors in offshore windfarm siting and call for the development of standardised decision-support frameworks that align geological, environmental, and socio-economic considerations. Future efforts should focus on harmonising methodologies across institutions and fostering collaboration among GSOs, policymakers, and industry stakeholders to ensure that offshore wind energy projects are based on scientifically sound decision-making.

Conclusion and Future Directions

The findings of this study underscore the critical role of Decision Support Systems (DSSs) and Tools (DSTs) in enabling evidence-based decision-making for both coastal vulnerability and offshore windfarm siting. While significant progress has been made in developing decision-support frameworks, challenges remain in standardising methodologies, integrating advanced technologies, and fostering cross-institutional collaboration.

Moving forward, efforts will focus on developing best-practice decision-support modules that build upon the existing inventory of DSSs. The refinement of standardised geological indices will be essential to improving the comparability and consistency of assessments across different regions. Additionally, the integration of Bayesian Networks, AI-driven modelling, and geospatial visualisation tools will enhance predictive capabilities and allow for more comprehensive risk assessments.

As the challenges of climate change, coastal hazards, and renewable energy expansion continue to evolve, ensuring transparent, science-based decision-making will be paramount. Strengthening collaboration between GSOs, policymakers, and industry partners will be key to aligning research efforts with practical applications, ultimately leading to more resilient coastal management and sustainable offshore wind energy development.

Table of Contents

List of Figures

List of Tables

1. Part 1 – Collation and Inventory of Existing Decision Support Modules in Relation to Coastal Vulnerability

2. Introduction

Coastal areas are sensitive zones that require careful management under increasing pressure due to human activity (e.g. urbanisation), climate change (e.g. sea-level rise) and extreme weather events. The assessment of the vulnerability of coastal zones requires an interdisciplinary approach, considering the major influence of geomorphology and surface geology on coastal evolution and associated risks. The overall scope of WP5 is to enable governments, industry, cultural heritage organisations and the marine research community to make informed decisions regarding the sustainable development, management and protection of coastal environments and the seabed.

Decision Support Systems (DSS) play a key role in enhancing coastal resilience by providing structured frameworks for evaluating coastal susceptibility and vulnerability and guiding sustainable management (Wong-Parodi et al., 2020). These systems integrate various data sources and analytical tools to help stakeholders make informed decisions about coastal planning, hazard mitigation, and resource management (Barzehkar et al., 2021).

Coastal susceptibility is according to The European Environmental Agency (EEA) the sensitivity of natural environments such as beaches and dunes to erosion/flooding (Ramieri et al., 2011; Rizzo et al., 2018), while coastal vulnerability incorporates human activities/uses. Hence, socio-economic aspects are also considered in coastal vulnerability assessments. Coastal risk is defined as the potential for adverse consequences for human or ecological systems, thereby incorporating a probabilistic approach (Reisinger et al., 2020). Coastal resilience is the capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure (IPCC, 2021).

Several DSSs have been developed for application in the coastal environment. These include e.g. DIVA (Dynamic Interactive Vulnerability Assessment), THESEUS, RISC-KIT (Resilience-Increasing Strategies for Coasts – toolkit), DESYCO and COMASO (Hinkel et al., 2013; Zanuttigh et al., 2014; Poelhekke et al., 2016; Torresan et al., 2016; Coelho et al., 2021). DSSs utilise several Decision Support Tools (DST). These include Geographical Information Systems (GIS), numerical modelling software (e.g. XBeach) as well as Multi-Criteria Decision Making (MCDM) and machine-learning approaches (e.g. Bayesian Networks) (Jäger et al., 2018). Outputs of a DSS can assist when deciding on mitigation measures applied to e.g. coastal hazards. The outputs are typically Decision Support Indices (DSI) that allow the inclusion of multiple physical, environmental and socioeconomic inputs expressing susceptibility, resilience and vulnerability (Furlan et al., 2021; Barzehkar et al., 2021).

Coastal vulnerability studies have often neglected the importance of geological parameters, often only including topographic/bathymetric data and sometimes rates of change in shoreline position (Sayers et al, 2002; van Verseveld et al., 2015; Jäger et al., 2018; Sanyu & Jimenez, 2021). In the COMASO DSS, a tool was included to design hard coastal structures (Coelho et al., 2021). The authors stated the importance of geotechnical properties of the bed and its dynamics, but did not include these in the further work, instead going for a simplified model based on incident wave height.

The overall aims of Task 5.4 on cross-thematic alignment are linking data, information and knowledge from WP5 to WP6 and to WP7 towards developing decision-support modules (deliverables D5.7/D5.8) to support informed decisions for a) managing and protecting the coastal zone, and b) derisking offshore wind energy installations, including the inherent connection between offshore wind energy installations

and the coastal zone. Hence, T5.4 contributes to the decision-making domain that builds on existing knowledge and on new knowledge, including new knowledge generated in WP5 (cf. Figure 1).
The preliminary objective of Task 5.4 presented in this part of the report was to collate existing decision support modules in relation to coastal vulnerability and to describe the modules and their application (T5.4a-1) in order to develop an inventory of existing decision support modules to be shared on EGDI (D5.4a-1).

Hence, the following specific objectives in this part of the report were:

- To create a conceptual model of a generic DSS and related components based on a literature review to be used as a guiding framework.
- To create a questionnaire for enquiring information on existing DSSs and related components used in relation to coastal vulnerability using the conceptual model as a guiding framework, and to circulate this to all Geological Survey Organisations (GSO).
- To collate and present existing DSSs and related components used by GSOs in relation to coastal vulnerability in a report format and subsequently share these on EGDI.

The subsequent objective of Task 5.4 to be presented in a later report is (cf. D5.8, M54):

- To develop and report best-practice decision support modules in relation to coastal vulnerability (T5.4a-2 and D5.4a-2)

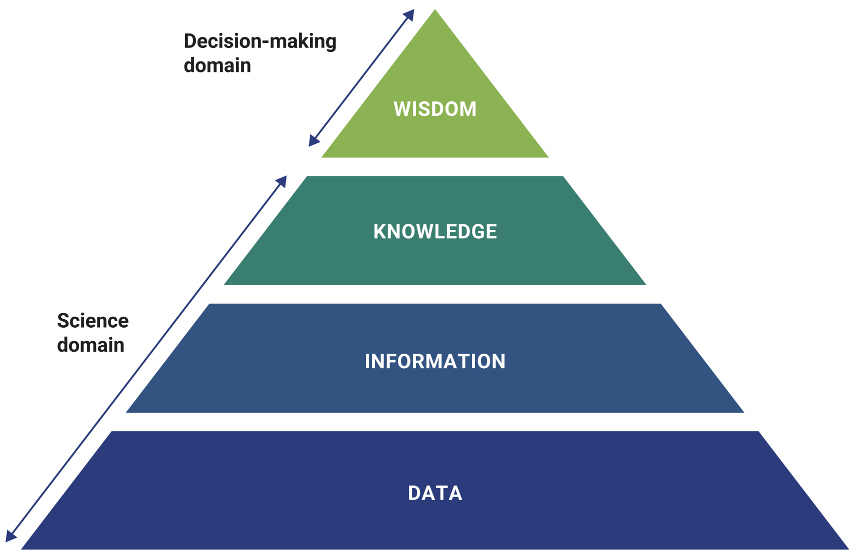

Figure 1. Data-Information-Knowledge-Wisdom (DIKW) Pyramid where T5.4 and this report contribute to the decision-making domain, building on existing knowledge and on new knowledge, including new knowledge generated in WP5.

Hence, this part of the report provides an inventory of existing DSSs, DSTs, and DSIs and other outputs that are applied in relation to coastal vulnerability, with the content being based on the responses to the questionnaire distributed to all GSOs in WP5, detailing their current practices, tools, and methodologies.

3. Materials and Methods

3.1. Conceptual model of generic DSS

A review of the literature on Decision Support Systems (DSS) and their application in coastal vulnerability assessments was conducted. The review focused on identifying the key components, tools, and outputs of existing DSS frameworks. The insights gathered were synthesised to develop a conceptual model representing a generic DSS for coastal vulnerability. The model, illustrated in Figure **2**, outlines the relationships between various DSS components, including input data layers, decision-support tools, analytical methods, and outputs. It serves as a guiding framework for subsequent tasks and was made generic to accommodate the assumed diverse workflows among GSOs.

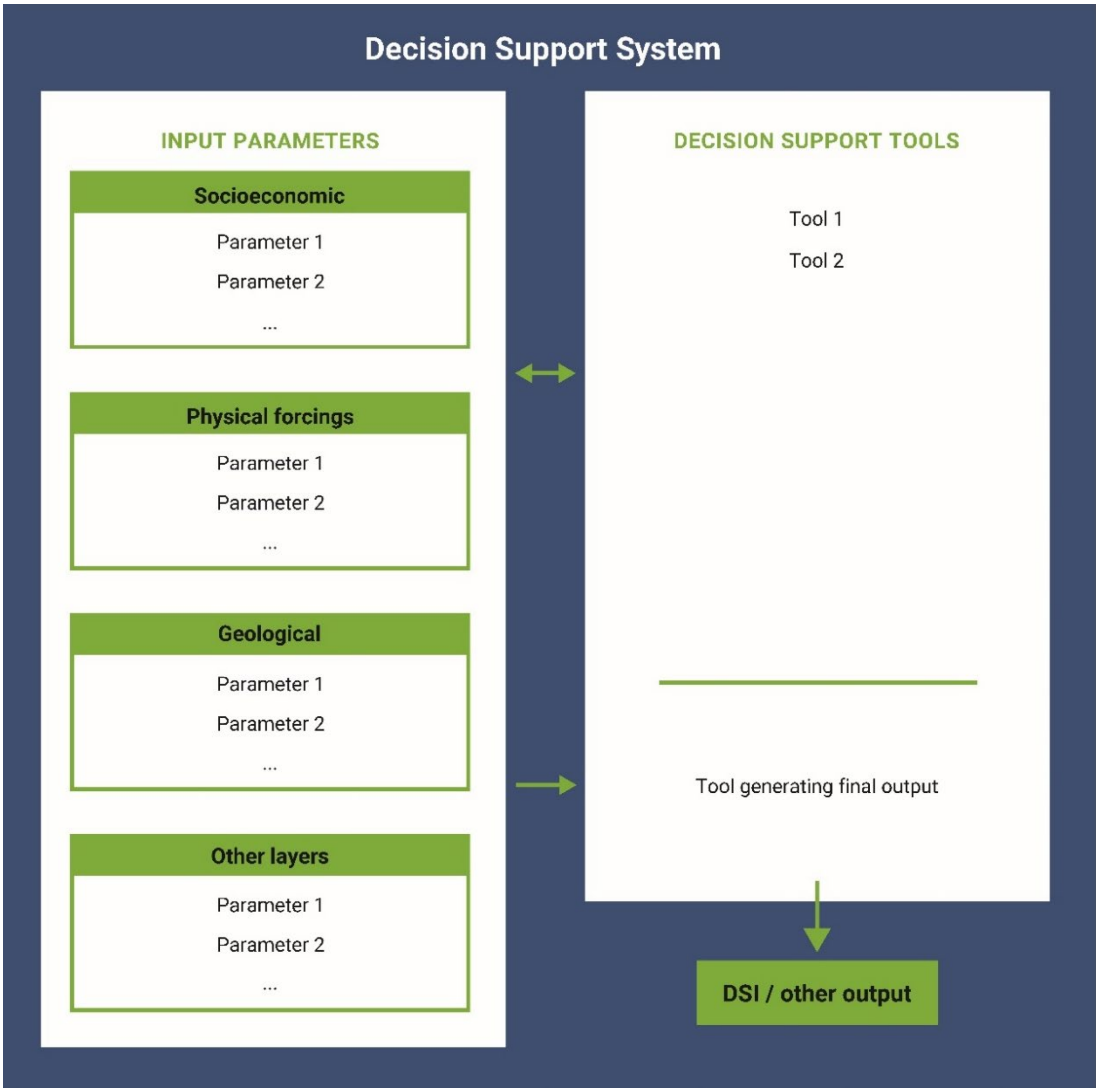

Figure 2. Conceptual model of a Decision Support System with input parameters / information layers, Decision Support Tools, and Decision support Indices or other outputs that can support decision-making.

The different elements of a DSS are shown in
Figure **2**. The blue box form the overall DSS; the white box to the left accounts for the parameters which are considered when analysing coastal vulnerability; the tools in the upper part of the white box to the right form the DSTs which are used to prepare data, e.g. GIS, XBeach, Python, European Ground Motion Service (EGMS) etc.; the tool in the lower part of the white box to the right is the DST which is applied to analyse the input parameters and derive an output; the green box to the right is the output produced by the DSS which can be utilised by decision-makers. This can be in the form of a DSI or in another format.

The conceptual model can integrate a wide range of components, such as Geographical Information Systems (GIS), Multi-Criteria Decision Analysis (MCDA) and predictive modelling approaches like Bayesian Networks and Artificial Neural Networks. This ensures the framework is adaptable for both established and emerging methodologies, enabling a holistic approach to decision-making in coastal management.

3.2. Questionnaire for enquiring information on existing DSS

A questionnaire was developed using the conceptual model as a foundation. The questionnaire was designed to gather detailed information on existing DSSs and DSTs used by GSOs, as well as outputs produced by GSOs when assessing coastal vulnerability. Key areas of inquiry included:

- The types of DSSs and DSTs utilised.
- The parameters considered when evaluating coastal vulnerability.
- The specific outputs generated to support decision-making processes.

Accompanying the questionnaire was an example showing a case-study fitted to the conceptual model. The study by Göke et al. (2018) concerned optimised offshore windfarm siting in the Baltic Sea. The questionnaire was circulated to GSOs involved in WP5. Quantitative and qualitative analyses were performed to summarise the findings. Additionally, responses were integrated in the conceptual model to enable cross-country comparisons.

4. Decision Support Systems (DSS)

Decision Support Systems (DSSs) are comprehensive frameworks that combine various tools and data layers to assist decision-making processes in managing coastal vulnerability. The systems are used to assess coastal risks, such as erosion, flooding, and sea-level rise, and to develop strategies for mitigating these risks. The questionnaire enquired: *"Do you or does your institute have expertise in DSSs for evaluating geology in relation to coastal vulnerability?"*.

The responses showed that expertise in DSSs varies across European countries. The analysis showed that 37% of the GSOs use a DSS in relation to coastal vulnerability, while 16% of the GSOs mentioned that another institution in their country applies a DSS in relation to coastal vulnerability (Figure 3). The spatial distribution of application of DSSs among GSOs can be seen in
Figure 4.

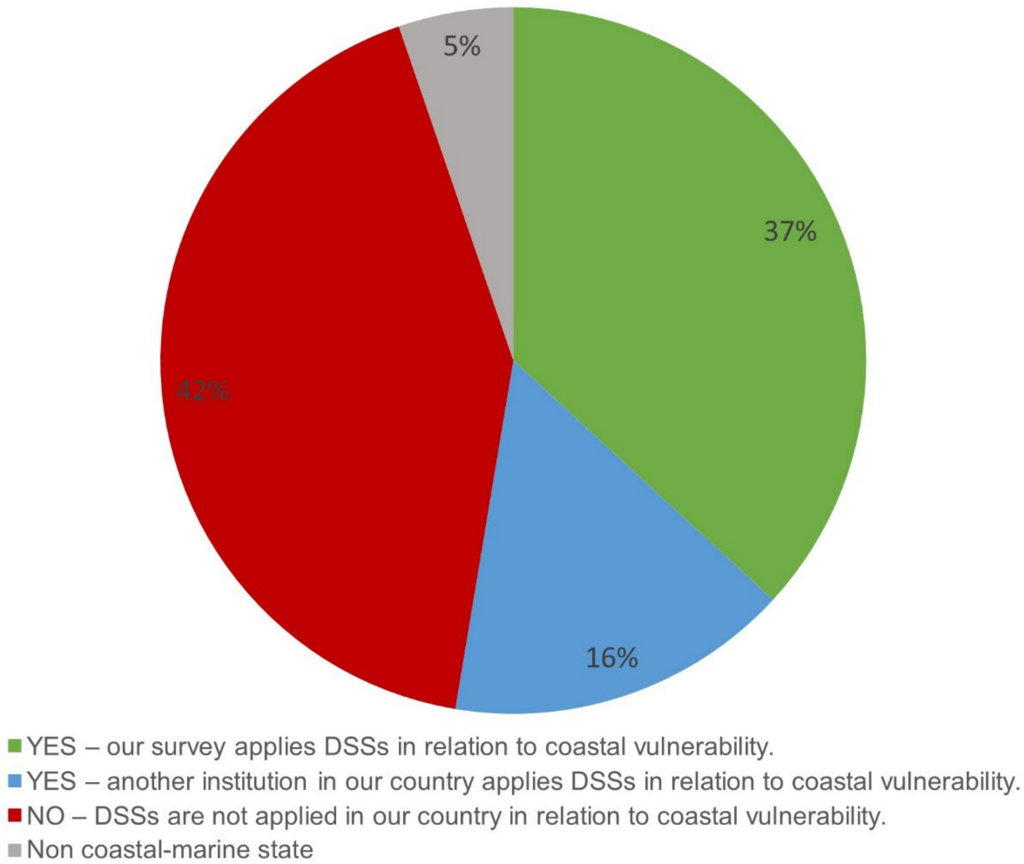

Figure 3. Percentage of geological surveys around Europe who applies a DSS. Number of respondents = 19.

The purpose of DSSs in coastal vulnerability assessments is multifaceted. In the responses to the questionnaire, the GSOs emphasised the following four purposes of utilising DSSs:

- Identify areas at risk of coastal hazards.
- Support the design of mitigation measures.
- Provide projections of future coastal dynamics.

•	Assist policymakers in making informed decisions based on scientific data.

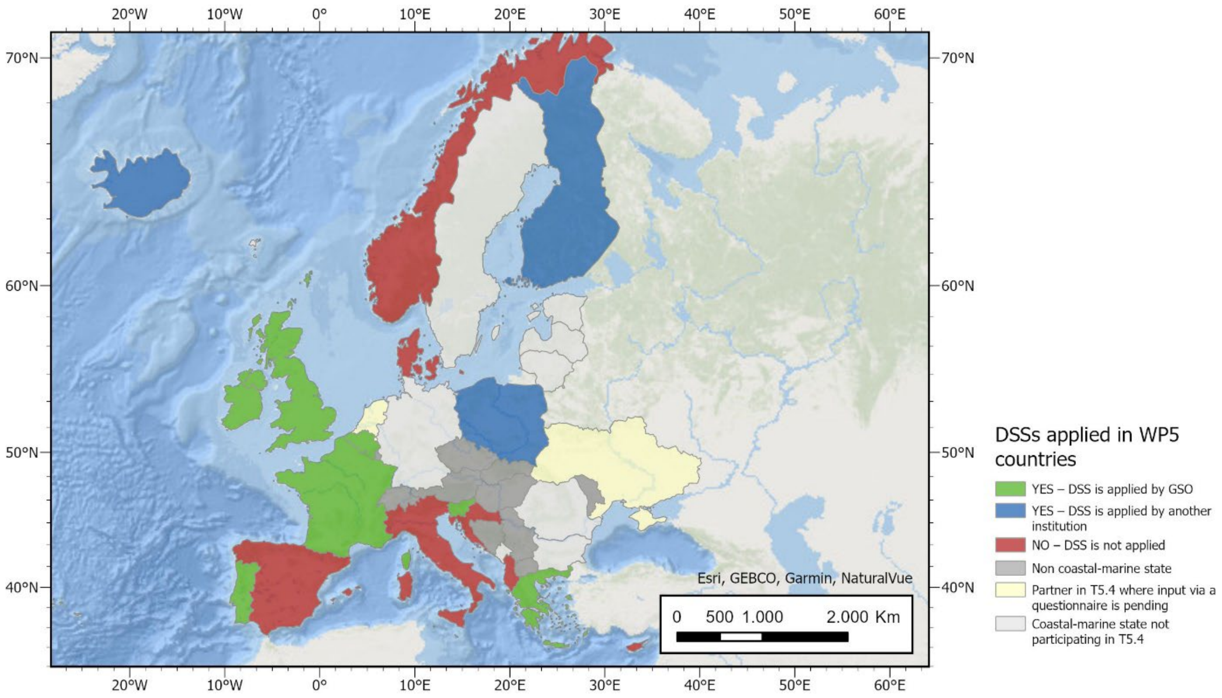

Figure 4. Spatial distribution of application of DSSs among GSOs.

Below are a few examples of DSS application among the project partners in WP5, to illustrate how these purposes are put into practice.

RBINS-GSB (Belgium) utilises the TILES DSS, which integrates geological datasets into a 3D voxel model. The model provides three-dimensional visualisations of the seabed, enabling decision-makers to assess subsurface lithology and geological uncertainty in the Belgian North Sea. It supports marine spatial planning (MSP) by consolidating data from multiple sources, ensuring accurate and up-to-date insights. A focus has been to provide easy querying, visualisation and download of 3D subsurface data.
The National and Kapodistrian University of Athens, Greece has developed a DSS focused on coastal vulnerability assessment, using GIS tools like ArcGIS Pro. The system maps coastal hazards such as erosion and inundation and includes projections for future risks. Coastal evolution trends are verified through old maps, satellite images and aerial photos to ensure the accuracy of predictions.
BGS (UK) collaborates with the European Space Agency’s (ESA) Destination Earth program to develop a Coastal Digital Twin. This dynamic system integrates satellite observations, ground measurements, and advanced computational models. It simulates coastal processes in real-time, providing precise predictions that enhance disaster preparedness and adaptation strategies.
GeoZS (Slovenia) highlights the "GH project" that provides color-coded vulnerability maps for landslides, supporting spatial planning decisions.

GSEU

5. Decision Support Tools (DST)

Decision Support Tools (DSTs) are essential components of DSSs that process data and extract relevant parameters to aid decision-making. The questionnaire inquired: *"Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters?"*
Based on the answers, GIS is widely used across all countries for mapping and analysing coastal features. Tools such as ArcGIS, QGIS, and MapInfo are essential for visualising spatial data. In Greece, GIS is used to track the evolution of coastal zones and predict future changes based on sea-level rise projections. Likewise, in Ireland and Portugal the GIS plugin Digital Shoreline Analysis System (DSAS) is utilised to analyse shoreline variability, calculate rates of change and point out areas experiencing higher shoreline oscillations.
Marine Spatial Planning (MSP) tools are used in countries like Finland and Italy to integrate environmental, social, and economic data, supporting sustainable coastal management.
Other tools mentioned include GroundHog Desktop used by BGS (UK), which processes geological data to create sediment thickness models, and The Coastal Modelling Environment (CoastalME), which simulates coastal landscape evolution under different scenarios, providing stakeholders with insights into potential future changes and helping them design effective mitigation measures (Payo et al., 2017).

5.1. Parameters / Information layers

The parameters / information layers which are deemed relevant when assessing coastal vulnerability can to some extent be extracted by use of the above-mentioned tools. Based on the answers to the question: *"Which geological parameters / information layers do you deem relevant when analysing coastal vulnerability?",* each parameter / layer mentioned was counted to find the frequency. When comparing the responses, some of the answers written covered the same parameter / layer despite the word being different. The grouping of answers can be seen in Table 1, and these groupings also serve as basis for the parameter / layer count shown in Table 2.

Table 1. Group name and corresponding Grouped Parameters / Information layers.

Group Name	Grouped Parameters / Information layers
Geomorphology	Geomorphology, Coastal morphology, Submarine morphology, Coastal features, Coastal type
Topography / Bathymetry	Topography, Bathymetry, Coastal slope, Elevation, Altitude above sea level
Lithology	Lithology, Geological maps, Geological structure, Bedrock
Coastal behaviour	Coastal dynamics, Shoreline changes, Coastal erosion, Coastal accretion, Erosion/accretion rate
Relative sea level	Sea level rise, Relative sea-level rise
Sediment composition	Sediments, Sediment composition, Sediment size composition, Sediment vertical distribution
Terrestrial hydrology	Hydrographic characteristics, Hydrological characteristics, Hydraulics
Metocean	Meteomarine parameters, Wave characteristics, Wind characteristics, Weather, Tides, Currents
Mass movement risks	Landslides, Debris flows, Turbidites
Solid earth risks	Earthquakes; Volcanic activity; Tectonic activity; Fault activity
Coastal protection	Coastal defences, Coastal protection structures
Cryospheric phenomena	Icebergs or winter sea ice; Glacial flash floods
Land use	Land use, Human interventions, Urbanisation, Socio-economic interventions, Land cover

Table 2. Count of coastal vulnerability parameters / information layers mentioned by GSOs. Number of respondents = 15.

Parameters / Information layers	Count	Countries
Topography / Bathymetry	12	Albania, Belgium, Cyprus, Denmark, Finland, France, Ireland, Italy, Portugal, Slovenia, Spain, United Kingdom
Geomorphology	11	Albania, Croatia, Cyprus, Finland, France, Greece, Iceland, Ireland, Italy, Portugal, Spain
Coastal behaviour	9	Albania, Cyprus, Denmark, France, Greece, Ireland, Italy, Portugal, Spain
Lithology	8	Belgium, Croatia, Cyprus, France, Greece, Ireland, Slovenia, Spain
Metocean	7	Denmark, France, Greece, Iceland, Italy, Portugal, Spain
Land use	5	Denmark, France, Greece, Italy, Portugal
Sediment composition	5	Cyprus, Denmark, Finland, Greece, United Kingdom
Relative sea level	5	Cyprus, Denmark, France, Italy, Portugal
Coastal protection	4	Denmark, Greece, Italy, United Kingdom
Infrastructure	4	Denmark, France, Iceland, Italy
(Terrestrial) Hydrology	2	France, Greece
Subsidence	2	France, United Kingdom
Solid earth risks	2	Iceland; Cyprus
Population density	2	Denmark, Italy
Mass-movement risks	2	Iceland, Slovenia
Natural ecosystems	2	France, Italy
Proximity to sources of erosion	1	Slovenia
Proximity to faults	1	Slovenia
Harmful substances in sediments	1	Finland
Cryospheric phenomena	1	Iceland
Substrate	1	Finland

5.2. Artificial Neural Networks and Bayesian Networks

Machine learning techniques, such as Artificial Neural Networks and Bayesian Networks could enhance the predictive accuracy of vulnerability assessments (Valchev et al., 2017; Durap, 2024). They can automatically determine the relative importance of different factors, reducing subjectivity in the analysis (Barzehkar et al. 2025). Additionally, machine learning models often provide probabilistic outputs, offering a measure of confidence in the aggregated output. This combination of capabilities makes machine learning a powerful tool when considering the interdependencies and weightings of multiple parameters to produce an objective and trustworthy output (Haryani et al., 2024; Nourdi et al., 2024).

In Belgium, Bayesian Networks have been applied to incorporate probabilistic reasoning into coastal vulnerability assessments as reported by RBINS-GSB. This approach helps handle uncertainties in geological data and decision-making processes (De Mol et al., 2019).

In France, Bayesian Networks have been employed in research, particularly for climate risk assessments, as reported by the BRGM. The work included advanced modelling using these networks to assess compound climate risks (Bulteau et al., 2015; Rohmer & Le Cozannet, 2019; Rohmer, 2020).

In the UK, seasonal trend decomposition has been applied, which incorporated elements of probabilistic reasoning and analysis for time series analysis to extract the pattern of motion.

6. Decision Support Indices (DSI) and Other Outputs

The outputs produced, with or without a DSS, should provide actionable, accurate and evidence-based information to support informed decisions for sustainable coastal management. The questionnaire asked: *"What outputs do you produce to evaluate the geology in relation to coastal vulnerability?"*.

6.1. Coastal Vulnerability Index (CVI)

Five different countries (Croatia, Cyprus, Iceland, Ireland, and UK) have experience with the Coastal Vulnerability Index (CVI)-approach according to the GSO respondents. Thus, the CVI-approach is the most widely used DSI for coastal assessments among the GSOs. It provides a standardised way to assess coastal vulnerability by combining various parameters like erosion and sea-level rise along with socio-economic parameters into a single score. The key parameters related to geology include:

- Geomorphology: The stability of coastal landforms.
- Coastal behaviour: Rates of erosion or accretion.
- Coastal Slope: The steepness of the coastline, affecting vulnerability to flooding.
- Sediment Composition: The type of sediment present, influencing erosion rates.

In Portugal, the ratio of net shoreline movement to total change in coastline movement is utilised as an index to highlight areas experiencing significant shoreline oscillations, as reported by LNEG.

6.2. Other Outputs

Many GSOs have not developed a CVI-approach. This may be explained by different responsibilities among the GSOs in the respective countries. Instead, maps displaying geological parameters, erosion/accretion, bathymetry etc. are being produced.
RBINS-GSB (Belgium) produces 3D geological suitability models that aggregate suitability degrees of individual geological parameters, such as lithology, bathymetry, and sediment composition.
BGS (UK) has previously applied a CVI-approach. Now, a database (GeoCoast) is implemented instead as it is considered more useful by stakeholders.

7. Discussion

The conceptual model provides a framework that facilitates cross-country comparisons by simplifying the diverse approaches employed in Decision Support Systems (DSS). This generalised structure supports the identification of commonalities among the different GSO approaches. However, the broad nature of the model inevitably reduces its ability to fully represent the complexities and context-specific adaptations of individual methodologies. While this simplification may limit the model’s level of detail, it remains a vital compromise to enable consistent comparative analysis. To make up for this simplification an accompanying text details the respective countries approach, thereby highlighting the diversity in approaches.

The positioning of the Coastal Vulnerability Index (CVI) in the conceptual model is challenging due to its dual role as both a tool and a final output. In some applications, the CVI may serve as final output; while in other applications, the CVI may serve as a tool and an intermediate step towards producing vulnerability maps. This reflects a broader challenge of accommodating region-specific practices and terminologies within a standardised conceptual model, requiring flexibility in its representation.

The responsibilities of GSOs in producing coastal vulnerability assessments differ significantly due to variations in how governments organise and delegate tasks related to coastal management. In some countries, GSOs are tasked with conducting comprehensive assessments and play a central role in managing coastal risks, while in others, their responsibilities are more specialised or limited to providing technical data. Additionally, similar outputs may be referred to by different terms. This may create the impression of significant differences in the work carried out by different surveys when, in reality, it may involve similar methodologies and results. For instance, one survey might produce "erosion maps" while another produces "susceptibility maps". These terminological variations can obscure the similarities in approaches and outputs across GSOs.

Machine learning techniques, such as Artificial Neural Networks and Bayesian Networks, introduce significant opportunities for enhancing coastal vulnerability assessments. These approaches can dynamically analyse complex, non-linear relationships between multiple parameters, offering probabilistic outputs that improve the reliability of predictions. For instance, Bayesian Networks have been employed in Belgium and France to integrate uncertainty into decision-making processes, facilitating more robust coastal risk assessments. Meanwhile, countries like Portugal and Greece have expressed interest in adopting these tools.

An example of progress within the EU on this topic is the RISC-KIT project, a toolkit funded by the EU (van Dongeren et al., 2016). It includes the following four tools: Coastal Risk Assessment Framework (CRAF), Hotspot Tool, Web-based management guide and a Storm Impact Database. CRAF locates areas of increased risk (e.g. wave overtopping, flooding and erosion) by ranking and aggregating scores into an index which can be asserted in a multi-criteria analysis along with stakeholders. High-risk areas can then be studied using the Hotspot Tool, which incorporates Bayesian Networks to visualise the relation between hazards, impacts and disaster risk reduction measures in a DSS (Plomaritis et al., 2018; Sanuy et al., 2020; Sanuy and Jimenez, 2021).

8. Summary and Conclusions

Initially, a conceptual model of a generic DSS and related components was created based on a literature review and used as a guiding framework.
Subsequently, a questionnaire for enquiring information on existing DSSs and related components used in relation to coastal vulnerability was created using the created conceptual model as a guiding framework. The questionnaire was circulated to all GSOs in WP5.
Existing DSSs and related components in relation to coastal vulnerability were collated from the questionnaires filled in by the GSOs, along with descriptions and examples of different applications.
Hence, existing decision support modules in relation to coastal vulnerability were collated and described along with their application; and an inventory of these existing decision support modules were developed for sharing on EGDI along with these descriptions.

Decision Support Systems (DSS), Tools (DST), and Indices (DSI) are valuable for coastal management. The information collated from European GSOs shows a diverse range of approaches tailored to local and regional needs. GIS-based tools and Coastal Vulnerability Indices (CVI) are widely used, but emerging technologies and advanced modelling platforms are also advancing. The analysis also shows, however, that not all coastal states have tailored approaches, and some coastal states have not applied a dedicated DSS, DST or DSI.

At a later stage and in a later report (cf. D5.8, M54), best-practice decision support modules in relation to coastal vulnerability will be developed building on the existing modules in the inventory presented in this report and to be shared on EGDI.

Future efforts should focus on cross-institutional collaboration and the continuous refinement of transparent DSSs to address the growing challenges posed by climate change and coastal hazards, as these challenges are often cross-sectorial and cross-border, and integrated coastal zone management should be based on informed decisions and transparency.

9. Part 2 – Collation and Inventory of Existing Decision Support Modules in Relation to Offshore Windfarm Siting

10. Introduction

A detailed understanding of contemporary geological processes occurring on the seabed and its subsurface geology is critical to all stages of the planning process and subsequent site investigation for the development of offshore windfarms and associated infrastructure (e.g. cables). The overall scope of WP5 is to enable governments, industry, cultural heritage organisations and the marine research community to make informed decisions regarding the sustainable development, management and protection of coastal environments and the seabed.

When searching for the optimal site for an offshore windfarm defining spatial boundaries, mapping key areas, identifying conflicts in spatial usage, outlining scenarios, and designing management actions are essential steps. For this, Decision Support Systems (DSS) can play a key role by providing structured frameworks for evaluating site suitability and guiding sustainable management (Pınarbaşı et al., 2017; Wong-Parodi et al., 2020). These systems integrate various data sources and analytical tools to help stakeholders make informed decisions about maritime/marine spatial planning (MSP) (Barzehkar et al., 2021).

Several DSSs have been developed with possibility of application in offshore windfarm siting. These include e.g. MARXAN, DPSIR and INDIMAR (Watts et al., 2009; Patrício et al., 2016; Abramic et al., 2021). DSSs utilise several Decision Support Tools (DST), the most used being Geographical Information Systems (GIS), Multi-Criteria Decision Making (MCDM) and Analytical Hierarchy Process (AHP) (Stelzenmüller et al., 2013; Kannen et al., 2016, Gkeka-Serpetsidaki et al., 2024). Outputs of a DSS can assist in planning of offshore windfarms considering multiple parameters, and thereby guiding sustainable management.

When analysing optimal offshore windfarm siting, the importance of geological parameters is often neglected, only including bathymetric data (Martin et al., 2013; Stefanakou et al., 2019; Tercan et al., 2020). Velenturf et al. (2021) argued that geoscience can contribute to offshore windfarm siting by e.g. clarifying constraining factors for foundations of wind turbines, predicting the need of anti-scour measures and inform of shallow gas and fluid mobility hazards.

The overall aims of Task 5.4 on cross-thematic alignment are linking data, information and knowledge from WP5 to WP6 and to WP7 towards developing decision-support modules (deliverables D5.7/D5.8) to support informed decisions for a) managing and protecting the coastal zone, and b) derisking offshore wind energy installations, including the inherent connection between offshore wind energy installations and the coastal zone. Hence, T5.4 contributes to the decision-making domain that builds on existing knowledge and on new knowledge, including new knowledge generated in WP5 (cf. Figure 1).

The preliminary objective of Task 5.4 presented in this part of the report was to collate existing decision support modules in relation to offshore windfarm siting and to describe the modules and their application (T5.4b-1) in order to develop an inventory of existing decision support modules to be shared on EGDI (D5.4b-1).

Hence, the following specific objectives in this part of the report were:

- To create a conceptual model of a generic DSS and related components based on a literature review to be used as a guiding framework.
- To create a questionnaire for enquiring information on existing DSSs and related components used in relation to offshore windfarm siting using the conceptual model as a guiding framework, and to circulate this to all Geological Survey Organisations (GSO).
- To collate and present existing DSSs and related components used by GSOs in relation to offshore windfarm siting in a report format and subsequently share these on EGDI.

The subsequent objective of Task 5.4 to be presented in a later report is (cf. D5.8, M54):

- To develop and report best-practice decision support modules in relation to offshore windfarm siting (T5.4b-2 and D5.4b-2).

Hence, this part of the report provides an inventory of existing DSSs, DSTs, and DSIs and other outputs that are applied in relation to offshore windfarm siting, with the content being based on the responses to the questionnaire distributed to all GSOs in WP5, detailing their current practices, tools, and methodologies.

11. Materials and Methods

See Part 1.

12. Decision Support Systems (DSS)

Decision Support Systems (DSSs) are comprehensive frameworks that combine various tools and data layers to assist decision-making processes in offshore windfarm siting. The systems are used to assess physical forcings, geological foundation etc. The questionnaire enquired: *"Do you or does your institute have expertise in DSSs for evaluating geology in relation to offshore windfarm siting?"*.

The responses showed that expertise in DSSs varies across European countries. The analysis showed that 16% of the GSOs use a DSS in relation to offshore windfarm siting, while 21% of the GSOs mentioned that another institution in their country applies a DSS in relation to offshore windfarm siting (Figure 5). The primary purpose of DSSs in this context is to identify suitable offshore windfarm locations while minimising environmental and socio-economic impacts. The spatial distribution of application of DSSs among GSOs can be seen in
Figure 6.

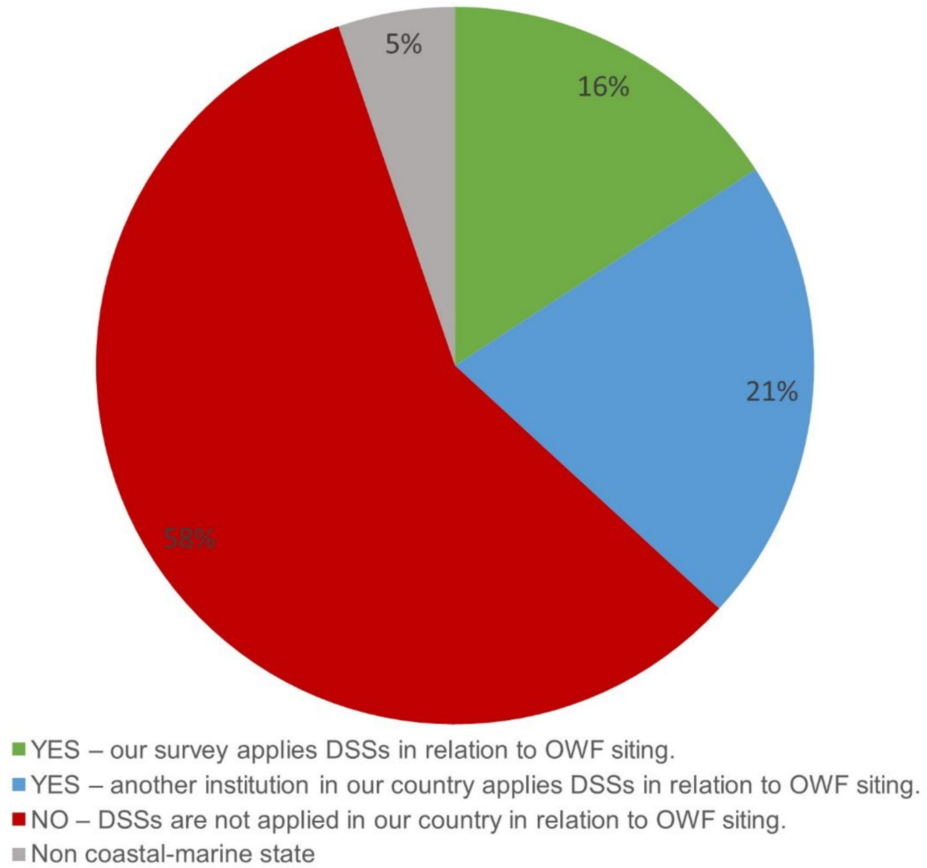

Figure 5. Percentage of geological surveys around Europe who applies a DSS. Number of respondents = 19.

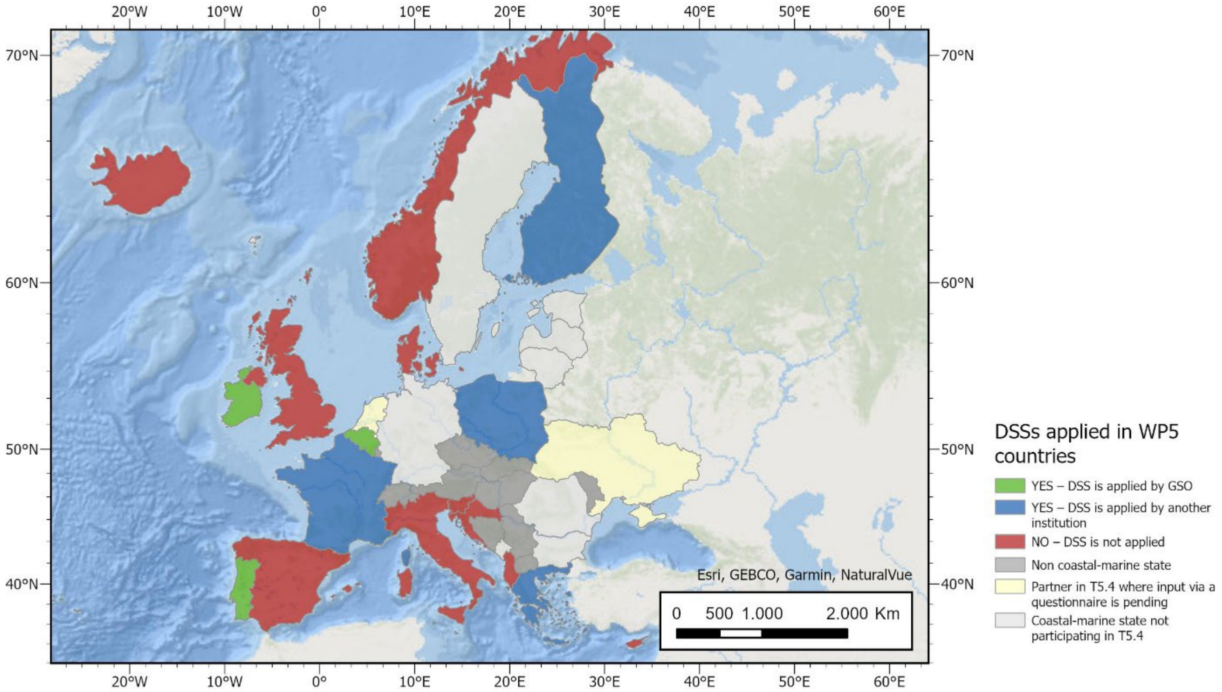

Figure 6. Spatial distribution of application of DSSs among GSOs.

Below are a few examples of DSS application among the project partners in WP5, to illustrate how these purposes are put into practice.

RBINS-GSB (Belgium) utilises the TILES DSS, which integrates geological datasets into a 3D voxel model. The model provides three-dimensional visualisations of the seabed, enabling decision-makers to assess subsurface lithology and geological uncertainty in the Belgian North Sea. It supports MSP by consolidating data from multiple sources, ensuring accurate and up-to-date insights. A focus has been to provide easy querying, visualisation and download of 3D subsurface data.

Several DSS applications focus on integrating ecological, geological, and socio-economic considerations. GTK (Finland) applies an MSP-framework that incorporates data on biodiversity, shipping routes and fisheries to identify zones compatible with windfarm installations. The DSSs play a central role in minimising conflicts with existing maritime activities and ensuring compatibility with environmental regulations.

13. Decision Support Tools (DST)

Decision Support Tools (DSTs) are essential components of DSSs that process data and extract relevant parameters to aid decision-making. The questionnaire inquired: *"Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters?"*

Based on the answers, GIS is widely used across all countries for offshore windfarm siting. Tools such as ArcGIS and QGIS are essential for visualising spatial data and perform overlay analyses.
In Portugal, numerical models are applied for energy simulation, while Multi-Criteria Decision Analysis (MCDA) is employed to account for multiple parameters.

Tools associated with MSP are used by GTK (Finland). These include zonation software for prioritising areas for conservation and development, balancing ecological sensitivity with economic goals.

In Belgium, Bayesian Networks have been applied to incorporate probabilistic reasoning into offshore windfarm siting as reported by RBINS-GSB. This approach helps handle uncertainties in geological data and decision-making processes (De Mol et al., 2019).

13.1. Parameters / Information layers

The parameters / information layers which are deemed relevant in relation to offshore windfarm siting can to some extent be extracted by use of the above-mentioned tools.

Table 3. Group name and corresponding Grouped Parameters / Information layers.

Group Name	Grouped Parameters / Information layers
Bathymetry	Water depth, Bathymetry
Seabed surface characteristics	Substrate type, Nature of seabed (rocky/soft), Marine sediments, Sediment distribution, Seabed surface composition
Shallow subsurface characteristics	Thickness of unconsolidated sediments, Thickness of soft sediments, Sediment thickness, Depth of bedrock surface, Subsurface composition
Lithology	Lithology, Structural geology
Geomorphology	Geomorphology, Marine dune dynamics
Zonation	Marine protected areas, Environmental protection areas, Reef areas, Tourism areas, Military zones, Fishing grounds
Coastal connection	Distance to coast, Coastal type and dynamic changes, Shoreline visual effect, Visibility buffers, Seascape and landscape
Infrastructure	Shipping lanes, Distance to grid, Existing infrastructure (cables, pipelines, etc.)
Solid earth risks	High geo-risk areas (volcanism, tectonics, etc.), Faults, Seismic activity
Metocean	Ocean currents, Wave height, Wind characteristics

Based on the answers to the question: *"Which geological parameters / information layers do you deem relevant in relation to optimal offshore windfarm siting?",* each parameter / layer mentioned was counted to find the frequency. When comparing the responses, some of the answers written covered the same parameter / layer despite the word being different. The grouping of answers can be seen in the table above, and these groupings also serve as basis for the parameter / layer count shown in the table below.

Table 4. Count of parameters / information layers related to offshore windfarm siting mentioned by GSOs. Number of respondents = 10.

Parameters / Information layers	Count	Countries
Seabed surface characteristics	8	Belgium, Croatia, Denmark, Finland, France, Iceland, It-aly, Portugal
Bathymetry	7	Albania, Croatia, Denmark, France, Iceland, Ireland, Portugal
Shallow subsurface characteristics	6	Belgium, Denmark, Finland, Iceland, Ireland, Portugal
Zonation	5	Denmark, Iceland, Ireland, Portugal, Finland
Coastal connection	5	Croatia, Denmark, Iceland, Portugal
Infrastructure	4	Denmark, Iceland, Ireland, Portugal
Metocean	4	Denmark, Iceland, Ireland, Portugal
Lithology	3	Croatia, Denmark, France
Geomorphology	3	Croatia, Denmark, France
Solid earth risks	3	France, Iceland, Ireland
Shipwrecks	2	Belgium, Ireland
Energy production parameters	1	Portugal
Sea Ice	1	Iceland

14. Decision Support Indices (DSI) and other outputs

The outputs produced, with or without a DSS, should provide actionable, accurate and evidence-based information to support informed decisions for offshore windfarm siting. The questionnaire asked: *"What outputs do you produce to evaluate the geology in relation to offshore windfarm siting?"*.

Of the 11 respondents, 8 GSOs (AGS, BRGM, ICGC, GTK, GSD, GEUS, LNEG and ISOR) mention that they produce geological maps of e.g. bathymetry, seabed substrate, subsurface composition. This is related to the fact that many of the GSOs only provide background information for offshore windfarm siting. In addition to the geological maps, GTK (Finland) developed a Geodiversity Index that offers a quantitative measure of geological variability and potential site suitability (Kaskela & Kotilainen, 2017).

RBINS-GSB (Belgium) produces 3D geological suitability models that aggregate suitability degrees of individual geological parameters, such as lithology, bathymetry, and sediment composition (Hademenoes et al., 2019).

15. Discussion

The conceptual model provides a framework that facilitates cross-country comparisons by simplifying the diverse approaches employed in Decision Support Systems (DSS). This generalised structure supports the identification of commonalities among the different GSO approaches. However, the broad nature of the model inevitably reduces its ability to fully represent the complexities and context-specific adaptations of individual methodologies. While this simplification may limit the model's level of detail, it remains a vital compromise to enable consistent comparative analysis. To make up for this simplification an accompanying text details the respective countries approach, thereby highlighting the diversity in approaches.

The responsibilities of GSOs in projects concerning offshore windfarm siting differ due to variations in how governments organise and delegate tasks related to offshore windfarm siting. Most GSOs are responsible for providing background information related to offshore windfarm siting (e.g. bathymetry and subsurface characteristics). Other GSOs have a larger responsibility, providing suitability maps. It is however unclear if the different outputs mentioned by GSOs are different in nature or if they to some degree might be explained by different terminologies about the same work. For instance, one survey might produce "suitability maps" while another produces "geological maps". In this case, it can be unclear if suitability maps indicate an assessment and maybe aggregation of different data layers, or if the suitability degree is only dependent on a single parameter.

An index-based approach can be highly relevant when examining geology for offshore windfarm siting. Currently, indices are mostly used to express environmental parameters (Azzelino et al., 2013). However, work has also been done in relation to geology. GTK (Finland) developed a geodiversity index (Kaskela & Kotilainen, 2017), while the GSEU WP5 T5.2 proposed a Geo-Assessment Matrix (Dakin et al., 2024). These methods provide systematic and quantifiable ways to assess the complexity and variability of geological conditions. By using a standardised index, developers can more easily compare different potential sites and identify areas with optimal geological characteristics for turbine installation and cable routing. This is particularly valuable for MSP and early-stage site selection, as it allows for a quick and comprehensive evaluation of large areas. By incorporating various geological parameters into a single index, decision-makers can more easily understand and compare the geological suitability of different locations. The scope of a geological index should however be decided on. As mentioned, it could be valuable in early-stage site selection. Here, data availability can be scarce, and the reduced complexity of the index should then reflect this lack of detailed data. Alternatively, the development of a geological index could take its starting point in the more detailed examinations undertaken after the initial screening. Here, detailed data are available, and more parameters could be included.

Machine learning techniques, such as Bayesian Networks, introduce opportunities for enhancing offshore windfarm siting. These approaches can dynamically analyse complex, non-linear relationships between multiple parameters, offering probabilistic outputs that improve the reliability of predictions. For instance, Bayesian Networks have been employed in Belgium to integrate uncertainty into decision-making processes, facilitating more robust analyses in projects on offshore windfarm siting. In the coastal zone, the use of Bayesian Networks is widespread, and it is among others used to enhance the applicability of the Coastal Vulnerability Index (Gutierrez et al., 2011; Beuzen et al., 2018; Durap, 2024). Further, Furlan et al. (2019) developed a GIS-based Bayesian Network to assess the probability of marine cumulative impacts, while Pınarbaşı et al (2019) used Bayesian Networks to identify feasible offshore windfarm sites, including percentage of seabed composed of sedimentary deposits as a parameter. A similar applicability of Bayesian Networks could be applied to a geological index focusing on offshore windfarm siting, incorporating multiple geological parameters. However, as the geological index is to be developed first, the inclusion of Bayesian Networks is not imminent.

Offshore windfarms are closely related to coastal zones, as they are typically located in shallow waters and connected to shore. This proximity allows for easier energy transmission to onshore users. A holistic approach considering both offshore windfarms and coastal zones is crucial because these developments can significantly affect marine ecosystems and coastal landscapes (Gill., 2005). Wind turbines can alter marine ecosystems by creating artificial reefs, potentially increasing biodiversity, but they may also disrupt existing habitats and migration patterns (Lloret et al., 2022; Ouro et al., 2024). Additionally, offshore windfarms can impact coastal tourism, fishing industries, and local cultural attachments to seascapes (Lange et al., 2010; Glasson et al., 2021). The GSOs also mentioned multiple parameters which have been grouped as ‘Coastal connection’. These include ‘Distance to coast’, ‘Coastal type and dynamic changes’, ‘Shoreline visual effect’ and ‘Visibility buffers’ (Table 2).

16. Summary and Conclusions

Initially, a conceptual model of a generic DSS and related components was created based on a literature review and used as a guiding framework.
Subsequently, a questionnaire for enquiring information on existing DSSs and related components used in relation to offshore windfarm siting was created using the created conceptual model as a guiding framework. The questionnaire was circulated to all GSOs in WP5.
Existing DSSs and related components in relation to offshore windfarm siting were collated from the questionnaires filled in by the GSOs, along with descriptions and examples of different applications.
Hence, existing decision support modules in relation to offshore windfarm siting were collated and described along with their application; and an inventory of these existing decision support modules were developed for sharing on EGDI along with these descriptions.

Decision Support Systems (DSS), Tools (DST), and Indices (DSI) are valuable for planning in relation to offshore windfarm siting. The information collated from European GSOs shows that offshore windfarm siting is still underdeveloped field. GIS-based tools and Multi-Criteria Decision Analysis are widely used, but technologies like Bayesian Networks and alternative approaches like the Geodiversity Index and the Geo-Assessment Matrix have also been developed. Index-based approaches can help facilitate the standardisation of geological assessment practices across countries and regions, promoting knowledge sharing and establishing scientific baselines to support informed decisions for offshore windfarm development.

At a later stage and in a later report (cf. D5.8, M54), best-practice decision support modules in relation to offshore windfarm siting will be developed building on the existing DSSs in the inventory presented in this report and to be shared on EGDI.

Future efforts should focus on cross-institutional collaboration and the continuous refinement of transparent DSSs to address the role of geoscience in the accelerating field of offshore wind, as optimisation and de-risking is often cross-sectorial and cross-border, and offshore windfarm siting should be based on informed decisions and transparency.

17. Annex I – Consortium Partners

	Partner Name	Acronym	Country
1	EuroGeoSurveys	EGS	Belgium
2	Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek	TNO	Netherlands
3	Sherbimi Gjeologjik Shqiptar	AGS	Albania
4	Vlaamse Gewest	VLO	Belgium
5	Bureau de Recherches Géologiques et Minières	BRGM	France
6	Ministry for Finance and Employment	MFE	Malta
7	Hrvatski Geološki Institut	HGI-CGS	Croatia
8	Institut Royal des Sciences Naturelles de Belgique	RBINS-GSB	Belgium
9	Państwowy Instytut Geologiczny – Państwowy Instytut Badawczy	PGI-NRI	Poland
10	Institut Cartogràfic i Geològic de Catalunya	ICGC	Spain
11	Česká Geologická Služba	CGS	Czechia
12	Department of Environment, Climate and Communications - Geological Survey Ireland	GSI	Ireland
13	Agencia Estatal Consejo Superior de Investigaciones Cientificas	CSIC-IGME	Spain
14	Bundesanstalt für Geowissenschaften und Rohstoffe	BGR	Germany
15	Geološki zavod Slovenije	GeoZS	Slovenia
16	Federalni Zavod za Geologiju Sarajevo	FZZG	Bosnia and Herzegovina
17	Istituto Superiore per la Protezione e la Ricerca Ambientale	ISPRA	Italy
18	Regione Umbria	-	Italy
19	State Research and Development Enterprise State Information Geological Fund of Ukraine	GIU	Ukraine
20	Institute of Geological Sciences National Academy of Sciences of Ukraine	IGS	Ukraine
21	M.P. Semenenko Institute of Geochemistry, Mineralogy and Ore Formation of NAS of Ukraine	IGMOF	Ukraine
22	Ukrainian Association of Geologists	UAG	Ukraine
23	Geologian Tutkimuskeskus	GTK	Finland
24	Geological Survey of Serbia	GZS	Serbia
25	Ministry of Agriculture, Rural Development and Environment of Cyprus	GSD	Cyprus
26	Norges Geologiske Undersøkelse	NGU	Norway

27	Latvijas Vides, ģeoloģijas un meteoroloģijas centrs SIA	LVGMC	Latvia
28	Sveriges Geologiska Undersökning	SGU	Sweden
29	Geological Survey of Denmark and Greenland	GEUS	Denmark
30	Institutul Geologic al României	IGR	Romania
31	Szabályozott Tevékenységek Felügyeleti Hatósága	SZTFH	Hungary
32	Eidgenössisches Departement für Verteidigung, Bevölkerungsschutz und Sport	VBS (DDPS)	Switzerland
33	Elliniki Archi Geologikon kai Metalleftikon Erevnon	HSGME	Greece
34	Laboratório Nacional de Energia e Geología I.P.	LNEG	Portugal
35	Lietuvos Geologijos Tarnyba prie Aplinkos Ministerijos	LGT	Lithuania
36	Geologische Bundesanstalt	GBA	Austria
37	Service Géologique de Luxembourg	SGL	Luxembourg
38	Eesti Geoloogiateenistus	EGT	Estonia
39	Štátny Geologický ústav Dionýza Štúra	SGUDS	Slovakia
40	Íslenskar Orkurannsóknir	ISOR	Iceland
41	Instituto Português do Mar e da Atmosfera	IPMA	Portugal
42	Jarðfeingi	Jardfeingi	Faroe Islands
43	Regierungspräsidium Freiburg	LGRB	Germany
44	Geologischer Dienst Nordrhein-Westfalen	GD NRW	Germany
45	Landesamt für Geologie und Bergwesen Sachsen-Anhalt	LfU	Germany
46	Vlaamse Milieumaatschappij	VMM	Belgium
47	Norwegian Petroleum Directorate	NPD	Norway
48	United Kingdom Research and Innovation - British Geological Survey	UKRI-BGS	UK

18. Annex II – Part 1 Inventory

The workflows described by the GSOs in the questionnaire were integrated in the schematic diagram visualising the conceptual model of a generic DSS and its components (cf. Figure **2**). This was done both in the cases where a DSS was applied in an assessment of geology in relation to coastal vulnerability and in the cases where a DSS was not applied. This integration revealed that the conceptual model exhibited limitations when trying to fit a broad spectrum of workflows to the model. Hence, the model and schematic diagram is a guiding framework, but it cannot always stand alone. Please refer to the text which accompanies the figures for the individual GSOs for an elaboration of the individual workflows and thus also a diversification of the different approaches.

AGS (Albania)

The conceptual approach of AGS (Albania) is shown in the schematic diagram in Figure 7.

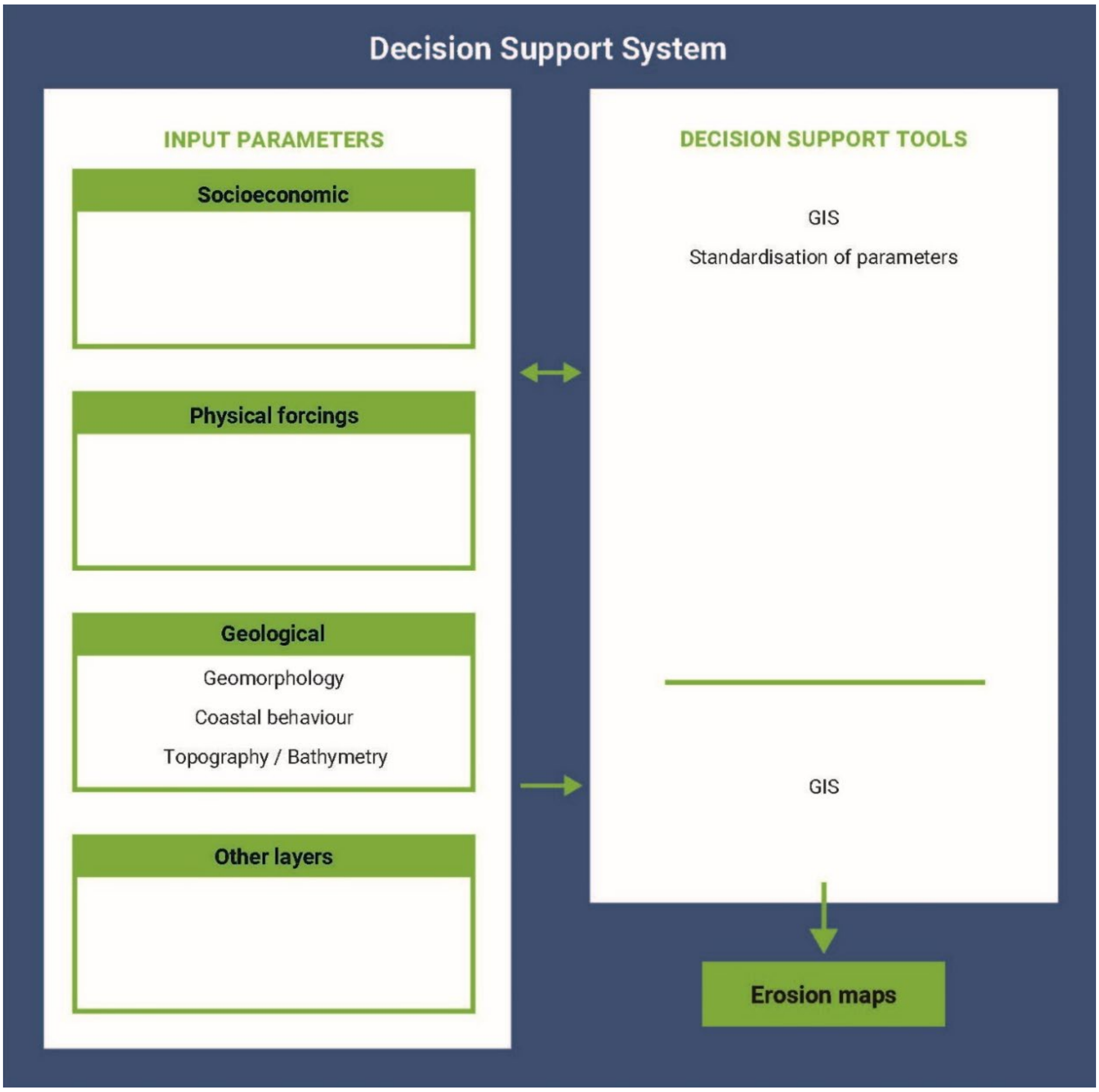

Figure 7. Conceptual approach to assess coastal vulnerability in Albania based on questionnaire filled in by AGS.

AGS reported that they currently do not use DSSs for coastal vulnerability assessment. ArcGIS is the primary DST, which AGS uses to create sedimentation rate maps illustrating coastal erosion and accumulation patterns. The relevant parameters are standardised in the process of making the sedimentation rate maps.

BRGM (France)

The conceptual approach of BRGM (France) is shown in the schematic diagram in Figure 8.

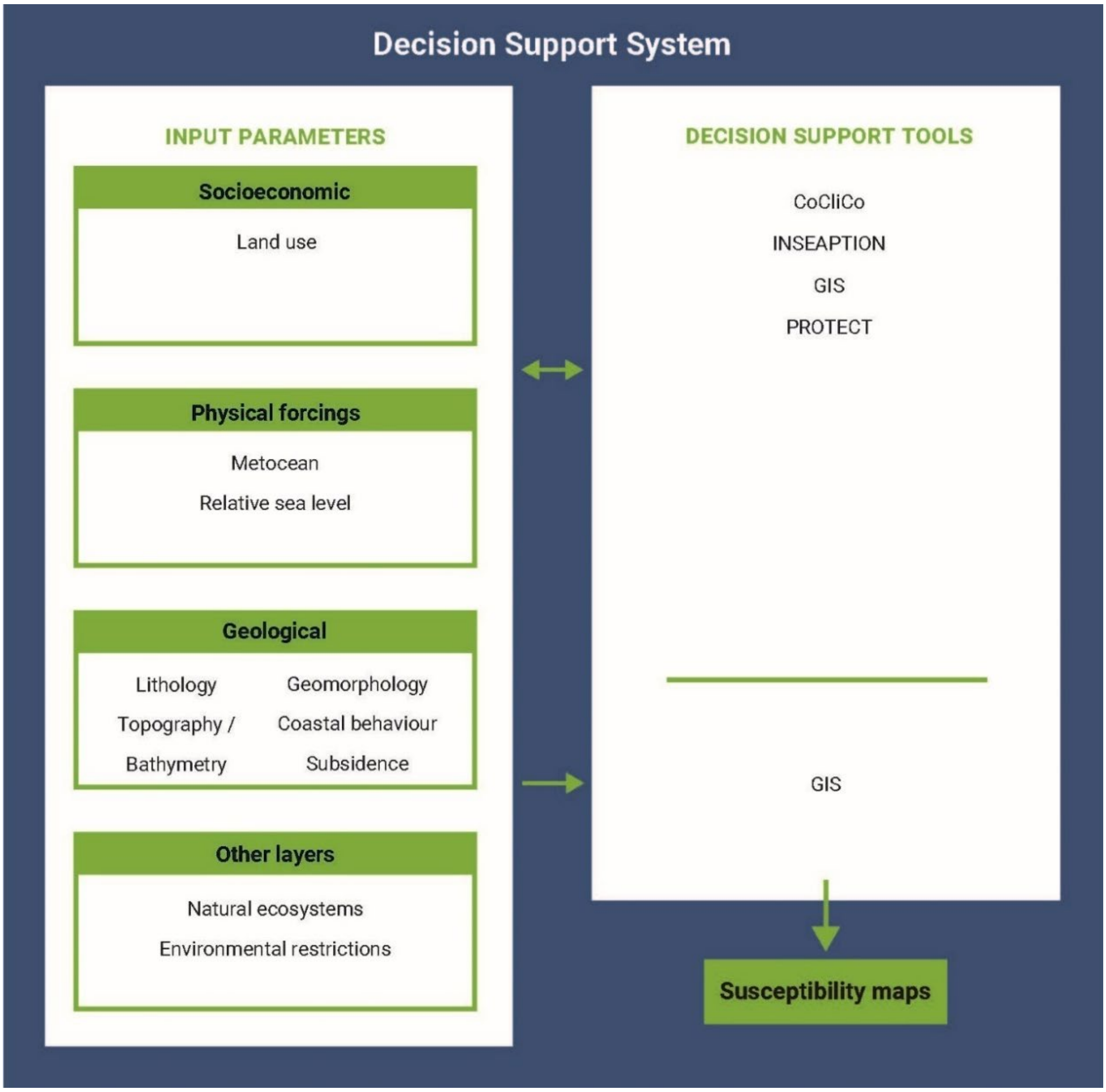

Figure 8. Conceptual approach to assess coastal vulnerability in France based on questionnaire filled in by BRGM.

BRGM is involved in the development of DSSs related to coastal vulnerability, although the role of BRGM often focuses on partnership rather than direct implementation. BRGM utilizes GIS tools (e.g., ArcGIS, QGIS) and develop tools like climate services to support decision-making. France's DSS applications are integrated into projects such as INSEAPTION, CoCliCo, and PROTECT. The projects present interactive maps showing areas exposed to coastal erosion and sea-level rise (Figure 8).

Another output is in the form of an index expressing Vertical Land Motion (VLM) based on data from the Copernicus European Ground Motion Service (EGMS) (Thiéblemont et al., 2024).

Current research efforts include exploring Bayesian Networks and advancing methodologies to improve decision-support effectiveness (Bulteau et al., 2015; Rohmer & Le Cozannet, 2019; Rohmer, 2020).

Further reading

Bulteau, T., Baills, A., Petitjean, L., Garcin, M., Palanisamy, H., & Le Cozannet, G. (2015). Gaining insight into regional coastal changes on La Réunion island through a Bayesian data mining approach. Geomorphology (Amsterdam, Netherlands), 228(228), 134–146. https://doi.org/10.1016/j.geomorph.2014.09.002

Rohmer, J., & Le Cozannet, G. (2019). Dominance of the mean sea level in the high-percentile sea levels time evolution with respect to large-scale climate variability: A Bayesian statistical approach. Environmental Research Letters, 14(1), 14008–. https://doi.org/10.1088/1748-9326/aaf0cd

Rohmer, J. (2020). Uncertainties in conditional probability tables of discrete Bayesian Belief Networks: A comprehensive review. Engineering Applications of Artificial Intelligence, 88, 103384–. https://doi.org/10.1016/j.engappai.2019.103384

Thiéblemont, R., Le Cozannet, G., Nicholls, R. J., Rohmer, J., Wöppelmann, G., Raucoules, D., Michele, M., Toimil, A., & Lincke, D. (2024). Assessing current coastal subsidence at continental scale: Insights from Europe using the European Ground Motion Service. Earth's Future, 12(8). https://doi.org/10.1029/2024EF004523

HGI-CGS (Croatia)

The conceptual approach of HGI-CGS (Croatia) is shown in the schematic diagram in Figure 9. HGI-CGS does not currently use DSSs in relation to coastal vulnerability. The work so far has focused on creating shapefiles representing coastal dynamics (erosion/accretion/stable) and resilience (high/low). A Coastal Vulnerability Index (CVI) is applied by scientists at Croatian universities but not by HGI-CGS (Ružić et al., 2019).

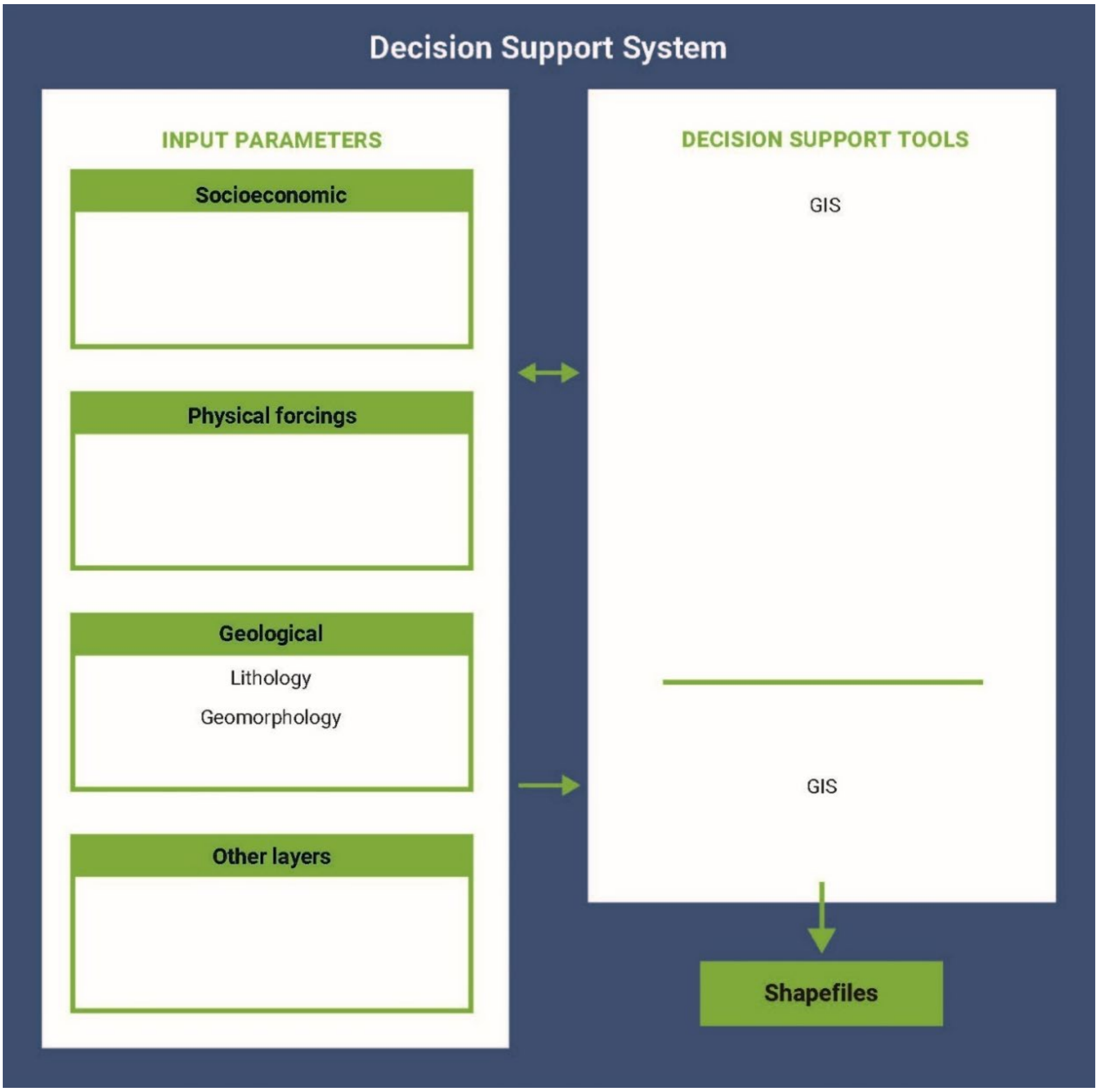

Figure 9. Conceptual approach to assess coastal vulnerability in Croatia based on questionnaire filled in by HGI-CGS.

Further reading

Ružić, I., Dugonjić Jovančević, S., Benac, Č., & Krvavica, N. (2019). Assessment of the Coastal Vulnerability Index in an area of complex geological conditions on the Krk Island, Northeast Adriatic Sea. Geosciences (Basel), 9(5), 219–. https://doi.org/10.3390/geosciences9050219

RBINS-GSB (Belgium)

The conceptual approach of RBINS-GSB (Belgium) is shown in the schematic diagram in Figure 10.

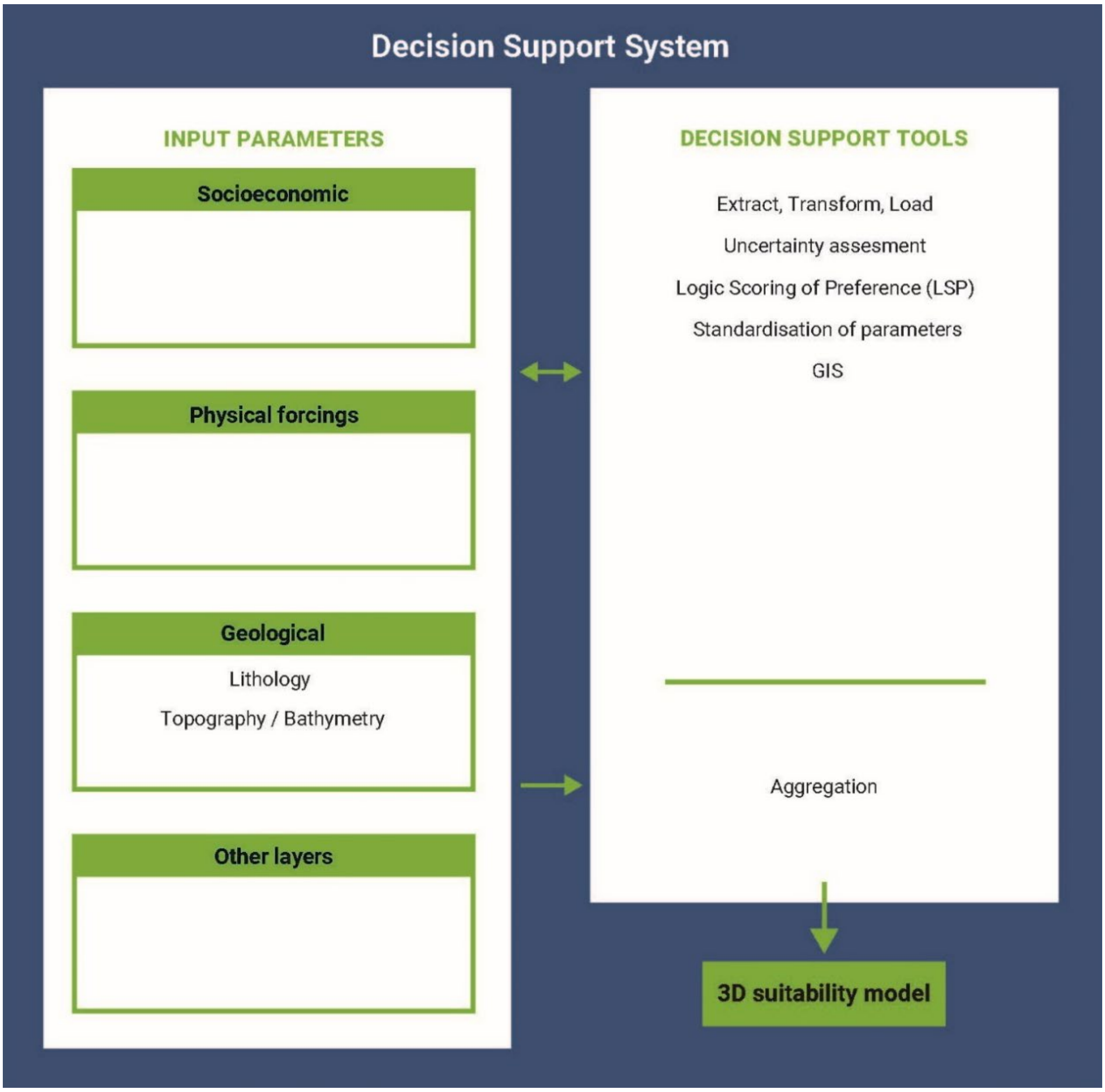

Figure 10. Conceptual approach to assess coastal vulnerability in Belgium based on questionnaire filled in by RBINS-GSB.

RBINS-GSB uses the TILES DSS to assess subsurface lithology and geology in the Belgian part of the North Sea. The DSS integrates various geological datasets into a voxel model, providing three-dimensional representations of the seabed. The TILES DSS incorporates multiple IT components to support data integration from multiple databases and other data sources and both a DST and a visualisation tool (De Tré et al., 2018). These models are essential for understanding geological risks and informing marine spatial planning (MSP). The system also includes methods for evaluating uncertainty in geological data by providing confidence scores to help users assess the reliability of the information, as described by Kint et al. (2020).

Geographic Multi-Criteria Decision Making (MCDM) tools are employed to process large volumes of geological data. These tools create suitability models that help decision-makers evaluate different coastal management scenarios. The MCDM approach involves an Extract, Transform, and Load (ETL) process to integrate data from multiple sources, ensuring that the system provides accurate and up-to-date information (De Tré et al., 2018). Kint et al. (2020) highlighted the importance of standardising lithological data to improve the quality and reliability of the outputs.

The output of the DSS is 3D suitability models that aggregates suitability degrees of individual geological parameters, such as lithology, bathymetry, and sediment composition (Figure 10).

The DSS and DST applications are evaluated based on several criteria, including ease of use, accuracy, and adaptability. Additionally, RBINS-GSB has explored the use of Bayesian Networks to incorporate probabilistic reasoning into coastal vulnerability assessments, as discussed by De Mol et al. (2019).

Further reading

De Mol, R., De Tré, G., Pelta, D. A., Cabrera, I. P., Verdegay, J. L., Yager, R. R., Ojeda-Aciego, M., Medina, J., Bouchon-Meunier, B., Cabrera, I. P., Yager, R. R., & Pelta, D. A. (2018). Applying suitability distributions in a geological context. In Information Processing and Management of Uncertainty in Knowledge-Based Systems. Theory and Foundations (Vol. 853, pp. 278–288). Springer International Publishing AG. https://doi.org/10.1007/978-3-319-91473-2_24

De Tré, G., De Mol, R., van Heteren, S., Stafleu, J., Chademenos, V., Missiaen, T., Kint, L., Terseleer, N., Van Lancker, V., Carrara, P., & Bordogna, G. (2018). Data quality assessment in volunteered geographic decision support. In Mobile Information Systems: Leveraging Volunteered Geographic Information for Earth Observation (Vol. 4, pp. 173–192). Springer International Publishing AG. https://doi.org/10.1007/978-3-319-70878-2_9

Hademenos, V., Stafleu, J., Missiaen, T., Kint, L., & Van Lancker, V. R. M. (2019). 3D subsurface characterisation of the Belgian Continental Shelf: A new voxel modelling approach. Netherlands Journal of Geosciences, 98. https://doi.org/10.1017/njg.2018.18

Kint, L., Hademenos, V., De Mol, R., Stafleu, J., van Heteren, S., & Van Lancker, V. (2021). Uncertainty assessment applied to marine subsurface datasets. Quarterly Journal of Engineering Geology and Hydrogeology, 54(1), 1–. https://doi.org/10.1144/qjegh2020-028

ICGC (Spain / Catalonia)

The conceptual approach of ICGC (Spain / Catalonia) is shown in the schematic diagram in Figure 11.

ICGC does not currently utilise DSSs for coastal vulnerability assessments. The same applies for the Geological and Mining Institute of Spain (IGME). ICGC focus on producing geothematic outputs, such as topographic maps, DEMs, bathymetric data, and geomorphological maps of storm surge flooding.

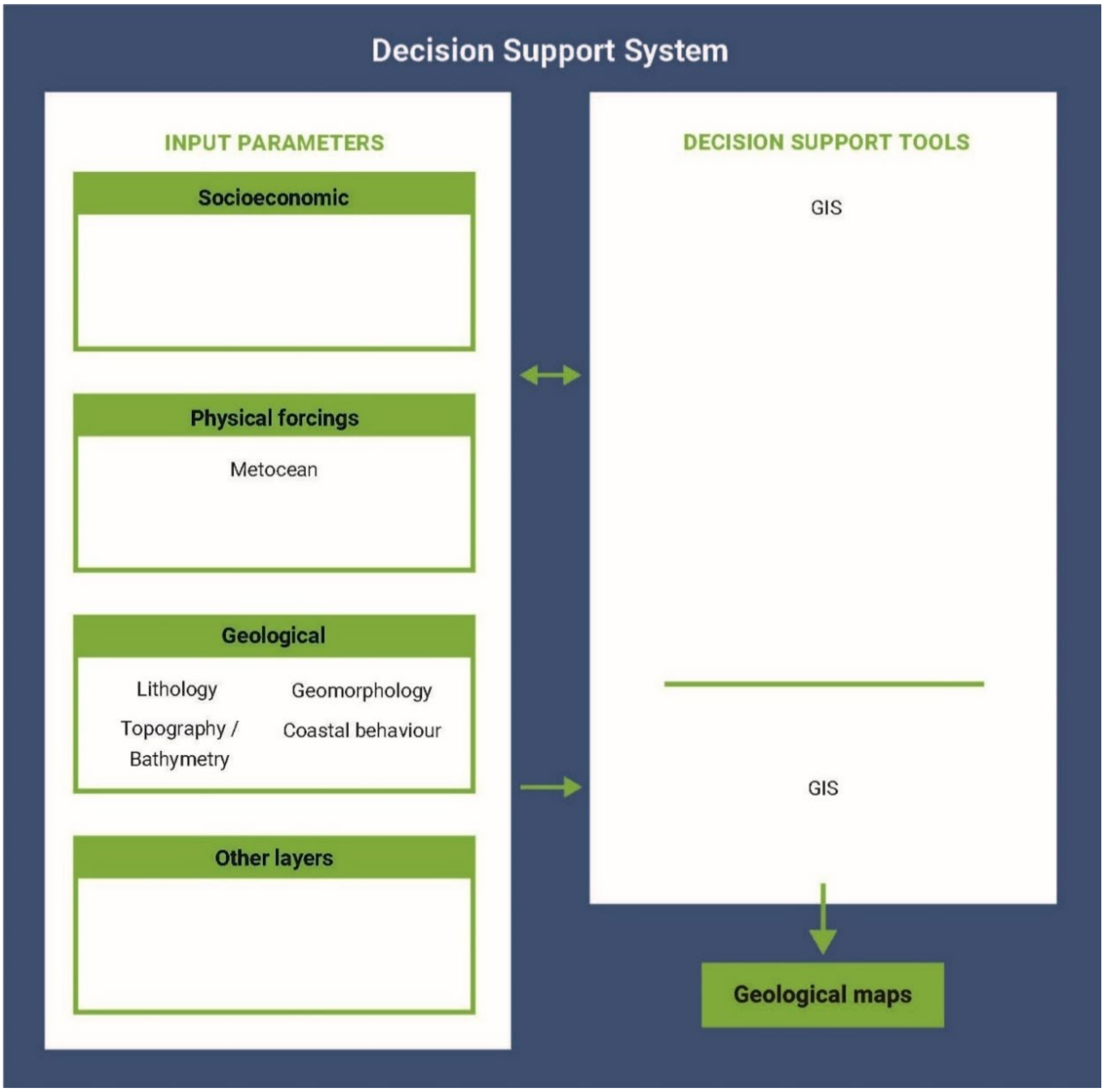

Figure 11. Conceptual approach to assess coastal vulnerability in Spain based on questionnaire filled in by ICGC.

GSI (Ireland)

The conceptual approach of GSI (Ireland) is shown in the schematic diagram in Figure 12.

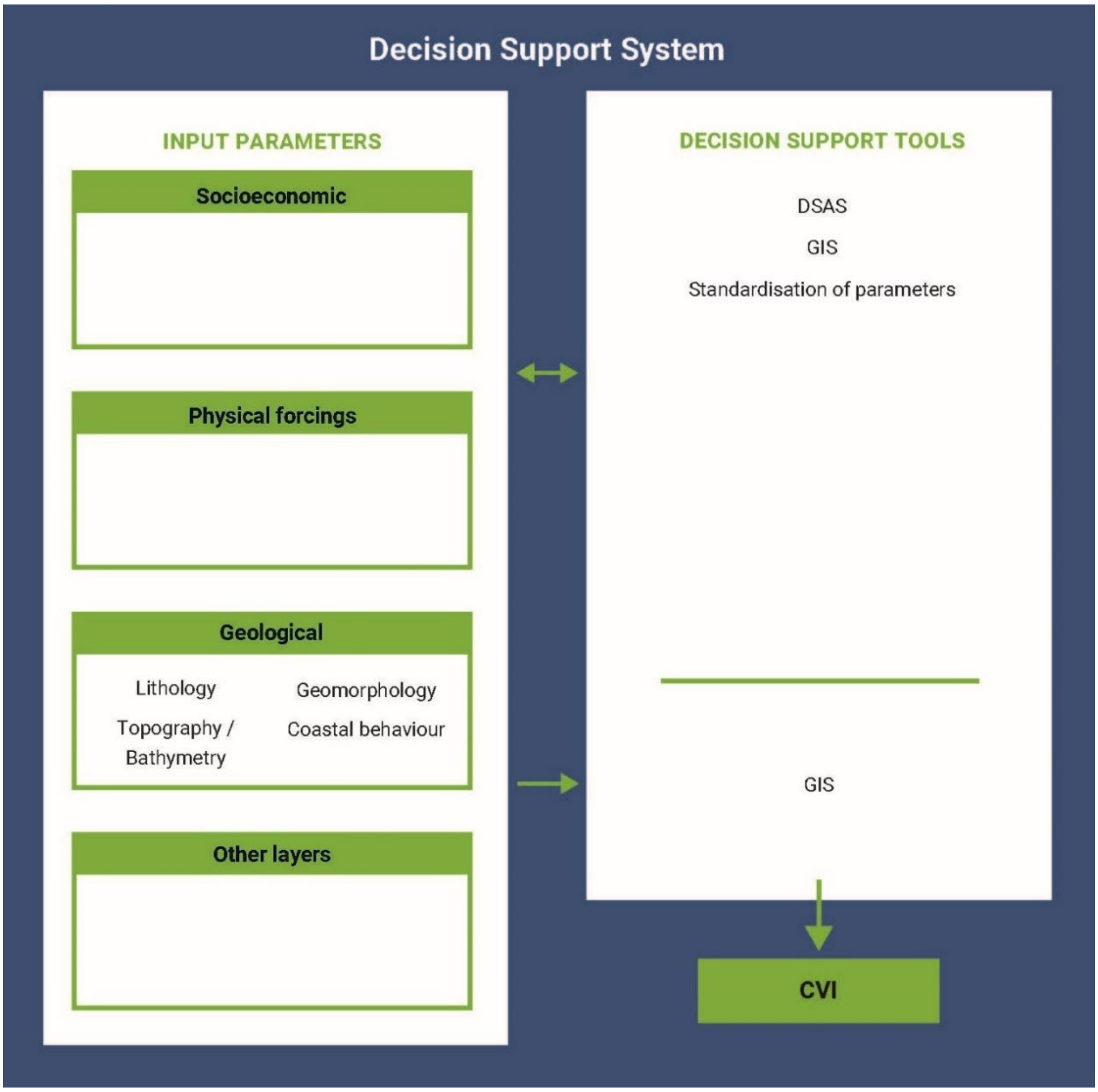

Figure 12. Conceptual approach to assess coastal vulnerability in Ireland based on questionnaire filled in by GSI.

GSI utilises a DSS when assessing coastal vulnerability. The workflow is based on work by USGS (Pendleton et al., 2010). To obtain the relevant parameters GIS is used as the primary tool (e.g. to process Lidar DTMs). The GIS plugin DSAS (Digital Shoreline Analysis System) is applied to calculate shoreline change rates based on vegetation line time series. The parameters are then standardised using discrete vulnerability categories and ranked. A simple formula is then applied to obtain a final coastal vulnerability index (CVI). The final CVI score is then ranked again from 1 to 5.

Further reading

Pendleton, E.A., Barras, J.A., Williams, S.J., and Twichell, D.C. (2010). Coastal vulnerability assessment of the Northern Gulf of Mexico to sea-level rise and coastal change. U.S. Geological Survey Open-File Report 2010-1146, at https://pubs.usgs.gov/of/2010/1146/

GeoZS (Slovenia)

The conceptual approach of GeoZS (Slovenia) is shown in the schematic diagram in Figure 13.

GeoZS has implemented a DSS that creates susceptibility maps for mass-movement processes such as landslides, rockfalls, and debris flows in Slovenian coastal areas (Komac et al., 2018).
The system uses various input parameters in both absolute value (e.g. slope) and assigned values (susceptibility of lithologic units to specific mass-movement processes). These parameters are weighted before they are aggregated to produce the final susceptibility map. The resulting susceptibility maps are colour coded. Each colour on the map corresponds to a specific recommendation for spatial planners regarding the suitability of an area for construction or infrastructure projects.

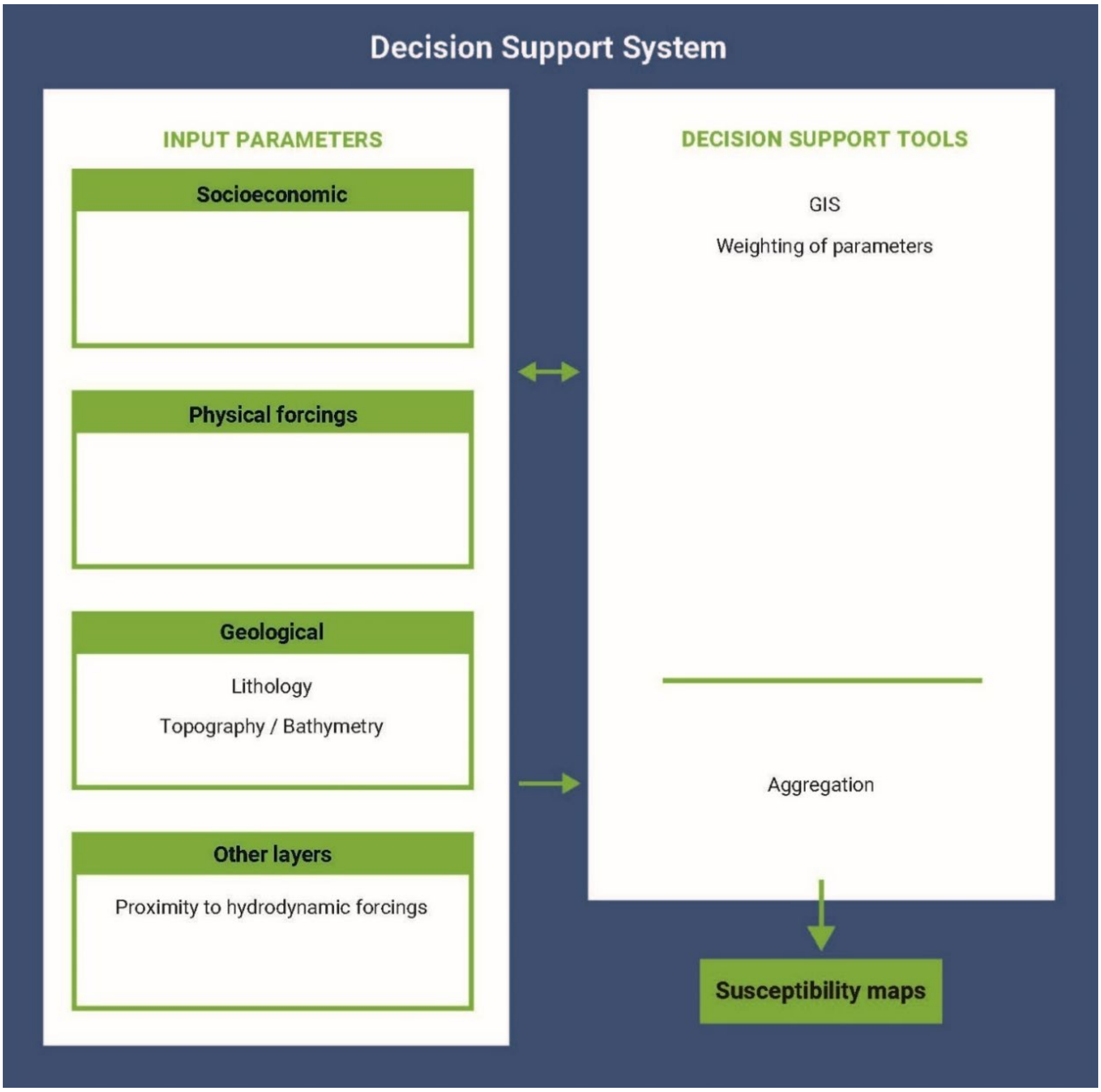

Figure 13. Conceptual approach to assess coastal vulnerability in Slovenia based on questionnaire filled in by GeoZS.

MASPREM is another DSS used by GeoZS. It is a nationwide warning system in Slovenia, established in 2011 to predict and warn about landslides, especially after heavy rainfall. The system operates automatically twice daily and uses open-source software on a scale of 1:250,000. It incorporates Slovenia's landslide susceptibility map, landslide triggering threshold values, and the rainfall forecast models ALADIN/SI and INCA. Using fuzzy logic, the probability of landslides is calculated and output to a 4-level warning scale. Electronic warnings are sent to responsible authorities if necessary. GeoZS has also created a web application ('Atlas Voda') for landslide inventory and emergency services, providing early warnings and support in case of increased hazard (Jemec Auflič et al., 2016; Peternel et al., 2024).

Further reading

Jemec Auflič, M., Šinigoj, J., Krivic, M., Podboj, M., Peternel, T., & Komac, M. (2016). Landslide prediction system for rainfall-induced landslides in Slovenia. Masprem Geologija, 59(2), 259–271.

Komac, M., Jež, J., Dang, K., Sassa, K., Arbanas, Ž., Yamagishi, H., McSaveney, M., Casagli, N., & Guzzetti, F. (2018). TXT-tool 1.386-2.1 Landslide susceptibility assessment method. In Landslide Dynamics: ISDR-ICL Landslide Interactive Teaching Tools (pp. 133–138). Springer International Publishing AG. https://doi.org/10.1007/978-3-319-57774-6_9

Peternel, T., Jemec Auflič, M., Krivic, M., Kumelj, Š., Domej, G., & Šinigoj, J. (2024). MASPREM—the Slovenian landslide forecasting and warning system. Congress of the CAIAG 20th Anniversary: Past Achievements and Future Challenges of Applied Geosciences in Central Asia (Conference paper).

ISPRA (Italy)

The conceptual approach of ISPRA (Italy) is shown in the schematic diagram in Figure 14.

ISPRA does not employ DSSs for coastal vulnerability assessments. However, the DSS Drivers-Pressures-State change-Impact-Response (DPSIR) framework has been used in some Italian studies (Patricio et al., 2016; Bruno et al., 2020).

GIS is the most applied tool. Some studies apply Multi-Criteria Decision Analysis (MCDA) methods which incorporate the Analytical Hierarchical Process (AHP) for weighting of parameters (De Serio et al., 2018; Pagano et al., 2023). Outputs most commonly consist of vulnerability maps.

In many Italian studies, indices like the Coastal Vulnerability Index (CVI) are derived (Aucelli et al., 2018; De Serio et al., 2018; Pantusa et al., 2022; De Luccio et al., 2023). Further, a Multi-Dimensional Coastal Vulnerability Index was proposed by Furlan et al. (2021).

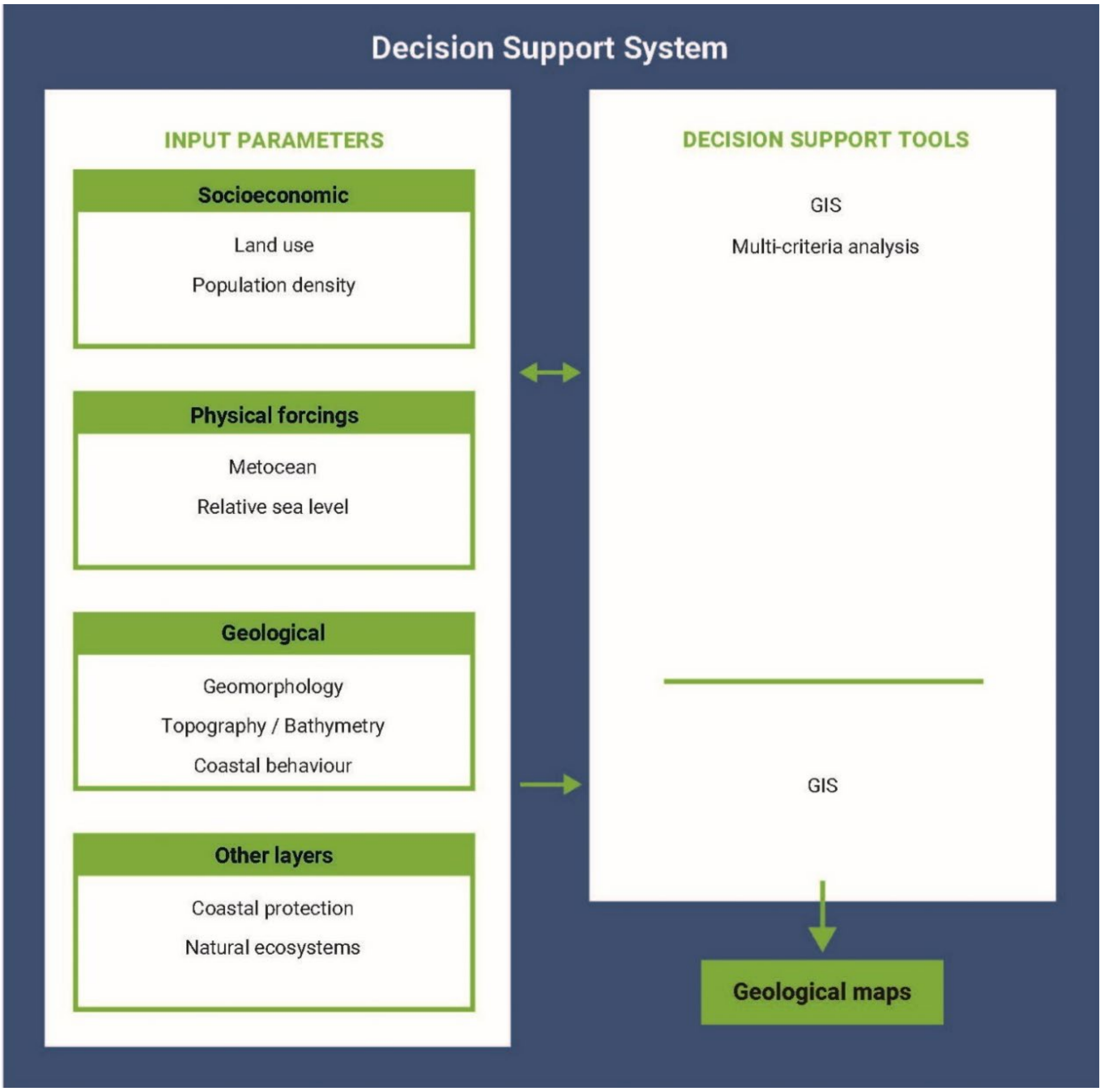

Figure 14. Conceptual approach to assess coastal vulnerability in Italy based on questionnaire filled in by ISPRA.

Further reading

Aucelli, P. P. C., Di Paola, G., Rizzo, A., & Rosskopf, C. M. (2018). Present day and future scenarios of coastal erosion and flooding processes along the Italian Adriatic coast: The case of Molise region. Environmental Earth Sciences, 77(10), 1–19. https://doi.org/10.1007/s12665-018-7535-y

Bruno, M. F., Saponieri, A., Molfetta, M. G., & Damiani, L. (2020). The DPSIR approach for coastal risk assessment under climate change at regional scale: The case of Apulian Coast (Italy). Journal of Marine Science and Engineering, 8(7), 531. https://doi.org/10.3390/jmse8070531

Di Luccio, D., Aucelli, P. P. C., Di Paola, G., Pennetta, M., Berti, M., Budillon, G., Florio, A., & Benassai, G. (2023). An integrated approach for coastal cliff susceptibility: The case study of Procida Island (southern Italy). The Science of the Total Environment, 855, 158759. https://doi.org/10.1016/j.scitotenv.2022.158759

De Serio, F., Armenio, E., Mossa, M., & Petrillo, A. F. (2018). How to define priorities in coastal vulnerability assessment. Geosciences (Basel), 8(11), 415. https://doi.org/10.3390/geosciences8110415

Furlan, E., Pozza, P. D., Michetti, M., Torresan, S., Critto, A., & Marcomini, A. (2021). Development of a multi-dimensional coastal vulnerability index: Assessing vulnerability to inundation scenarios in the Italian coast. The Science of the Total Environment, 772, 144650. https://doi.org/10.1016/j.scitotenv.2020.144650

Pagano, M., Fernetti, M., Busetti, M., Ghribi, M., & Camerlenghi, A. (2023). Multicriteria GIS-based analysis for the evaluation of the vulnerability of the marine environment in the Gulf of Trieste (north-eastern Adriatic Sea) for sustainable blue economy and maritime spatial planning. People and Nature (Hoboken, N.J.), 5(6), 2006–2025. https://doi.org/10.1002/pan3.10537

Pantusa, D., D'Alessandro, F., Frega, F., Francone, A., & Tomasicchio, G. R. (2022). Improvement of a coastal vulnerability index and its application along the Calabria coastline, Italy. Scientific Reports, 12(1), 21959. https://doi.org/10.1038/s41598-022-26374-w

Patrício, J., Elliott, M., Mazik, K., Papadopoulou, K. N., & Smith, C. J. (2016). DPSIR—Two decades of trying to develop a unifying framework for marine environmental management? Frontiers in Marine Science, 3, 177.

GTK (Finland)

The conceptual approach of GTK (Finland) is shown in the schematic diagram in Figure 15.

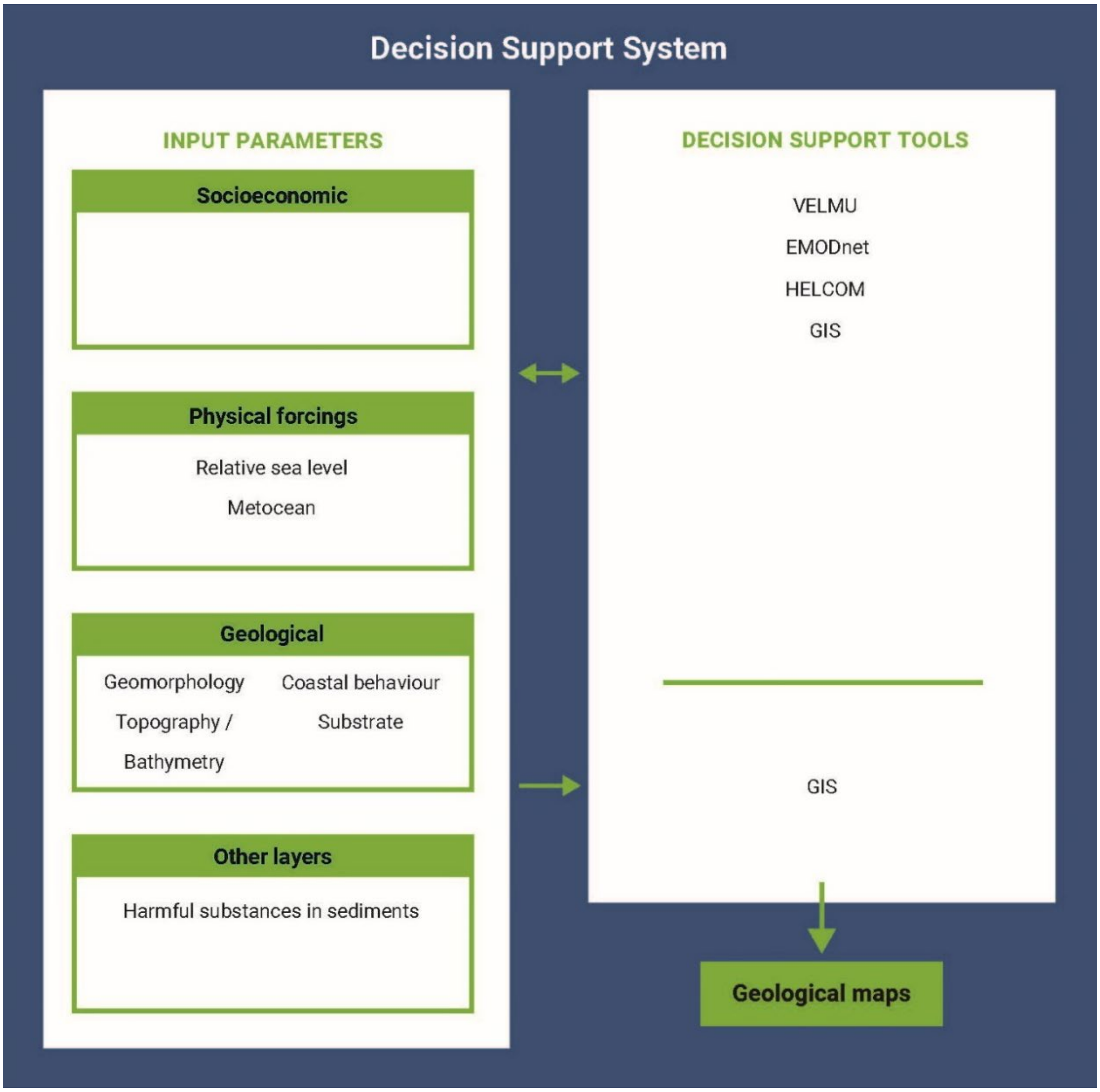

Figure 15. Conceptual approach to assess coastal vulnerability in Finland based on questionnaire filled in by GTK.

GTK does not utilise DSSs for coastal vulnerability assessment. Other institutions in Finland employ Marine Spatial Planning (MSP) and Coastal Zone Management (CZM) Tools to facilitate integrated, multi-purpose planning. Areas vulnerable to environmental change are derived from the use of the tools. Other mentionable tools are EMODnet Central Portal, the VELMU map portal, and HELCOM data services for processing and sharing marine data (Figure 15).

GTK produces information about the seabed geological structures, composition, and processes, and parameters for the environmental assessments like information on acid sulphate soils (ASSs).

GSD (Cyprus)

The conceptual approach of GSD (Cyprus) is shown in the schematic diagram in Figure 16.

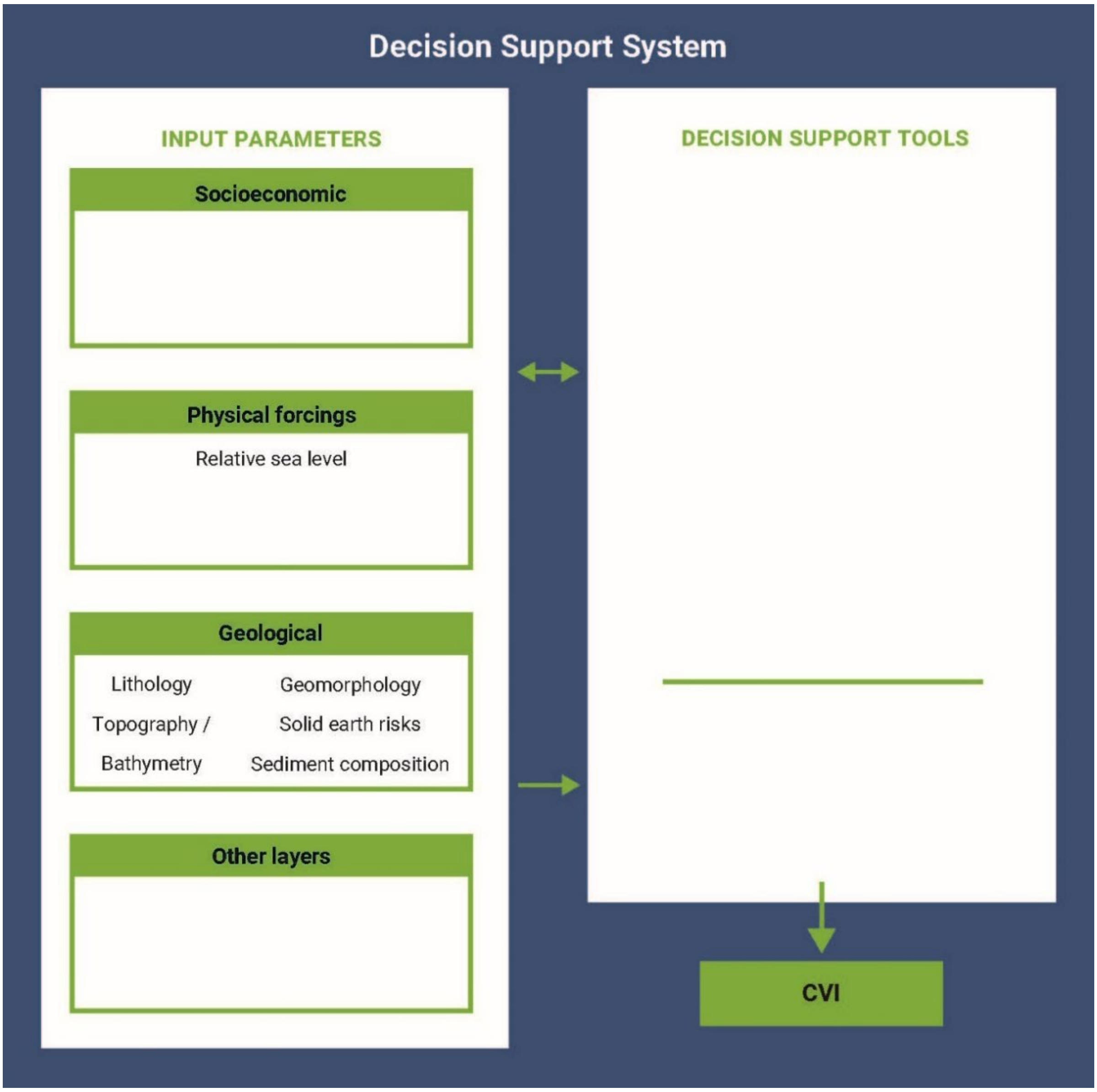

Figure 16. Conceptual approach to assess coastal vulnerability in Cyprus based on questionnaire filled in by GSD.

GSD does not currently utilise DSSs for coastal vulnerability assessment and is not aware of other institutions in the country using such systems. GSD produces a variety of maps to evaluate geology in relation to coastal vulnerability. These include geologic maps of rock types and structures; topographic and bathymetric maps; seafloor sediment maps; shoreline change maps; hazard maps identifying areas at risk from specific hazards. Further, Coastal Vulnerability Index (CVI) is also applied and incorporated in maps showing overall vulnerability based on the other data outputs as well as relative sea level rise (Figure 16).

GSEU

GEUS (Denmark)

The conceptual approach of GEUS (Denmark) is shown in the schematic diagram in Figure 17.

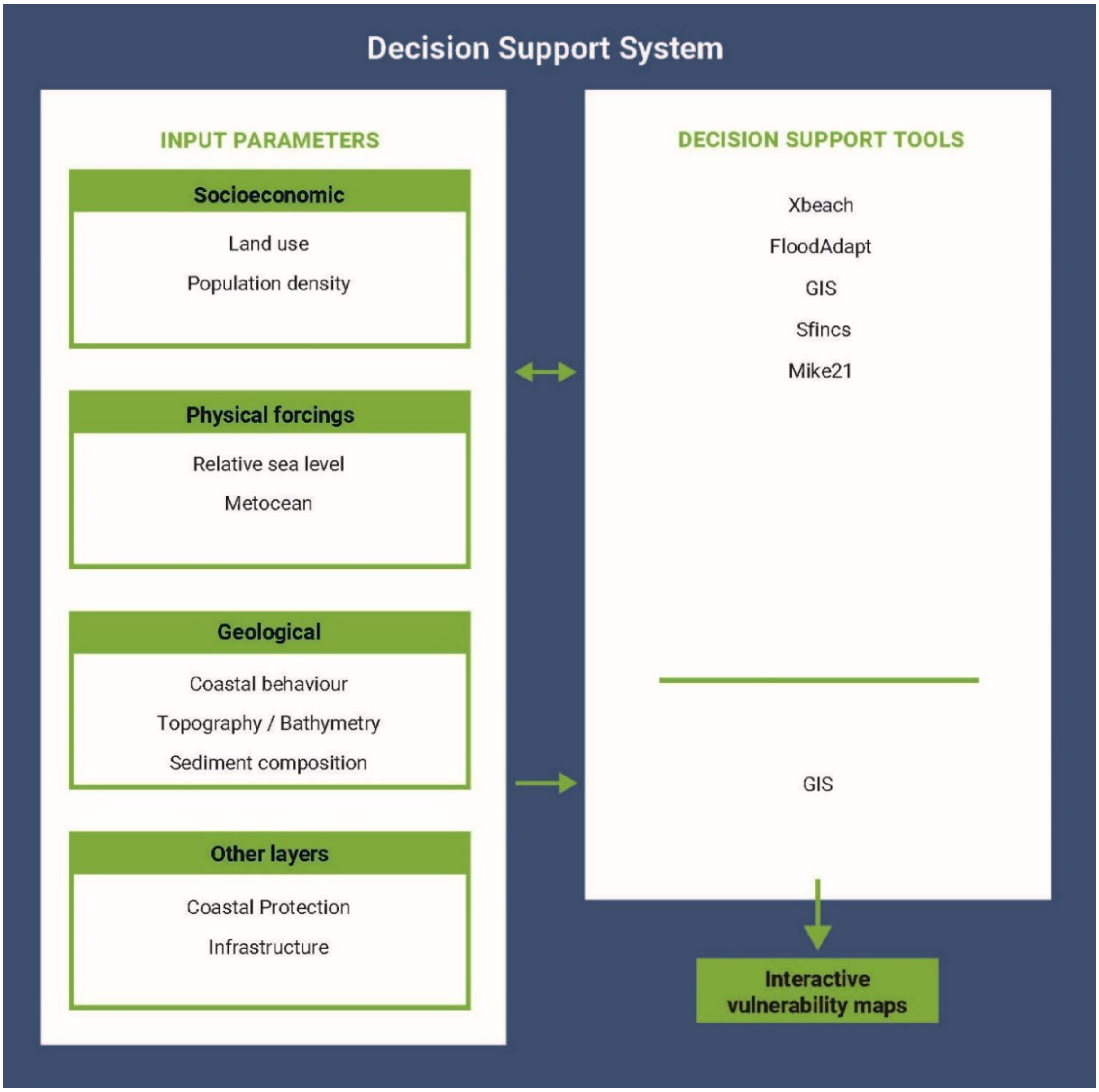

Figure 17. Conceptual approach to assess coastal vulnerability in Denmark based on questionnaire filled in by GEUS.

In Denmark, a DSS has not been developed for application in coastal vulnerability studies. GIS is the primary DST. It is utilised to analyse and aggregate spatial data and to present data on a WebGIS platform. Numerical modelling softwares like XBeach, Mike21 and Sfincs are also widely used (Figure 17). The outputs are interactive vulnerability maps presented in a WebGIS solution which provides information on erosion and flooding susceptibility, economic cost of damage (vulnerability), and recommendations on mitigation strategy. These maps use a 100 m x 100 m grid and account for climate change impacts for susceptibility and vulnerability in 2070 and 2120 (output for 2020 is also available). A Social Vulnerability Index for flooding and erosion, incorporating demographic and economic data to assess susceptibility and resilience is also utilised.

HSGME (Greece)

The conceptual approach of HSGME (Greece) is shown in the schematic diagram in Figure 18.

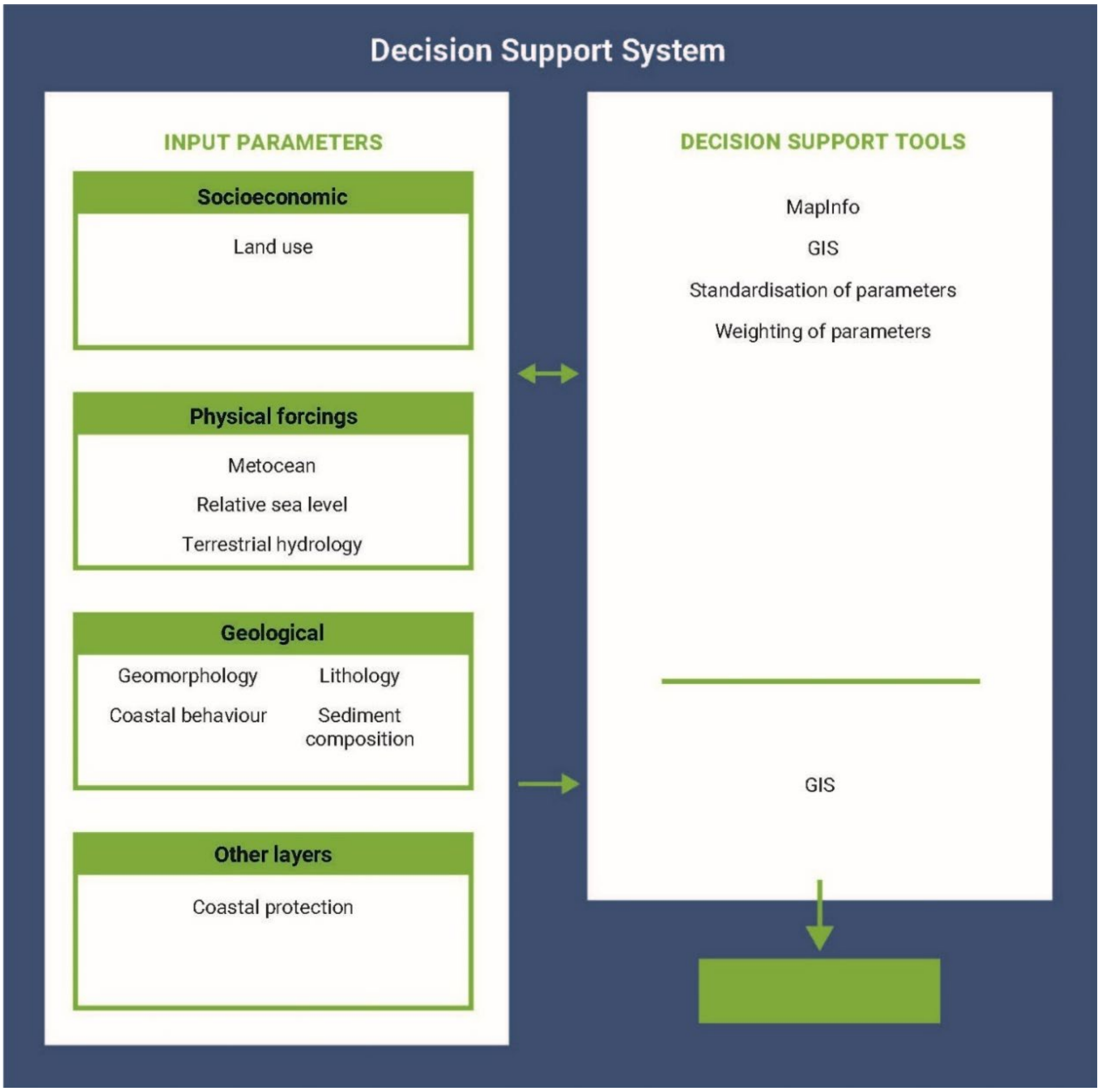

Figure 18. Conceptual approach to assess coastal vulnerability in Greece based on questionnaire filled in by HSGME.

HSGME has developed a DSS for coastal vulnerability assessments, with a focus on addressing hazards like erosion, inundation, and sea-level rise. The system, which is primarily based on GIS software, analyses spatial data to evaluate current conditions, identify risk factors, and propose mitigation strategies. The relevant parameters, which are shown in Figure 18, are weighted. As the DSS is developed for a regional domain, the weighting of the individual parameters change from area to area.

Artificial Neural Networks have been used in runoff erosion hazard assessments, but the plan is to apply them in coastal vulnerability assessments as well.

LNEG (Portugal)

The conceptual approach of LNEG (Portugal) is shown in the schematic diagram in Figure 19.

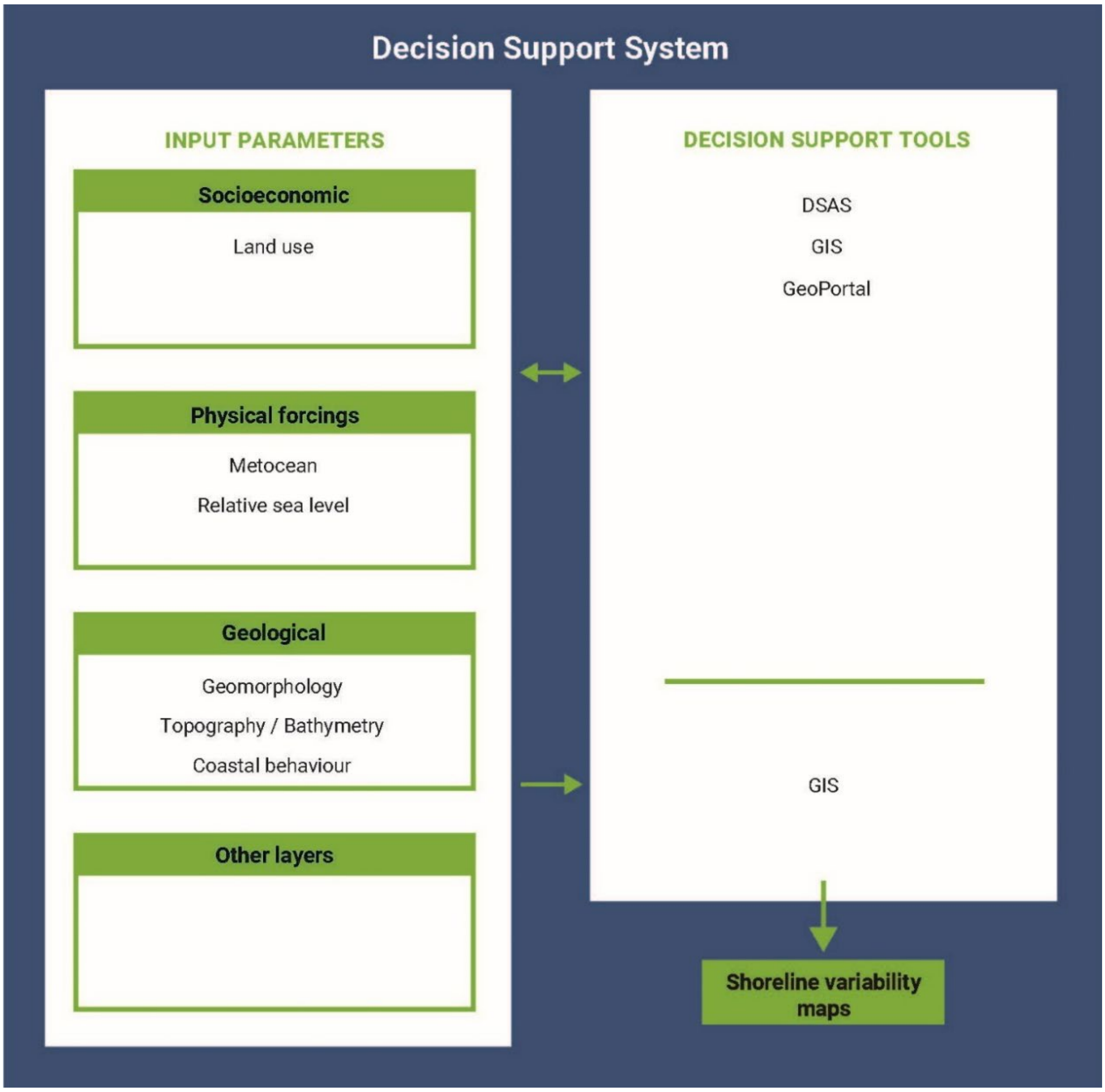

Figure 19. Conceptual approach to assess coastal vulnerability in Portugal based on questionnaire filled in by LNEG.

LNEG actively utilises DSSs. GeoPortal of Energy and Geology is such a DSS from where it is possible to produce information on long-term shoreline variability, on a high-resolution scale, for some coastal sectors.

Key DSTs include ArcGIS Pro and the Digital Shoreline Analysis System (DSAS), which are used to analyse shoreline variability and calculate metrics like Shoreline Change Envelope (SCE), which is a measure of the total change in coastline movement. Net Shoreline Movement (NSM), which is the distance between oldest and youngest detected shoreline position, and Linear Regression Rate (LRR). Outputs include high-resolution shoreline variability maps, represented as the ratio of NSM to SCE to highlight areas experiencing significant shoreline oscillations.

ISOR (Iceland)

The conceptual approach of ISOR (Iceland) is shown in the schematic diagram in Figure 20.

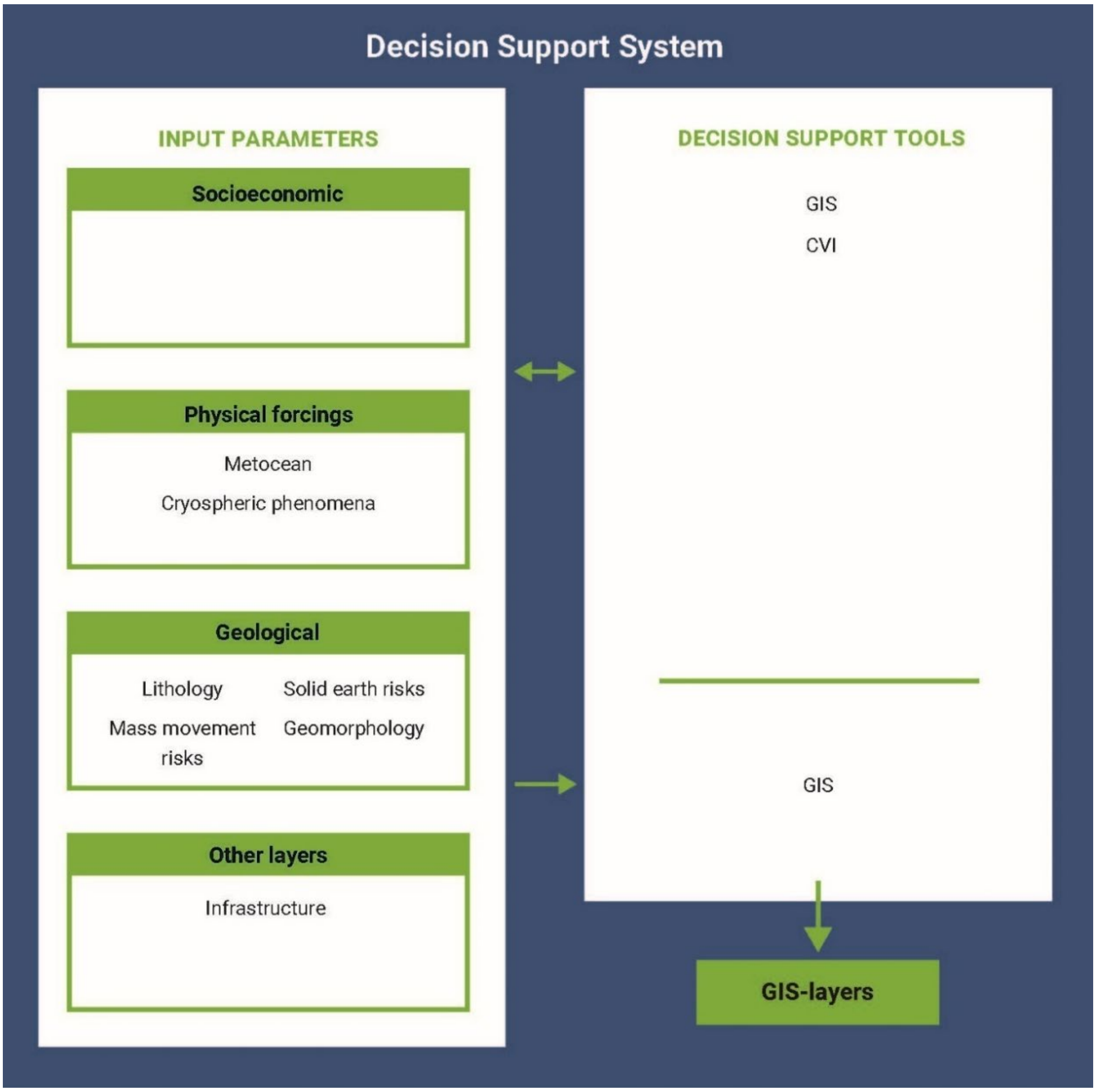

Figure 20. Conceptual approach to assess coastal vulnerability in Iceland based on questionnaire filled in by ISOR.

ISOR does not utilise DSSs when analysing coastal vulnerability. Coastal vulnerability assessments are localised and in development through student projects. The MET-Office of Iceland conducts landslides and avalanche monitoring (https://www.vedur.is/ofanflod/snjoflodaspa/).
GIS is the primary tool applied. A Coastal Vulnerability Index (CVI) has been applied in student projects but is yet to be implemented on a national scale.

Further reading

Davies, W. T. R. (2012). Applying a Coastal Vulnerability Index (CVI) to the Westfjords, Iceland: A preliminary assessment (Master's thesis). University of Akureyri, Ísafjörður.

BGS (United Kingdom)

The conceptual approach of BGS (United Kingdom) is shown in the schematic diagram in Figure 21.

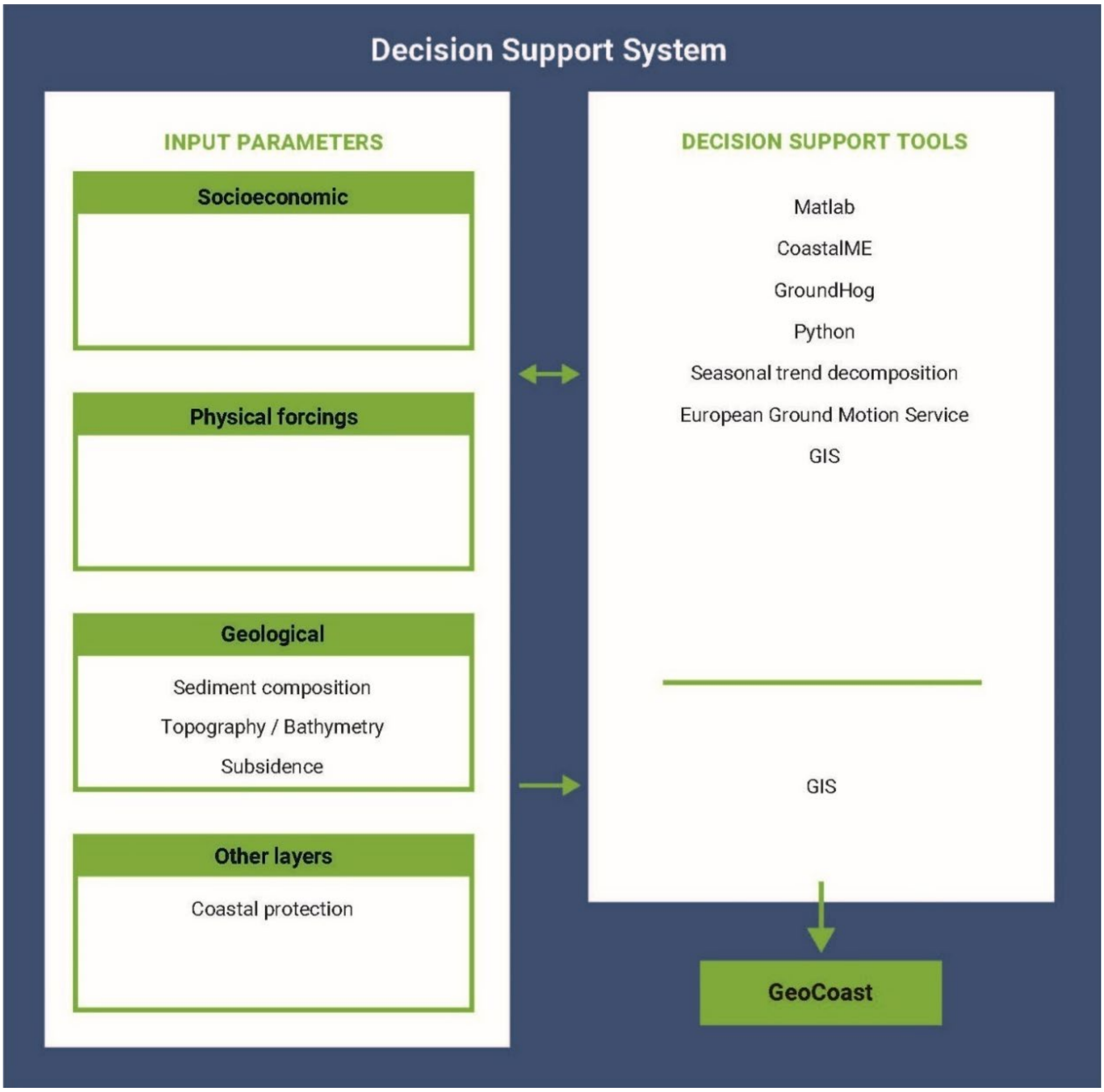

Figure 21. Conceptual approach to assess coastal vulnerability in United Kingdom based on questionnaire filled in by BGS.

BGS employs DSSs and DSTs to address coastal vulnerability, with a strong focus on innovative projects like the Coastal Digital Twin. This initiative, part of the ESA Destination Earth program (2024–2026), aims at creating a highly accurate digital replica of Earth to simulate coastal processes and support decision-making for climate change adaptation, disaster preparedness, and environmental conservation.

Key tools include standard geospatial platforms (e.g., GIS), as well as Coastal Modelling Environment (CoastalME), which enable dynamic modelling of coastal and nearshore landscapes under different scenarios, GroundHog Desktop software and the European Ground Motion Service (EGMS). The systems analyse parameters such as coastal erosion, subsidence, and sediment dynamics (Payo et al., 2017; Torrecillas et al., 2024).

Seasonal trend decomposition tools are applied for time-series analysis, integrating probabilistic reasoning to improve coastal vulnerability assessments.

BGS started using indices (e.g. CVI) and then moved to a database (GeoCoast) as this was found more useful by stakeholders (Jenkins et al., 2016; British Geological Survey, 2022). GeoCoast Premium provides a range of geological and geomorphological properties that influence coastal vulnerability. They are provided as attributed 50 m grid cells around the coastline of Great Britain. A detailed suite of statistical data based on the underlying datasets is also provided. In addition, there is a tool to compare or share best practise at a regional scale and streamline the consideration of multiple underlying datasets through a simple, high-level scheme, presented as domains.

Further reading

BRITISH GEOLOGICAL SURVEY. (2022). User guide: BGS GeoCoast V1. British Geological Survey Open Report, OR/21/001, 48pp.

Jenkins, G. O., Mee, K., Richardson, J. F. M., Lee, K. A., Westhead, R. K., Carter, G. D. O., & Hurst, M. D. (2016). User guide BGS Coastal Vulnerability Index version 1. Nottingham, UK: British Geological Survey, 16pp. (OR/16/039) (Unpublished).

Payo, A., Favis-Mortlock, D., Dickson, M., Hall, J. W., Hurst, M. D., Walkden, M. J. A., Townend, I., Ives, M. C., Nicholls, R. J., & Ellis, M. A. (2017). Coastal Modelling Environment version 1.0: A framework for integrating landform-specific component models in order to simulate decadal to centennial morphological changes on complex coasts. Geoscientific Model Development, 10(7), 2715–2740. https://doi.org/10.5194/gmd-10-2715-2017

Torrecillas, C., Payo, A., Cobos, M., Burke, H., Morgan, D., Smith, H., & Jenkins, G. O. (2024). Sediment Thickness Model of Andalusia's Nearshore and Coastal Inland Topography. Journal of Marine Science and Engineering, 12(2), 269. https://doi.org/10.3390/jmse12020269

19. Appendix III – Part 1: Questionnaire Responses per GSO

The input that was provided via a questionnaire by the partners in T5.4 as well as other partners in WP5 is shown below, subdivided according to GSOs and decision support modules (DSS, DST, DSI), respectively. Any typos in the input to the questionnaires were corrected.

AGS (Albania)

Do you or does your institute have expertise in DSSs for evaluating the geology in relation to coastal vulnerability?

No, we don't have expertise in DSS for evaluating the geology in relation to coastal vulnerability.

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

No, we are not aware of any other institution which works with DSS/DSI

Which DSSs do you work with in projects concerning coastal vulnerability (1)?

We don’t use DSS, we use ArcGIS for creating sedimentation rates maps of erosion and accumulation.

What is the purpose of the DSSs?

\-

What is the domain: local, regional, national or international?

\-

How do you evaluate the DSS?

\-

Additional comments concerning DSSs.

\-

Which geological parameters / information layers do you deem relevant when analysing coastal vulnerability (3)?

geomorphology, coastal dynamic, bathymetry for coastal slope.

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

We don’t use DST.

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to coastal vulnerability (4)?

We use ArcGIS program to evaluate the difference of coastal shore and geology.

Are the parameters weighted and/or standardised. If so, how (4)?

Our parameters are standardised by our scientific government institution, Albanian Geological Survey.

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

No, we don’t apply Artificial Neutral Networks.

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

No, we don’t have considered yet on using these tools.

Additional comments concerning DSTs and information layers / parameters.

\-

What outputs do you produce to evaluate the geology in relation to coastal vulnerability (5)?

Why these outputs?

We produce coastal maps, surfaces of erosion and accumulation during the seashore and the bathymetry of the sea and lagoon.

Do you have any experiences with indices as a measurement of the geology in relation to coastal vulnerability?

Yes, we have experience with indices.

If yes! Please describe the indices.

we have studied the ecosystems, habitats and infrastructure as indices for vulnerability.

Additional comments concerning DSIs and other outputs.

-

BRGM (France)

Do you or does your institute have expertise in DSSs for evaluating the geology in relation to coastal vulnerability?

Yes

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

We recognise that we (BRGM) are not always directly involved in implementing DSSs but are sometimes partners (more or less closely) in past, current and future projects. Despite everything, these are interesting elements to be informed about. And from our point of view, we are very involved in decision support in our own way, sometimes using less sophisticated tools, or with GIS tools, or while developing tools such as climate services.

Goneri LE COZANNET could be the contact entry (G.LeCozannet@brgm.fr) in connection with the projects he is leading, has led or is a partner in.

Which DSSs do you work with in projects concerning coastal vulnerability (1)?

we can mention the projects:

- INSEAPTION (2017-2021) (https://www.inseaption.eu/) => Coastal climate services development / + the implementation of DIVA model by the Global Climate Forum (https://globalclimateforum.org/portfolio-item/diva-model/)
- CoCliCo (2021 - ongoing) (https://coclicoservices.eu/) => upcoming platform, produced by DELTARES)
- PROTECT (2021 - ongoing) (https://protect-slr.eu/objectives/)
- AdApto+ (2024 - ongoing) => upcoming DSS (contact o.brivois@brgm.fr) (suite du project Adapto https://www.lifeadapto.eu/home.html)

What is the purpose of the DSSs?

/

What is the domain: local, regional, national or international?

for national stakeholders

How do you evaluate the DSS?

/

Additional comments concerning DSSs.

/

Which geological parameters / information layers do you deem relevant when analysing coastal vulnerability (3)?

The data are:

- geological maps
- lithology
- geomorphology (coastal features, coastal erosion and accretion, shoreline changes and evolution trends, …)
- coastal slopes
- meteomarine parameters (wind, waves, currents, surges)
- tides (tidal range / highest water level...)
- coastal elevation and topography (low-lying areas, coastal flood plains, wetlands..)
- relative sea level rise (future projections)
- resources (fluid extraction, etc.)
- hydraulics (hydraulic connectivity, drainage network, rivers and groundwater)
- land use (coastal urbanization, infrastructure, activities)
- socio-economic activities
- natural ecosystems
- marine and coastal environmental restrictions (regulatory zones)

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

GIS tools (ArcGIS, QGIS, and so on), or while developing tools such as (coastal) climate services.

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to coastal vulnerability (4)?

GIS tools (ArcGIS, QGIS, and so on), or while developing tools such as (coastal) climate services.

Are the parameters weighted and/or standardised. If so, how (4)?

/

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

Yes

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

Research works of Jeremy ROHMER (BRGM ; j.rohmer@brgm.fr) (e.g. https://brgm.hal.science/hal-02386579v1/file/Rohmer_EAAI_HAL.pdf or https://hal.science/hal-02380692/document)

PhD thesis in progress at BRGM: Mirna BADILLO (2024 - 2027) "An integrated approach to assessing the impact of compound climate risks in the context of small islands". In the frame of the FUTURISKS project. Supervisors: Virginie DUVAT (La Rochelle university), Goneri LE COZANNET (BRGM) and Jeremy ROHMER (BRGM)

Previous works within BRGM teams, for example the article: Bulteau et al., 2015 (https://doi.org/10.1016/j.geomorph.2014.09.002; https://www.sciencedirect.com/science/article/pii/S0169555X14004607?via%3Dihub)

Additional comments concerning DSTs and information layers / parameters.

/

What outputs do you produce to evaluate the geology in relation to coastal vulnerability (5)?

Why these outputs?

/

Do you have any experiences with indices as a measurement of the geology in relation to coastal vulnerability?

Yes

If yes! Please describe the indices.

For example the Vertical Land Motion (VLM) assessment: e.g. works in BRGM / Rémi THIEBLEMONT (r.thieblemont@brgm.fr) https://doi.org/10.1029/2024EF004523; https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2024EF004523

Additional comments concerning DSIs and other outputs.

/

HGI-CGS (Croatia)

Do you or does your institute have expertise in DSSs for evaluating the geology in relation to coastal vulnerability?

NO

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

NA

Which DSSs do you work with in projects concerning coastal vulnerability (1)?

NA

What is the purpose of the DSSs?

NA

What is the domain: local, regional, national or international?

NA

How do you evaluate the DSS?

NA

Additional comments concerning DSSs.

NA

Which geological parameters / information layers do you deem relevant when analysing coastal vulnerability (3)?

lithology, geomorphology

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

NONE

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to coastal vulnerability (4)?

ArcGIS

Are the parameters weighted and/or standardised. If so, how (4)?

No

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

No

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

No

Additional comments concerning DSTs and information layers / parameters.

NA

What outputs do you produce to evaluate the geology in relation to coastal vulnerability (5)?

Why these outputs?

Mostly shapefiles. So far, we didn't produce any indices. For EMODnet Coastal migration/Coastal resilience we used EROSION classes to classify lithology, then reclassified to areas with prograding, retrograding or stable coastline, and low or high resilience.

Do you have any experiences with indices as a measurement of the geology in relation to coastal vulnerability?

No

If yes! Please describe the indices.

No. Other colleagues used CVI (Coastal Vulnerability Index, Gornitz, V. (1991.): Global coastal hazards from future sea level rise. Palaeogeography, Palaeoclimatology, Palaeoecology (Global and Planetary Change Section), 89(4), 379–398. doi.org/10.1016/0031-0182(91)90173-O) to present coastal vulnerability (e.g. Benac, Čedomir, Andrea Tadić, Vedrana Petrović, Dado Jakupović, Gorana Ljubičić, Nino Krvavica i Igor Ružić. "Vulnerability of Krk Island Coasts." Hrvatske vode 29, br. 117 (2021): 187-200.)

Additional comments concerning DSIs and other outputs.

NA

RBINS-GSB (Belgium)

Do you or does your institute have expertise in DSSs for evaluating the geology in relation to coastal vulnerability?

Yes

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

Vera Van Lancker (vvanlancker@naturalsciences.be); Lars Kint (lkint@naturalsciences.be)

Subsurface lithology and geology in the Belgian part of the North Sea (Hademenos et al. 2018) + Uncertainty assessment (Kint et al. 2020)

Which DSSs do you work with in projects concerning coastal vulnerability (1)?

TILES DSS (http://www.bmdc.be/tiles-dss/) Currently not available

What is the purpose of the DSSs?

A decision support application opens up the voxel model for specific requests on lithology, geology and uncertainty information in areas of interest in the Belgian part of the North Sea.

What is the domain: local, regional, national or international?

National

How do you evaluate the DSS?

Easy querying, visualisation and download of 3D subsurface sediments for areas of interest in the Belgian part of the North Sea.

Additional comments concerning DSSs.

Long-term support and maintenance of a DSS is needed through long-term or updated coding language, software, etc.

Which geological parameters / information layers do you deem relevant when analysing coastal vulnerability (3)?

Manual TILES DSS (2020):

- Most common lithological classes
- Heterogeneity of the lithological class
- (average) probability
- (average) entropy
- Most common lithostratigraphy
- (average) borehole density
- (average) percentage of the lithological class
- (average) quality

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

De Tré et al. (2018): "Geographic MCDM relies on the availability of several IT components, including databases and other data resources, a data integration component, a decision support tool and a visualization tool. Data from different sources are used for evaluating the decision criteria. In a first step, each data source is subject to a kind of Extract, Transform and Load (ETL) process, which extracts the relevant data from the source, transforms it into the correct format and prepares it as input for the decision support tool. For main data sources that do not change often, like 3D lithological classification models, ETL is done in advance. In the next step, the integrated input data are processed by the decision support tool. In TILES, an LSP-based approach is used for the computation of suitability degrees for a 3D suitability model. This model is enriched with metadata expressing the confidence that experts have in the computed suitability degrees. The enriched suitability model is loaded into dedicated visualization software for easily accessible presentation to the decision-maker."

De Tré et al. (2018):"The simplified attribute tree shown emphasizes that for a marine exploitation decision (root node), one has to consider data that are related to the lithology, bathymetry, ecology, restricted areas and locations of shipwrecks. As a measure of lithology, the probabilities for different kinds of sediment (in the example limited to fine sand, coarse sand and clay) are considered. A restricted area can be a military zone or an area where power supplies, pipelines or telecommunication lines are located."

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to coastal vulnerability (4)?

De Tré et al. (2018): "In our previous research, we studied 2D suitability maps constructed using the LSP approach [16]. In this work, we used the same technique to create 3D suitability models, as depicted in Fig. 3. It entails a three-step method consisting of (1) elementary attribute selection, (2) elementary criteria specification and evaluation and (3) aggregation."

Other: Geographical Information System (ArcGIS, QGIS, etc.)

Are the parameters weighted and/or standardised. If so, how (4)?

Yes, in the creation of the sediment dataset, the voxel model and the DSS of the subsurface of the Belgian part of the North Sea.

Kint et al. (2020): "Lithological data and associated metadata were harmonized and standardized to facilitate the generation of seamless seabed maps (Van Lancker and van Heteren 2013) following internationally proposed or agreed guidelines (e.g. Geo-Seas for geological and geophysical data (van Heteren 2010), SeaDataNet for oceanographic data, and INSPIRE for spatial information). To ensure machine-readability, interoperability and compatibility of the data, lithological descriptions available as text were transferred to code.

Hademenos et al. (2018): "To model offshore aggregate resources, a methodological workflow was developed based on the voxel modelling approach of Stafleu et al. (2011) and expanded with seismic data. It comprises the following steps: (1a) Standardisation and lithological classification of borehole descriptions; (1b, 3) Delineation of seismic acoustic facies and their seismostratigraphical interpretation; (2) Stratigraphic interpretation of the boreholes; (4) Construction of the 2D stratigraphical layer model; (5) Assignment of lithostratigraphical units to the 3D voxel model; (6) 3D interpolation of lithological class within each lithostratigraphical unit; (7) Assessment of the information entropy of the model."

De Tré et al. (2018): "A scientific solution for data quality assessment using (geographic) multi-criteria decision-making based on LSP suitability models relies on the identification and specification of elementary data quality aspects for the elementary attributes that are involved in the decision-making process. For each elementary data quality aspect, a corresponding elementary quality criterion is specified. Evaluation of these elementary quality criteria for a given voxel in a geographical voxel space yields elementary confidence scores for that voxel. These elementary confidence scores are then aggregated to an overall confidence degree by applying a novel, extended version of the LSP aggregation structure. Every LSP aggregator is extended so that it takes both suitability degrees and confidence degrees as arguments and computes a couple that consists of an aggregated suitability degree and an aggregated confidence degree. The aggregated suitability degree is computed in exactly the same way as in regular suitability modelling. For the aggregated confidence degree, a weighted sum of the input confidence degrees is computed, with the weights reflecting the impact of the corresponding input suitability degrees on the computation
of the aggregated suitability degree. In our future research, we aim to study alternatives for the weighted sum aggregation in order to further improve the semantic properties of the aggregation, so that this aggregation even better reflects and complements expert reasoning."

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

Yes

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

De Mol (2019): "In the Bayesian interpretation (based on Bayes' theory of Bayesian inference but actually pioneered by Laplace), probability is a subjective indicator of belief. Different agents might assign different probabilities to different outcomes and there is no reason for someone to believe one agent over the other. Bayesian probabilities further also rely on the assumption that agents are perfectly rational [3, 21], though evidence has shown that this claim is doubtful [17]. This interpretation is often applied in the context of betting games, to set payout rates for outcomes in correspondence to their perceived probability of occurring, which is immediate evidence that perceived probabilities can be used to turn a profit and are not necessarily fair. Au contraire, this interpretation relies on the idea that the true likeliness of the outcomes can be hidden behind slightly manipulated probabilities in order to trick gamblers into entering an unfair game, the lottery being a prime example thereof.

Additional comments concerning DSTs and information layers / parameters.

-

What outputs do you produce to evaluate the geology in relation to coastal vulnerability (5)? Why these outputs?

De Tré et al. (2018): "Key to the decision support tool used in TILES is the creation of 3D suitability models. As input, a 3D voxel model of the subsurface of the Belgian part of the North Sea is being constructed. Each voxel is currently fixed in size (length and width 200 m, height 1 m). The model currently includes voxels that range from 4 m above mean sea level to 75 m below it.

Van Lancker et al. (2019): "Main DSS attributes relate to the integrated data, information and knowledge, the 3D geological models and some first output from 4D process models. Advanced criteria-evaluation techniques were developed to support the construction of specialized geographical maps of the sea region under investigation. Such maps, hereafter called 'suitability maps', are able to show geological boundaries, distributions of particular resource qualities, and the resource estimation at various cut-off grades, all calculated in a time-efficient manner encouraging online use of the tool. Additionally, user functions of the BPNS, as available from the Marine Atlas (Belgian Marine Data Centre), were incorporated: infrastructure (e.g. pipelines; electricity and telecommunication cables; windmills; navigation routes), human activity (e.g. tourism, safety), legal status (e.g. areas reserved for special activities), economic development (e.g. expansion of industries). A user can make dynamically a series of tailor-made suitability maps that assist in resource assessments."

Do you have any experiences with indices as a measurement of the geology in relation to coastal vulnerability?

-

If yes! Please describe the indices.

-

Additional comments concerning DSIs and other outputs.

-

ICGC (Spain / Catalonia)

Do you or does your institute have expertise in DSSs for evaluating the geology in relation to coastal vulnerability?

No

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

No, I'm not aware of any.

Which DSSs do you work with in projects concerning coastal vulnerability (1)?

None

What is the purpose of the DSSs?

NA

What is the domain: local, regional, national or international?

NA

How do you evaluate the DSS?

NA

Additional comments concerning DSSs.

NA

Which geological parameters / information layers do you deem relevant when analysing coastal vulnerability (3)?

NA

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

NA

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to coastal vulnerability (4)?

NA

Are the parameters weighted and/or standardised. If so, how (4)?

No

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

No

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

NA

Additional comments concerning DSTs and information layers / parameters.

NA

What outputs do you produce to evaluate the geology in relation to coastal vulnerability (5)? Why these outputs?

We create basic information for decision-making: topographic maps, DEMs, geological, orthophotos, bathymetry.

We also generate geothematic products https://www.icgc.cat/ca/Ambits-tematics/Litoral-Dinamica-de-la-costa:

-We document the effects of storms on the coast (https://www.icgc.cat/ca/Eines-i-visors/Visors/Evolucio-de-la-costa

-Geomorphological maps of storm surge flooding (pending publication)

-Permanent flooding map https://visors.icgc.cat/inundacio-permanent/

-Danger and risk studies of flooding and erosion https://visors.icgc.cat/sidl/#10.9/40.6786/0.6722

-Cartography of slope movements along the entire coast of Catalonia (pending publication)

Do you have any experiences with indices as a measurement of the geology in relation to coastal vulnerability?

No

If yes! Please describe the indices.

NA

Additional comments concerning DSIs and other outputs.

We are currently working on a CVI, but I don't not know when it will be finished.

GSI (Ireland)

Do you or does your institute have expertise in DSSs for evaluating the geology in relation to coastal vulnerability?

Yes

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

Silvia.caloca@gsi.ie; xavier.monteys@gsi.ie

Which DSSs do you work with in projects concerning coastal vulnerability (1)?

Costal Vulnerability Index workflow

What is the purpose of the DSSs?

Categorise the coast into units of vulnerability regarding its susceptibility to change.

What is the domain: local, regional, national or international?

National

How do you evaluate the DSS?

NA

Additional comments concerning DSSs.

NA

Which geological parameters / information layers do you deem relevant when analysing coastal vulnerability (3)?

Shoreline change rates, geomorphology classes, cliff type, coastal slope.

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

Shoreline change rates are extracted using vegetation line time series in DSAS 5.2 (USGS). Coastal Slope and cliff type parameters are largely extracted from Lidar DTM data and GIS tools.

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to coastal vulnerability (4)?

NA

Are the parameters weighted and/or standardised. If so, how (4)?

Parameters are standardised using discrete vulnerability categories.

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

No

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

We have considered to include Bayesian network methods to forecast coastal vulnerability

Additional comments concerning DSTs and information layers / parameters.

NA

What outputs do you produce to evaluate the geology in relation to coastal vulnerability (5)? Why these outputs?

Geomorphology classes, cliff type, coastal slope, shoreline change rates

Do you have any experiences with indices as a measurement of the geology in relation to coastal vulnerability?

Yes

If yes! Please describe the indices.

We use a CVI modified from USGS index-based methodology (Thieler et al., (2000); Pendleton et al., (2010))

Additional comments concerning DSIs and other outputs.
NA

GeoZS (Slovenia)

Do you or does your institute have expertise in DSSs for evaluating the geology in relation to coastal vulnerability?
Yes

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

Jernej Jež (jernej.jez@geo-zs.si) is the contact person for the "GH project" run at the GeoZS. This DSS is aimed at creating ready-to-use vulnerability maps for mass-movement processes and includes all Slovenian coastal areas. Mateja Jemec Auflič (mateja.jemec-auflic@geo-zs.si) is the contact person for "MASPREM" - landslide forecasting system. Another DSS (not at GeoZS) covering parts of the Slovenian coast shows areas at risk of flooding. Another DSS covering parts of the Slovenian coast shows areas at risk of flooding. The contact person is maja.kregar@gov.si. Both DSSs are included in the "Atlas voda" webgis viewer:
https://geohub.gov.si/portal/apps/webappviewer/index.html?id=f89cc3835fcd48b5a980343570e0b64e

Which DSSs do you work with in projects concerning coastal vulnerability (1)?
With the GH project

What is the purpose of the DSSs?
The DSS is intended as support for spatial planning. It visually shows areas more or less prone to mass-movement processes (landslides, rockfalls, debris flows and all three combined) with a color-coded system. Each colour has an assigned recommendation for the spatial planner to follow when considering if an area is suitable for construction, infrastructure projects, etc. The MASPREM DSS provides landslide forecast models for the Civil Administration office in case of extreme rainfall events.

What is the domain: local, regional, national or international?
National

How do you evaluate the DSS?
The DSSs are a useful source of information for both the general public (in case of GH) as well as the governmental bodies.

Additional comments concerning DSSs.
NA

Which geological parameters / information layers do you deem relevant when analysing coastal vulnerability (3)?
For landslides: Lithology, slope, aspect, curvature, proximity to sources of erosion (sea, rivers, estuaries) and faults and fault zones, altitude above sea level. For rockfalls: Lithology, slope, proximity to fault zone.

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?
We use GIS systems (ArcGIS pro): each input parameter has either an absolute value (e.g. slope) or assigned value (e.g. susceptibility of a lithologic unit to a specific mass-movement process). The end product from the processing with the DST is a colour-coded susceptibility map.

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to coastal vulnerability (4)?

Field validation of the modelled results.

Are the parameters weighted and/or standardised. If so, how (4)?

The parameters are weighted, but we cannot disclose details due to contractual obligations.

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

No

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

We have not yet considered the latter as we follow a pre-defined methodology. Additionally, we do not have adequate in-house knowledge.

Additional comments concerning DSTs and information layers / parameters.

NA

What outputs do you produce to evaluate the geology in relation to coastal vulnerability (5)?

Why these outputs?

Mass-movement susceptibility maps.

Do you have any experiences with indices as a measurement of the geology in relation to coastal vulnerability?

No

If yes! Please describe the indices.

NA

Additional comments concerning DSIs and other outputs.

NA

ISPRA (Italy)

Do you or does your institute have expertise in DSSs for evaluating the geology in relation to coastal vulnerability?

No

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

NA

Which DSSs do you work with in projects concerning coastal vulnerability (1)?

NAWhat is the purpose of the DSSs?

NA

What is the domain: local, regional, national or international?

NA

How do you evaluate the DSS?

NA

Additional comments concerning DSSs.

NA

Which geological parameters / information layers do you deem relevant when analysing coastal vulnerability (3)?

Common parameters include geomorphology, coastal slope, shoreline erosion/accretion rate, relative sea-level rise, mean wave height, and mean tidal range. Some studies also consider land use, coastal protection structures, population density and natural ecosystems.

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

Geographic Information Systems (GIS) are often used to process and analyse data.

ISPRA realizes national information layer: e.g. shoreline erosion/accretion, coastal landslides, coastal habitats.When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to coastal vulnerability (4)?

Multicriteria GIS-based analysis

Are the parameters weighted and/or standardised. If so, how (4)?

NA

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

NA

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

NA

Additional comments concerning DSTs and information layers / parameters.

NA

What outputs do you produce to evaluate the geology in relation to coastal vulnerability (5)? Why these outputs?

NA

Do you have any experiences with indices as a measurement of the geology in relation to coastal vulnerability?

No

If yes! Please describe the indices.

NA

Additional comments concerning DSIs and other outputs.

NA

GTK (Finland)

Do you or does your institute have expertise in DSSs for evaluating the geology in relation to coastal vulnerability?

No

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

We have expertise in geology at GTK, but not in DSS's evaluating coastal vulnerability. In Finland, DSSs addressing coastal vulnerability focus on understanding and mitigating the impacts of climate change, rising sea levels, and other natural and anthropogenic pressures. These systems combine environmental, social, and economic data to support sustainable coastal management. In Finland, Flood Risk Management systems are coordinated by ELY Centres. Climate Risk and Vulnerability

Assessments evaluate the susceptibility of coastal areas to climate change impacts including sea-level rise, increased storm surges, and erosion. National Climate Risk Assessments are coordinated by the Ministry of Agriculture and Forestry. Marine Spatial Planning (MSP) and Coastal Zone Management Tools integrate multi-use planning while identifying areas vulnerable to environmental change. Biodiversity and Ecosystem Service Assessments assess the vulnerability of coastal ecosystems and the services they provide to communities.

Which DSSs do you work with in projects concerning coastal vulnerability (1)?

We provide seabed geological information for e.g., marine habitat mapping purposes

What is the purpose of the DSSs?

Flood Risk Management Systems address coastal flooding risks due to storm surges, high water levels, and ice movement. Climate Risk and Vulnerability Assessments evaluate the susceptibility of coastal areas to climate change impacts including sea-level rise, increased storm surges, and erosion. MSP and Coastal Zone Management Tools integrate multi-use planning while identifying areas vulnerable to environmental change. Biodiversity and Ecosystem Service Assessments assess the vulnerability of coastal ecosystems and the services they provide to communities.

What is the domain: local, regional, national or international?

National

How do you evaluate the DSS?

Not sure

Additional comments concerning DSSs.

NA

Which geological parameters / information layers do you deem relevant when analysing coastal vulnerability (3)?

Substrate, coastline, bedrock, geomorphology, harmful substances in sediments (like ASS's), bathymetry/topography and derivatives from those like roughness.

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

We do not actually make coastal vulnerability analysis at GTK. However, we consider following DST's useful: EMODnet Central Portal for marine data, VELMU map portal for Finnish Marine Inventory data, HELCOM data service, GIS Desktop. For geological parameter see above.

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to coastal vulnerability (4)?

We do not actually make coastal vulnerability analysis at GTK. However, we consider following DST's useful: EMODnet Central Portal for marine data, VELMU map portal for Finnish Marine Inventory data, HELCOM data service, GIS Desktop. For geological parameter see above.

Are the parameters weighted and/or standardised. If so, how (4)?

NA

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

No

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

NA

Additional comments concerning DSTs and information layers / parameters.

We do not actually make coastal vulnerability analysis at GTK

What outputs do you produce to evaluate the geology in relation to coastal vulnerability (5)? Why these outputs?

We do not actually make coastal vulnerability analysis at GTK, but we produce information about the seabed geological structures, composition, and processes, and parameters for the environmental assessments like information on acid sulphate soils (ASS).

Do you have any experiences with indices as a measurement of the geology in relation to coastal vulnerability?

No

If yes! Please describe the indices.

NA

Additional comments concerning DSIs and other outputs.

NA

GSD (Cyprus)

Do you or does your institute have expertise in DSSs for evaluating the geology in relation to coastal vulnerability?

no

If yes! Who is the contact person? What is the field? If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

no

Which DSSs do you work with in projects concerning coastal vulnerability (1)?

NA

What is the purpose of the DSSs?

NA

What is the domain: local, regional, national or international?

NA

How do you evaluate the DSS?

NA

Additional comments concerning DSSs.

NA

Which geological parameters / information layers do you deem relevant when analysing coastal vulnerability (3)?

NA

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

NA

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to coastal vulnerability (4)?

NA

Are the parameters weighted and/or standardised. If so, how (4)?

NA

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

NA

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

NA

Additional comments concerning DSTs and information layers / parameters.

NA

What outputs do you produce to evaluate the geology in relation to coastal vulnerability (5)? Why these outputs?

Key outputs for evaluating geology in relation to coastal vulnerability:
Geologic maps: Show rock types and structures.
Topographic maps: Illustrate landforms and elevation.
Bathymetric maps: Map seafloor depth and topography.
Seafloor sediment maps: Show sediment distribution.
Shoreline change maps: Track coastal changes over time.
Coastal Vulnerability Index (CVI) maps: Assess overall vulnerability.
Hazard maps: Identify areas at risk from specific hazards.

Why these outputs?
Geology influences coastal stability and erosion.
Topography affects wave energy and flooding.
Bathymetry impacts wave patterns and sediment transport.
Seafloor sediment determines seabed stability and erodibility.
Shoreline change tracks coastal trends.
Hazard maps pinpoint areas at risk for targeted management.
By combining these outputs, we can understand coastal vulnerability and develop effective management strategies.

Do you have any experiences with indices as a measurement of the geology in relation to coastal vulnerability?

Yes

If yes! Please describe the indices.

One common index is the Coastal Vulnerability Index (CVI). It combines various factors like:
Geomorphology: Coastal landforms and their stability.
Shoreline change: Erosion or accretion rates.
Coastal slope: Steepness of the coastline.
Relative sea level rise: Rate of sea level increase.
Sediment type: Sand, mud, or rock, influencing erosion rates.
Rock type: Strength and resistance to weathering.
Fault activity: Potential for seismic hazards.
Using these indices, geological surveys can provide valuable insights for coastal management and planning.

Additional comments concerning DSIs and other outputs.

NA

GEUS (Denmark)

Do you or does your institute have expertise in DSSs for evaluating the geology in relation to coastal vulnerability?

No

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

NA

Which DSSs do you work with in projects concerning coastal vulnerability (1)?

NA

What is the purpose of the DSSs?

NA

What is the domain: local, regional, national or international?

NA

How do you evaluate the DSS?

NA

Additional comments concerning DSSs.

A single software, framework or workflow have not been developed to standardize the way of doing coastal vulnerability assessment.

Which geological parameters / information layers do you deem relevant when analysing coastal vulnerability (3)?

Existing coastal protection; water level; wind speed; wind set-up; wave characteristics; topography; bathymetry; land use; population density; sediment composition; infrastructure.

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

XBeach; Mike21; ArcGIS Pro; Sfincs; FloodAdapt

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to coastal vulnerability (4)?

ArcGIS Pro

Are the parameters weighted and/or standardised. If so, how (4)?

The parameters are not standardised or weighted but are instead represented with an economic value, which makes them comparable. Some socio-economic parameters have a higher economic value than others, which relates to a weighting of the parameters.

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

NA

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

NA

Additional comments concerning DSTs and information layers / parameters.

In the current analytical work, it is assumed that existing dikes are stable and that they will not deteriorate. A tool is under development which should address this optimistic assumption. Based on parameters on the strength of the dike.

What outputs do you produce to evaluate the geology in relation to coastal vulnerability (5)? Why these outputs?

Interactive vulnerability maps in webgis:

Kystplanlægger (Eng: 'Coastal Planner'). Data layers in 100 x 100 m grid cells showing the susceptibility of erosion and flooding in 2020, 2070 and 2120 at 6 different events with respective return periods ranging from 50 to 10.000 years, while taking into account the effects of climate change (scenario: RCP8.5). Further it shows the vulnerability of the coast which considers the beforementioned susceptibility, the percentage risk of a given event as well as the economic cost of damage on infrastructure, property, livestock, crops and companies. Data is color-coded based on costs. A data layer with recommendations on mitigation strategy is also available.

Do you have any experiences with indices as a measurement of the geology in relation to coastal vulnerability?

No

If yes! Please describe the indices.

A Social Vulnerability Index was developed in relation to flooding and erosion. It relies on demographic information. Data is in 100x100 meter grid cells, and the index uses five key indicators that assess both susceptibility (negative factors) and resilience (positive factors) at the neighbourhood level. Key indicators: Age; Health, Socio-economic conditions: ability to receive and understand information; neighbourhood resilience (bonding factors). Indicators are weighted equally. The index is transformed to a 0-10 scale by use of Natural Breaks in ArcGIS Pro.

The economic vulnerability caused by erosion and flooding susceptibility is on a monetary scale divided in groups by Natural Breaks in ArcGIS Pro.

Additional comments concerning DSIs and other outputs.

A second version of Kystplanlægger is under development (hopefully ready in 2027). In the new version it should be possible to draw a line representing a dike, assign a height to the dike and then compute the mitigation effect it will have.

HSGME (Greece)

Do you or does your institute have expertise in DSSs for evaluating the geology in relation to coastal vulnerability?

Yes

If yes! Who is the contact person? What is the field? If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

Prof. Niki-Nikoletta Evelpidou, Department of Geology and Geoenvironment, National and Kapodistrian University of Athens; evelpidou@geol.uoa.gr. Fields of expertise: Geomorphology, Geographic Information Systems (GIS), coastal geomorphology, coastal hazards, coastal vulnerability, sea-level rise, Nature based Solutions

Which DSSs do you work with in projects concerning coastal vulnerability (1)?

We have developed a DSS for coastal vulnerability assessment (coastal erosion and inundation hazard), based on GIS softwares: MapInfo Professional and ESRI products (ArcMap, ArcGIS Pro, ArcGIS Online)

What is the purpose of the DSSs?

To evaluate the current & future situation of the coastal zone; to identify factors (natural and human-induced) that create or accelerate a problem (e.g. coastal erosion, inundation etc.); to identify measures and mitigation strategies and how they can be applied; to evaluate their efficiency in connection to the implementation cost, before implementation and after implementation

What is the domain: local, regional, national or international?

Regional

How do you evaluate the DSS?

By comparing the results with: (a) actual observations, data and measurements from the coastal zone; (b) historic data on the coastal zone (e.g. evolutional trend of the coastline, based on old maps, satellite images, aerial photos etc.); (c) similar comparisons in areas and regional settings where the DSS have actually worked.

Additional comments concerning DSSs.

NA

Which geological parameters / information layers do you deem relevant when analysing coastal vulnerability (3)?

geomorphological observations (in general); characteristics of the coastal and submarine morphology; presence of vegetation, sediments, cliffs, streams, river estuaries, forests and other geomorphological features, as well as their spatial characteristics; size, composition and distribution of coastal sediments (in detail); presence and type of human interventions; wave and wind characteristics (in detail); geological and tectonic structure of the coastal area; geological structure and geomorphological observations on the broader area (mainland); hydrographic and hydrological characteristics of the broader mainland (drainage basin); evolution of the coastal zone at a broader scale (e.g. through satellite images etc.)

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

(2) Geographic Information Systems; (3) spatial distribution of the characteristics mentioned above; evolution of the coastal zone from the past to the present (e.g. since the last 50-100 years); evolution of the coastal zone in the next 100 years, considering sea-level rise projections; evolution of the coastal zone within a desired time scale, considering current geomorphological regime (see previous question), existing, future and proposed interventions (e.g. coastal constructions, nature-based solutions etc.)

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to coastal vulnerability (4)?

Geographic Information Systems

Are the parameters weighted and/or standardised. If so, how (4)?

Yes. Each different area will require a different weighting of the parameters, and a standard answer cannot be given that will be case-independent. As many input parameters among those already mentioned are to be included and with as much accuracy and detail as possible, in order for the weighting and the final outputs to be proper and accurate. How they are standardised depends upon: the availability and accuracy of existing data; the time and budget available to collect the missing data; local conditions (e.g. weather issues) that may hinder or facilitate the collection of additional data; the time available to process the data and run the necessary models in detail; the integrity of the equipment and materials available in the field and in the post-field analyses.

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

Sometimes but usually no

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

Artificial Neural Networks have been used in runoff erosion hazard assessment, but the plan is to apply them in coastal vulnerability as well

Additional comments concerning DSTs and information layers / parameters.

NA

What outputs do you produce to evaluate the geology in relation to coastal vulnerability (5)? Why these outputs?

All the data mentioned above are necessary for integrated coastal zone management, including application of mitigation strategies and protection measures. When unavailable and missing, these data should be collected or generated (e.g. using GIS), because they all affect the coastal zone evolution and the efficiency of any applied measure. Skipping or simply estimating any of those data is highly avoided, and accurate measurements are to be done to acquire them.

Do you have any experiences with indices as a measurement of the geology in relation to coastal vulnerability?

Yes

If yes! Please describe the indices.

Previous (Holocene) changes and trends in the coastal zone, based on indices: (a) geomorphological ones (e.g. tidal notches, abrasion platforms, beachrocks); (b) archaeological ones (e.g. ancient harbours, cemeteries, temples, settlements and other constructions); (c) biological ones (e.g. Lithophaga holes and other biological marks); (d) sedimentological ones (involving sediment dating methods, such as U/Th, OSL, 14C etc.). Also, through boreholes in coastal lagoonal environments, where previous environmental, climatic and geomorphological conditions can be reconstructed.

Additional comments concerning DSIs and other outputs.

NA

LNEG (Portugal)

Do you or does your institute have expertise in DSSs for evaluating the geology in relation to coastal vulnerability?

Yes

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

Sílvia Nave (silvia.nave@lneg.pt); Coastal geology

Which DSSs do you work with in projects concerning coastal vulnerability (1)?

SIG (ArcGIS Pro, Environmental System Research Institute (ESRI));

GeoPortal of Energy and Geology https://geoportal.lneg.pt/en/, with possibility of interaction with several layers of information https://geoportal.lneg.pt/mapa/?Mapa=GeologiaCosteira

What is the purpose of the DSSs?

Get information on long-term shoreline variability, on a high-resolution scale, for some coastal sectors, to support decision-making on long-term planning and adaptation strategies to overcome threats to the Portuguese coast, such as increased risks due to climate change and coastal erosion.

What is the domain: local, regional, national or international?

National

How do you evaluate the DSS?

The data obtained from the DSS is compared to related works, previously developed at lower resolution.

Additional comments concerning DSSs.

No additional comments.

Which geological parameters / information layers do you deem relevant when analysing coastal vulnerability (3)?

coastal geomorphology
shoreline erosion/accretion rates
land cover
coastal elevation
tidal range
significant wave height
sea-level rise

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

(2) Digital Shoreline Analysis System (DSAS), an add-in within the ESRI
(3) Net Shoreline Movement (NSM), Linear Regression Rate (LRR), Shoreline Change Envelope (SCE)
Net Shoreline Movement (NSM) corresponds to the distance between the oldest and the youngest coastline
Linear Regression Rate (LRR), a statistical parameter, that determines a rate-of-change
Shoreline Change Envelope (SCE), is the measure of the total change in coastline movement considering all available coastline positions and reporting their distances, without reference to their specific dates

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to coastal vulnerability (4)?

SIG (ArcGIS Pro, ESRI)

Are the parameters weighted and/or standardised. If so, how (4)?

No

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

No

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

So far, we were focused on understanding the past variability of the shoreline, but we are considering using Artificial Neural Networks or a Bayesian Network in the future, to predict coastal vulnerability

Additional comments concerning DSTs and information layers / parameters.

DSAS enables a user to calculate rate-of-change statistics from multiple historical shoreline positions, so the input parameter is shoreline position, which is achieved through the analysis of historical aerial photographs and ortophoto maps, geology and digital terrain models.

What outputs do you produce to evaluate the geology in relation to coastal vulnerability (5)? Why these outputs?

We also use Coastal Vulnerability index, given by Abs[NSM/SCE], as a complement tool to the net shoreline movement (NSM) and the shoreline change rates (LRR) for specific time windows, as the Abs[NSM/SCE] highlights the areas that experienced higher oscillations of the shoreline.

Do you have any experiences with indices as a measurement of the geology in relation to coastal vulnerability?

No

If yes! Please describe the indices.

NA

Additional comments concerning DSIs and other outputs.
No additional comments.

ISOR (Iceland)

Do you or does your institute have expertise in DSSs for evaluating the geology in relation to coastal vulnerability?
No

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

ISOR produced the first coastal assessment for EMODnet Geology. Coastal vulnerability studies are often localised and in development through students' projects, e.g., Davies, W.T.R. (2012). Applying a Coastal Vulnerability Index (CVI) to the Westfjords, Iceland: a preliminary assessment. MSc. thesis, University of Akureyri, p. 109.
(https://skemman.is/bitstream/1946/12297/1/William%20Davies%20-%20Applying%20a%20Coastal%20Vulnerability%20Index%20%28CVI%29%20to%20the%20Westfjords%20Iceland%20a%20preliminary%20assessment%20-%20REVISED%20-%20FORMATTED.pdf);
Víkingsson, S (2016). Notes on Coastal Behavior in Iceland. Prepared for EMODnet Geology, ÍSOR-2016/001, p. 18, 2 appendices.
The MET-Office of Iceland conducts landslides and avalanche monitoring (https://www.vedur.is/ofanflod/snjoflodaspa/).
The first marine spatial planning is being conducted by the National Planning Agency of Iceland (https://www.skipulag.is/en/) for selected areas in Iceland with the primary focus on aquaculture and environment, e.g., student project (https://opinvisindi.is/handle/20.500.11815/4750) and publication - Wilke M (2023) Public participation in marine spatial planning in Iceland. Front. Mar. Sci. 10:1154645. https://doi.org/10.3389/fmars.2023.1154645.

Which DSSs do you work with in projects concerning coastal vulnerability (1)?

EMODnet Geology guidelines; CVI, MSP from students; traditionally, the MET-Office of Iceland has monitored the hazards (weather and geology) with its institute-specific system tied into the Department of Civil Protection and Emergency Management (https://www.almannavarnir.is/english/about-the-department-of-civil-protection-and-emergency-management/).

What is the purpose of the DSSs?

We have to implement a DSS tool, but have to define our coastal types, CVI, or MSP first. The environmental components have to be defined and what industries assessments have to be conducted.

What is the domain: local, regional, national or international?

CVI and MSP studies exist for local and regional areas. A comprehensive analysis and assessment on a national basis is missing.

How do you evaluate the DSS?

Local settings, environment, public perception and participation, and industrial needs.

Additional comments concerning DSSs.

Early days for Iceland and we are right so starting to consider to implement DSS based on coastal studies.

Which geological parameters / information layers do you deem relevant when analysing coastal vulnerability (3)?

Coastal type, weather, infrastructure, geo-risks tied to WP5.2 (e.g., Coastal instability / mass movement (includes landslides, debris flows, turbidites); Strong currents (includes longshore drift & mobile sediments); Storm surges; Earthquakes; Volcanic activity; Tectonic activity; Icebergs or winter sea ice; Glacial flash floods)

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

Iceland developed onshore regulations, hazard assessment format, and mitigation measures for land occurrences for landslides and avalanches the MET Office of Iceland (https://www.vedur.is/ofanflod/haettumat/). Coastal DSTs need to be developed.

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to coastal vulnerability (4)?

GIS systems and reporting (e.g., for surface geology mapping, DEMs, aerial photography, historical records, etc.)

Are the parameters weighted and/or standardised. If so, how (4)?

No

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

No

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

We have to implement a DSS tool, but have to define our coastal types, CVI, or MSP first. The environmental components have to be defined and what industries assessments have to be conducted.

Additional comments concerning DSTs and information layers / parameters.

For Iceland, we are still figuring out, how to establish a cross-institute workflow to develop a coastal vulnerability assessment strategy, before we can defined the implementation, monitoring strategies, documentation, and finally DSS / DST approaches.

What outputs do you produce to evaluate the geology in relation to coastal vulnerability (5)? Why these outputs?

For now, these are coastal point assessments that are stored as GIS layers and its associated meta-data.

Do you have any experiences with indices as a measurement of the geology in relation to coastal vulnerability?

No

If yes! Please describe the indices.

NA

Additional comments concerning DSIs and other outputs.

There is a clear understanding that the EMODnet Geology coastal ribbon assessment is just a start. A countrywide study should be conducted based on published standards, e.g. Furlan, E., Dalla Pozza, P., Michetti, M., Torresan, S., Critto, A., Marcomini, A. (2021), Development of a Multi-Dimensional Coastal Vulnerability Index: assessing vulnerability to inundation scenarios in the Italian coast. Sci. Total Environ. 144650.

BGS (United Kingdom)

Do you or does your institute have expertise in DSSs for evaluating the geology in relation to coastal vulnerability?

Yes

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

Dr Andres Payo, head of Coasts & Estuaries (agarcia@bgs.ac.uk)

Which DSSs do you work with in projects concerning coastal vulnerability (1)?

At the European scale we are working with the European Space Agency (ESA), developing a Coastal Digital Twin as part of the ESA Destination Earth program project (2024-2026). This is a cutting-edge initiative to create a highly accurate digital replica of Earth, designed to simulate physical, biological and social systems and support the analysis of the planet's dynamics in near-real time. It will integrate vast amounts of data from satellite observations, ground measurements, and advanced computational, AI/ML and process models to provide insights into Earth's systems, such as climate, oceans, forests, and human activities. Under the DTE project ARGANS (UK), with sister companies adwäisEO (Luxembourg) and ACRI-ST (France), partnered with Biosfera (Spain), the British Geological Survey (UK), CLS (France), COVARTEC (Norway), LIST (Luxembourg) and the University of Southampton (UK) have been given the opportunity to develop a digital twin to represent Coastal Processes and Extremes. This involves designing and implementing a digital twin architecture within the ESA DestinE platform to showcase four coastal use cases, these include EO-supported models of (i) coastal erosion, (ii) coastal flooding plus (iii) mangrove and (iv) sargassum dynamics to understand their effects upon ecosystem health, carbon, biodiversity and consequent economic impacts.

What is the purpose of the DSSs?

Outputs from the digital twin will enhance disaster preparedness and response by improving predictions of storm surges and flooding, by providing information to support evacuation scenarios and identifying vulnerable infrastructures and communities to enable pre-emptive measures. It will support climate change adaptation by tracking changes in coastline dynamics, identifying areas for adaptive infrastructure such as seawalls and green buffers and in doing so help policy makers weigh trade-offs between development and environmental conservation under 'what if?' scenarios. It will advance environmental conservation by tracking marine and coastal habitats enabling targeted conservation efforts to support mangrove restoration and sargassum control bringing potential benefits of healthier marine ecosystems, increased biodiversity, sediment stabilisation and carbon storage. Accessible dynamic visualisations will make scenarios easy to understand and promote education and public awareness, allowing communities to participate in planning and advocate for their interests

What is the domain: local, regional, national or international?

Local

How do you evaluate the DSS?

This is a step change in the way information on climate change and future coastal erosion is provided, aiming to help face the complex challenges posed by our changing climate. Destination Earth will help scientists and policymakers to understand the complex interactions that the environment and humans will play in shaping Earth's future. Destination Earth will also form the baseline for effective European adaptation strategies in support of the green transition, helping the EU reach its goal of becoming carbon neutral by 2050, and the implementation of the European Commission's Green Deal and Digital Strategy.

Additional comments concerning DSSs.

The DT-coast project will be running for two years (2024-2026) and one of the outcomes is to produce a roadmap on how to scale up the prototype that we will developing into global scale models. This is in very good timing with the Geological Survey for Europe project, that will allow us to include in the roadmap how the data provided by the different geological surveys could be used as part of this Digital Twin Earth initiative.

Which geological parameters / information layers do you deem relevant when analysing coastal vulnerability (3)?

subsidence in coastal lowland areas; topography and bathymetry; shallow subsurface sediment size composition (e.g. percentage of fines, sand and gravels as either drift material or consolidated) and vertical distribution (e.g. sediment thickness model J. Mar. Sci. Eng. 2024, 12(2), 269; https://doi.org/10.3390/jmse12020269); coastal defences location, elevation and foundation.

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

#1) we extract metrics of ground motion from the European Ground Motion Service. We classify the insar time series according to its pattern over time. This enables us to not only those point behaving in a linear fashion but also those with non-linear or seasonal pattern of motion. For points with a seasonal pattern of motion we extract the strength of the seasonality. For those points with non-linear motion we can identify when the time series pattern changed. Extraction of the above information enables us to better integrate the movement with geological data to understand the mechanism of motion. #2) we use the Coastal Modelling Environment software (https://github.com/coastalme/coastalme/) to explore how the 3D coastal and nearshore landscape will evolve over time under different "what if" scenarios. From the evolving 3D coastal models, we extract Digital Elevation Model of Differences and bespoke metrics used by the stakeholders such as distance of a particular asset/house/infrastructure to the cliff edge/Mean Sea Level line, etc. We use the GroundHog Desktop v2.8.7 Software (https://www.bgs.ac.uk/technologies/software/groundhog/) to translate the geological data into the sediment thickness model input for CoastalME.

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to coastal vulnerability (4)?

We use standard geospatial tools GIS, bespoke scripts (Python, MATLAB, QGIS, ...). We use sensitivity analysis to evaluate how uncertainty in the geological data might result in the 4D coastal landscape evolution and therefore uncertainty around the coastal vulnerability assessments.

Are the parameters weighted and/or standardised. If so, how (4)?

For the 4D coastal landscape evolution modelling, we use the geological parameters described above to create a simulation model or a digital representation of a physical reality on which elevation is a key control on the vulnerability, and we do not standardise or weight the parameters.

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

Yes

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

we use seasonal trend decomposition tools for time series analysis to extract the pattern of motion.

Additional comments concerning DSTs and information layers / parameters.

Please notice that we have defined two types of DSTs that are currently actively in use by BGS staff. One for assessing subsidence and another one (CoastalME) to assess vulnerability and risk.

What outputs do you produce to evaluate the geology in relation to coastal vulnerability (5)? Why these outputs?

We have created a dataset called GeoCoast with an open and a premium version (https://www.bgs.ac.uk/datasets/geocoast-open/ & https://www.bgs.ac.uk/datasets/geocoast-premium/). GeoCoast Premium provides a range of geological and geomorphological properties that influence coastal vulnerability. They are provided as attributed 50 m grid cells around the coastline of Great Britain. The data has been developed from BGS databases and datasets, regional expertise and additional analytics to compile the essential baseline geo-information necessary to feed into coastal vulnerability analyses and assessments for resilience and adaptation. GeoCoast Open provides a range of historic images and diagrams extracted from our archives, memoirs and other publications that can provide a reference for coastal change. It also contains a detailed suite of statistical data based on the underlying datasets (GeoCoast Premium). These include, for example, percentage of county at threat from inundation and percentage of county coastline with high susceptibility to erosion. In addition, there is a tool to compare or share best practise at a regional scale and streamline the consideration of multiple underlying datasets through a simple, high-level scheme, presented as domains.

Do you have any experiences with indices as a measurement of the geology in relation to coastal vulnerability?

Yes

If yes! Please describe the indices.

Version 1 of the CVI consists of four data layers in Geographic Information System (GIS) format that identify areas susceptible to flooding and coastal erosion in Great Britain within 1km of the British coast. This data has been produced by geologists including engineering and coastal specialists and information specialists at the British Geological Survey. The separate layers listed below and are briefly explained in the reference shown below: #1) Erosion susceptibility, #2) Cliff top height, #3) geological indicators of flooding, #4) groundwater flooding REF: Jenkins, G.O.; Mee, K.; Richardson, J.F.M.; Lee, K.A.; Westhead, R.K.; Carter, G.D.O.; Hurst, M.D.. 2016 User guide BGS Coastal Vulnerability Index version 1. Nottingham, UK, British Geological Survey, 16pp. (OR/16/039) (Unpublished) https://nora.nerc.ac.uk/id/eprint/521681

Additional comments concerning DSIs and other outputs.

BGS started using indices (e.g. CVI) and then moved to a database (GeoCoast) as this is found more useful by our stakeholders.

20. Annex IV – Part 1: Questionnaire Responses about DSSs, DSTs and DSIs

Desicion Support Systems

Do you or does your institute have expertise in DSSs for evaluating the geology in relation to coastal vulnerability?

AGS (Albania)

No, we don't have expertise in DSS for evaluating the geology in relation to coastal vulnerability.

BRGM (France)

Yes

HGI-CGS (Croatia)

NO

RBINS-GSB (Belgium)

Yes

ICGC (Spain / Catalonia)

No

GSI (Ireland)

Yes

GeoZS (Slovenia)

Yes

ISPRA (Italy)

No

GTK (Finland)

No

GSD (Cyprus)

no

GEUS (Denmark)

No

HSGME (Greece)

Yes

LNEG (Portugal)

Yes

ISOR (Iceland)

No

BGS (United Kingdom)

Yes

If yes! Who is the contact person? What is the field?
If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

AGS (Albania)

No we are not aware of any other institution which works with DSS/DSI

BRGM (France)

We recognise that we (BRGM) are not always directly involved in implementing DSS but are sometimes partners (more or less closely) in past, current and future projects. Despite everything, these are interesting elements to be informed about. And from our point of view, we are very involved in decision support in our own way, sometimes using less sophisticated tools, or with GIS tools, or while developing tools such as climate services.

Goneri LE COZANNET could be the contact entry (G.LeCozannet@brgm.fr) in connection with the projects he is leading, has led or is a partner in.

HGI-CGS (Croatia)

NA

RBINS-GSB (Belgium)

Vera Van Lancker (vvanlancker@naturalsciences.be); Lars Kint (lkint@naturalsciences.be)

Subsurface lithology and geology in the Belgian part of the North Sea (Hademenos et al. 2018) + Uncertainty assessment (Kint et al. 2020)

ICGC (Spain / Catalonia)

No, I'm not aware of any.

GSI (Ireland)

Silvia.caloca@gsi.ie; xavier.monteys@gsi.ie

GeoZS (Slovenia)

Jernej Jež (jernej.jez@geo-zs.si) is the contact person for the "GH project" run at the GeoZS. This DSS is aimed at creating ready-to-use vulnerability maps for mass-movement processes and includes all Slovenian coastal areas. Mateja Jemec Auflič (mateja.jemec-auflic@geo-zs.si) is the contact person for "MASPREM" - landslide forecasting system. Another DSS (not at GeoZS) covering parts of the Slovenian coast shows areas at risk of flooding. Another DSS covering parts of the Slovenian coast shows areas at risk of flooding. The contact person is maja.kregar@gov.si. Both DSSs are included in the "Atlas voda" webgis viewer

https://geohub.gov.si/portal/apps/webappviewer/index.html?id=f89cc3835fcd48b5a980343570e0b64e

ISPRA (Italy)

NA

GTK (Finland)

We have expertise in geology at GTK, but not in DSS's evaluating coastal vulnerability. In Finland, DSSs addressing coastal vulnerability focus on understanding and mitigating the impacts of climate change, rising sea levels, and other natural and anthropogenic pressures. These systems combine environmental, social, and economic data to support sustainable coastal management. In Finland, Flood Risk Management systems are coordinated by ELY Centres. Climate Risk and Vulnerability Assessments evaluate the susceptibility of coastal areas to climate change impacts including sea-level rise, increased storm surges, and erosion. National Climate Risk Assessments are coordinated by the Ministry of Agriculture and Forestry. Marine Spatial Planning (MSP) and Coastal Zone Management Tools integrate multi-use planning while identifying areas vulnerable to environmental change. Biodiversity and Ecosystem Service Assessments assess the vulnerability of coastal ecosystems and the services they provide to communities.

GSD (Cyprus)

no

GEUS (Denmark)

NA

HSGME (Greece)

Prof. Niki-Nikoletta Evelpidou, Department of Geology and Geoenvironment, National and Kapodistrian University of Athens; evelpidou@geol.uoa.gr. Fields of expertise: Geomorphology, Geographic Information Systems (GIS), coastal geomorphology, coastal hazards, coastal vulnerability, sea-level rise, Nature based Solutions

LNEG (Portugal)

Sílvia Nave (silvia.nave@lneg.pt); Coastal geology

ISOR (Iceland)

ISOR produced the first coastal assessment for EMODnet Geology. Coastal vulnerability studies are often localised and in development through students' projects, e.g., Davies, W.T.R. (2012). Applying a Coastal Vulnerability Index (CVI) to the Westfjords, Iceland: a preliminary assessment. MSc. thesis, University of Akureyri, p. 109. (https://skemman.is/bitstream/1946/12297/1/William%20Davies%20-%20Applying%20a%20Coastal%20Vulnerability%20Index%20%28CVI%29%20to%20the%20Westfjords%20Iceland%20a%20preliminary%20assessment%20-%20REVISED%20-%20FORMATTED.pdf); Víkingsson, S (2016). Notes on Coastal Behavior in Iceland. Prepared for EMODnet Geology, ÍSOR-2016/001, p. 18, 2 appendices.

The MET-Office of Iceland conducts landslides and avalanche monitoring (https://www.vedur.is/ofanflod/snjoflodaspa/).

The first marine spatial planning is being conducted by the National Planning Agency of Iceland (https://www.skipulag.is/en/) for selected areas in Iceland with the primary focus on aquaculture and environment, e.g., student project (https://opinvisindi.is/handle/20.500.11815/4750) and publication - Wilke M (2023) Public participation in marine spatial planning in Iceland. Front. Mar. Sci. 10:1154645. https://doi.org/10.3389/fmars.2023.1154645.

BGS (United Kingdom)

Dr Andres Payo, head of Coasts & Estuaries (agarcia@bgs.ac.uk)

Which DSSs do you work with in projects concerning coastal vulnerability (1)?

AGS (Albania)

We don't use DSS, we use Arch GIS for creating sedimentation rates maps of erosion and accumulation.

BRGM (France)

we can mention the projects:

- INSEAPTION (2017-2021) (https://www.inseaption.eu/) => Coastal climate services development / + the implementation of DIVA mode by the Global Climate Forum (https://globalclimateforum.org/portfolio-item/diva-model/)
- CoCliCo (2021 - ongoing) (https://coclicoservices.eu/) => upcoming platform, produced by DELTARES)
- PROTECT (2021 - ongoing) (https://protect-slr.eu/objectives/)
- AdApto+ (2024 - ongoing) => upcoming DSS (contact o.brivois@brgm.fr) (suite du project Adapto https://www.lifeadapto.eu/home.html)

HGI-CGS (Croatia)

NA

RBINS-GSB (Belgium)

TILES DSS (http://www.bmdc.be/tiles-dss/) Currently not available

ICGC (Spain / Catalonia)

None

GSI (Ireland)

Costal Vulnerability Index workflow

GeoZS (Slovenia)

With the GH project

ISPRA (Italy)

NAGTK (Finland)

We provide seabed geological information for e.g., marine habitat mapping purposes

GSD (Cyprus)

NA

GEUS (Denmark)

NA

HSGME (Greece)

We have developed a DSS for coastal vulnerability assessment (coastal erosion and inundation hazard), based on GIS softwares: MapInfo Professional and ESRI products (ArcMap, ArcGIS Pro, ArcGIS Online)

LNEG (Portugal)

SIG (ArcGIS Pro, Environmental System Research Institute (ESRI));

GeoPortal of Energy and Geology https://geoportal.lneg.pt/en/, with possibility of interaction with several layers of information https://geoportal.lneg.pt/mapa/?Mapa=GeologiaCosteira

ISOR (Iceland)

EMODnet Geology guidelines; CVI, MSP from students; traditionally, the MET-Office of Iceland has monitored the hazards (weather and geology) with its institute-specific system tied into the Department of Civil Protection and Emergency Management (https://www.almannavarnir.is/english/about-the-department-of-civil-protection-and-emergency-management/).

BGS (United Kingdom)

At the European scale we are working with the European Space Agency (ESA), developing a Coastal Digital Twin as part of the ESA Destination Earth program project (2024-2026). This is a cutting-edge initiative to create a highly accurate digital replica of Earth, designed to simulate physical, biological and social systems and support the analysis of the planet's dynamics in near-real time. It will integrate vast amounts of data from satellite observations, ground measurements, and advanced computational, AI/ML and process models to provide insights into Earth's systems, such as climate, oceans, forests, and human activities. Under the DTE project ARGANS (UK), with sister companies adwäisEO (Luxembourg) and ACRI-ST (France), partnered with Biosfera (Spain), the British Geological Survey (UK), CLS (France), COVARTEC (Norway), LIST (Luxembourg) and the University of Southampton (UK) have been given the opportunity to develop a digital twin to represent Coastal Processes and Extremes. This involves designing and implementing a digital twin architecture within the ESA DestinE platform to showcase four coastal use cases, these include EO-supported models of (i) coastal erosion, (ii) coastal flooding plus (iii) mangrove and (iv) sargassum dynamics to understand their effects upon ecosystem health, carbon, biodiversity and consequent economic impacts.

What is the purpose of the DSSs?

AGS (Albania)

-

BRGM (France)

/

HGI-CGS (Croatia)

NA

RBINS-GSB (Belgium)

A decision support application opens up the voxel model for specific requests on lithology, geology and uncertainty information in areas of interest in the Belgian part of the North Sea.

ICGC (Spain / Catalonia)

NA

GSI (Ireland)

Categorise the coast into units of vulnerability regarding its susceptibility to change.

GeoZS (Slovenia)

The DSS is intended as support for spatial planning. It visually shows areas more or less prone to mass-movement processes (landslides, rockfalls, debris flows and all three combined) with a color-coded system. Each colour has an assigned recommendation for the spatial planner to follow when considering if an area is suitable for construction, infrastructure projects, etc. The MASPREM DSS provides landslide forecast models for the Civil Administration office in case of extreme rainfall events.

ISPRA (Italy)

NA

GTK (Finland)

Flood Risk Management Systems address coastal flooding risks due to storm surges, high water levels, and ice movement. Climate Risk and Vulnerability Assessments evaluate the susceptibility of coastal areas to climate change impacts including sea-level rise, increased storm surges, and erosion. MSP and Coastal Zone Management Tools integrate multi-use planning while identifying areas vulnerable to environmental change. Biodiversity and Ecosystem Service Assessments assess the vulnerability of coastal ecosystems and the services they provide to communities.

GSD (Cyprus)

NA

GEUS (Denmark)

NA

HSGME (Greece)

To evaluate the current & future situation of the coastal zone; to identify factors (natural and human-induced) that create or accelerate a problem (e.g. coastal erosion, inundation etc.); to identify measures and mitigation strategies and how they can be applied; to evaluate their efficiency in connection to the implementation cost, before implementation and after implementation

LNEG (Portugal)

Get information on long-term shoreline variability, on a high-resolution scale, for some coastal sectors, to support decision-making on long-term planning and adaptation strategies to overcome threats to the Portuguese coast, such as increased risks due to climate change and coastal erosion.

ISOR (Iceland)

We have to implement a DSS tool, but have to define our coastal types, CVI, or MSP first. The environmental components have to be defined and what industries assessments have to be conducted.

BGS (United Kingdom)

Outputs from the digital twin will enhance disaster preparedness and response by improving predictions of storm surges and flooding, by providing information to support evacuation scenarios and identifying vulnerable infrastructures and communities to enable pre-emptive measures. It will support climate change adaptation by tracking changes in coastline dynamics, identifying areas for adaptive infrastructure such as seawalls and green buffers and in doing so help policy makers weigh trade-offs between development and environmental conservation under 'what if?' scenarios. It will advance environmental conservation by tracking marine and coastal habitats enabling targeted conservation efforts to support mangrove restoration and sargassum control bringing potential benefits of healthier marine ecosystems, increased biodiversity, sediment stabilisation and carbon storage. Accessible dynamic visualisations will make scenarios easy to understand and promote education and public awareness, allowing communities to participate in planning and advocate for their interests

What is the domain: local, regional, national or international?

AGS (Albania)

-

BRGM (France)

for national stakeholders

HGI-CGS (Croatia)

NA

RBINS-GSB (Belgium)

National

ICGC (Spain / Catalonia)

NA

GSI (Ireland)

National

GeoZS (Slovenia)

National

ISPRA (Italy)

NA

GTK (Finland)

National

GSD (Cyprus)

NA

GEUS (Denmark)

NA

HSGME (Greece)

Regional

LNEG (Portugal)

National

ISOR (Iceland)

CVI and MSP studies exist for local and regional areas. A comprehensive analysis and assessment on a national basis is missing.

BGS (United Kingdom)

Local

How do you evaluate the DSS?

AGS (Albania)

-

BRGM (France)

/

HGI-CGS (Croatia)

NA

RBINS-GSB (Belgium)

Easy querying, visualisation and download of 3D subsurface sediments for areas of interest in the Belgian part of the North Sea.

ICGC (Spain / Catalonia)

NA

GSI (Ireland)

NA

GeoZS (Slovenia)

The DSSs are a useful source of information for both the general public (in case of GH) as well as the governmental bodies.

ISPRA (Italy)

NA

GTK (Finland)

Not sure

GSD (Cyprus)

NA

GEUS (Denmark)

NA

HSGME (Greece)

By comparing the results with: (a) actual observations, data and measurements from the coastal zone; (b) historic data on the coastal zone (e.g. evolutional trend of the coastline, based on old maps, satellite images, aerial photos etc.); (c) similar comparisons in areas and regional settings where the DSS have actually worked.

LNEG (Portugal)

The data obtained from the DSS is compared to related works, previously developed at lower resolution.

ISOR (Iceland)

Local settings, environment, public perception and participation, and industrial needs.

BGS (United Kingdom)

This is a step change in the way information on climate change and future coastal erosion is provided, aiming to help face the complex challenges posed by our changing climate. Destination Earth will help scientists and policymakers to understand the complex interactions that the environment and humans will play in shaping Earth's future. Destination Earth will also form the baseline for effective European adaptation strategies in support of the green transition, helping the EU reach its goal of becoming carbon neutral by 2050, and the implementation of the European Commission's Green Deal and Digital Strategy.

Additional comments concerning DSSs.

AGS (Albania)

-

BRGM (France)

/

HGI-CGS (Croatia)

NA

RBINS-GSB (Belgium)

Long-term support and maintenance of a DSS is needed through long-term or updated coding language, software, etc.

ICGC (Spain / Catalonia)

NA

GSI (Ireland)

NA

GeoZS (Slovenia)

NA

ISPRA (Italy)

NA

GTK (Finland)

NA

GSD (Cyprus)

NA

GEUS (Denmark)

A single software, framework or workflow have not been developed to standardize the way of doing coastal vulnerability assessment.

HSGME (Greece)

NA

LNEG (Portugal)

No additional comments.

ISOR (Iceland)

Early days for Iceland and we are right so starting to consider to implement DSS based on coastal studies.

BGS (United Kingdom)

The DT-coast project will be running for two years (2024-2026) and one of the outcomes is to produce a roadmap on how to scale up the prototype that we will developing into global scale models. This is in very good timing with the Geological Survey for Europe project, that will allow us to include in the roadmap how the data provided by the different geological surveys could be used as part of this Digital Twin Earth initiative.

Decision Support Tools and parameters

Which geological parameters / information layers do you deem relevant when analysing coastal vulnerability (3)?

AGS (Albania)

geomorphology, coastal dynamic, bathymetry for coastal slope

BRGM (France)

The data are :

- geological maps
- lithology
- geomorphology (coastal features, coastal erosion and accretion, shoreline changes and evolution trends, …)
- coastal slopes
- meteomarine parameters (wind, waves, currents, surges)
- tides (tidal range / highest water level...)
- coastal elevation and topography (low-lying areas, coastal flood plains, wetlands..)
- relative sea level rise (future projections)
- resources (fluid extraction, etc.)
- hydraulics (hydraulic connectivity, drainage network, rivers and groundwater)
- land use (coastal urbanization, infrastructure, activities)
- socio-economic activities
- natural ecosystems
- marine and coastal environmental restrictions (regulatory zones)

HGI-CGS (Croatia)

lithology, geomorphology

RBINS-GSB (Belgium)

Manual TILES DSS (2020):

- Most common lithological classes
- Heterogeneity of the lithological class
- (average) probability
- (average) entropy
- Most common lithostratigraphy
- (average) borehole density
- (average) percentage of the lithological class
- (average) quality

ICGC (Spain / Catalonia)

NA

GSI (Ireland)

Shoreline change rates, geomorphology classes, cliff type, coastal slope.

GeoZS (Slovenia)

For landslides: Lithology, slope, aspect, curvature, proximity to sources of erosion (sea, rivers, estuaries) and faults and fault zones, altitude above sea level. For rockfalls: Lithology, slope, proximity to fault zone.

ISPRA (Italy)

Common parameters include geomorphology, coastal slope, shoreline erosion/accretion rate, relative sea-level rise, mean wave height, and mean tidal range. Some studies also consider land use, coastal protection structures, population density and natural ecosystems.GTK (Finland)

Substrate, coastline, bedrock, geomorphology, harmful substances in sediments (like ASS's), bathymetry/topography and derivatives from those like roughness.

GSD (Cyprus)

NA

GEUS (Denmark)

Existing coastal protection; water level; wind speed; wind set-up; wave characteristics; topography; bathymetry; land use; population density; sediment composition; infrastructure

HSGME (Greece)

geomorphological observations (in general); characteristics of the coastal and submarine morphology; presence of vegetation, sediments, cliffs, streams, river estuaries, forests and other geomorphological features, as well as their spatial characteristics; size, composition and distribution of coastal sediments (in detail); presence and type of human interventions; wave and wind characteristics (in detail); geological and tectonic structure of the coastal area; geological structure and geomorphological observations on the broader area (mainland); hydrographic and hydrological characteristics of the broader mainland (drainage basin); evolution of the coastal zone at a broader scale (e.g. through satellite images etc.)

LNEG (Portugal)

coastal geomorphology
shoreline erosion/accretion rates
land cover
coastal elevation
tidal range
significant wave height
sea-level rise

ISOR (Iceland)

Coastal type, weather, infrastructure, geo-risks tied to WP5.2 (e.g., Coastal instability / mass movement (includes landslides, debris flows, turbidites); Strong currents (includes longshore drift & mobile sediments); Storm surges; Earthquakes; Volcanic activity; Tectonic activity; Icebergs or winter sea ice; Glacial flash floods)

BGS (United Kingdom)

subsidence in coastal lowland areas; topography and bathymetry; shallow subsurface sediment size composition (e.g. percentage of fines, sand and gravels as either drift material or consolidated) and vertical distribution (e.g. sediment thickness model J. Mar. Sci. Eng. 2024, 12(2), 269; https://doi.org/10.3390/jmse12020269); coastal defences location, elevation and foundation;

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

AGS (Albania)

We don’t use DST

BRGM (France)

GIS tools (ArcGIS, QGIS, and so on), or while developing tools such as (coastal) climate services.

HGI-CGS (Croatia)

NONE

RBINS-GSB (Belgium)

De Tré et al. (2018): "Geographic MCDM relies on the availability of several IT components, including databases and other data resources, a data integration component, a decision support tool and a visualization tool. Data from different sources are used for evaluating the decision criteria. In a first step, each data source is subject to a kind of Extract, Transform and Load (ETL) process, which extracts the relevant data from the source, transforms it into the correct format and prepares it as input for the decision support tool. For main data sources that do not change often, like 3D lithological classification models, ETL is done in advance. In the next step, the integrated input data are processed by the decision support tool. In TILES, an LSP-based approach is used for the computation of suitability degrees for a 3D suitability model. This model is enriched with metadata expressing the confidence that experts have in the computed suitability degrees. The enriched suitability model is loaded into dedicated visualization software for easily accessible presentation to the decision-maker."

De Tré et al. (2018):"The simplified attribute tree shown emphasizes that for a marine exploitation decision (root node), one has to consider data that are related to the lithology, bathymetry, ecology, restricted areas and locations of shipwrecks. As a measure of lithology, the probabilities for different kinds of sediment (in the example limited to fine sand, coarse sand and clay) are considered. A restricted area can be a military zone or an area where power supplies, pipelines or telecommunication lines are located."

ICGC (Spain / Catalonia)

NA

GSI (Ireland)

Shoreline change rates are extracted using vegetation line time series in DSAS 5.2 (USGS). Coastal Slope and cliff type parameters are largely extracted from Lidar DTM data and GIS tools.

GeoZS (Slovenia)

We use GIS systems (ArcGIS pro): each input parameter has either an absolute value (e.g. slope) or assigned value (e.g. susceptibility of a lithologic unit to a specific mass-movement process). The end product from the processing with the DST is a colour-coded susceptibility map.

ISPRA (Italy)

Geographic Information Systems (GIS) are often used to process and analyse data.
ISPRA realizes national information layer: e.g. shoreline erosion/accretion, coastal landslides, coastal habitats.

GTK (Finland)

We do not actually make coastal vulnerability analysis at GTK. However, we consider following DST's useful: EMODnet Central Portal for marine data, VELMU map portal for Finnish Marine Inventory data, HELCOM data service, GIS Desktop. For geological parameter see above.

GSD (Cyprus)

NA

GEUS (Denmark)

XBeach; Mike21; ArcGIS Pro; Sfincs; FloodAdapt

HSGME (Greece)

(2) Geographic Information Systems; (3) spatial distribution of the characteristics mentioned above; evolution of the coastal zone from the past to the present (e.g. since the last 50-100 years); evolution of the coastal zone in the next 100 years, considering sea-level rise projections; evolution of the coastal zone within a desired time scale, considering current geomorphological regime (see previous question), existing, future and proposed interventions (e.g. coastal constructions, nature-based solutions etc.)

LNEG (Portugal)

(1) Digital Shoreline Analysis System (DSAS), an add-in within the ESRI
(2) Net Shoreline Movement (NSM), Linear Regression Rate (LRR), Shoreline Change Envelope (SCE)
(3) Net Shoreline Movement (NSM) corresponds to the distance between the oldest and the youngest coastline
(4) Linear Regression Rate (LRR), a statistical parameter, that determines a rate-of-change

(5) Shoreline Change Envelope (SCE), is the measure of the total change in coastline movement considering all available coastline positions and reporting their distances, without reference to their specific dates

ISOR (Iceland)

Iceland developed onshore regulations, hazard assessment format, and mitigation measures for land occurrences for landslides and avalanches the MET Office of Iceland (https://www.vedur.is/ofanflod/haettumat/). Coastal DSTs need to be developed.

BGS (United Kingdom)

#1) we extract metrics of ground motion from the European Ground Motion Service. We classify the insar time series according to its pattern over time. this enables us to not only those point behaving in a linear fashion but also those with non-linear or seasonal pattern of motion. for points with a seasonal pattern of motion we extract the strength of the seasonality. For those points with non-linear motion we can identify when the time series pattern changed. Extraction of the above information enables us to better integrate the movement with geological data to understand the mechanism of motion. #2) we use the Coastal Modelling Environment software (https://github.com/coastalme/coastalme/) to explore how the 3D coastal and nearshore landscape will evolve over time under different "what if" scenarios. From the evolving 3D coastal models, we extract Digital Elevation Model of Differences and bespoke metrics used by the stakeholders such as distance of a particular asset/house/infrastructure to the cliff edge/Mean Sea Level line, etc. We use the GroundHog Desktop v2.8.7 Software (https://www.bgs.ac.uk/technologies/software/groundhog/) to translate the geological data into the sediment thickness model input for CoastalME.

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to coastal vulnerability (4)?

AGS (Albania)

We use ArcGIS program to evaluate the difference of coastal shore and geology.

BRGM (France)

GIS tools (ArcGIS, QGIS, and so on), or while developing tools such as (coastal) climate services.

HGI-CGS (Croatia)

ArcGIS

RBINS-GSB (Belgium)

De Tré et al. (2018): "In our previous research, we studied 2D suitability maps constructed using the LSP approach [16]. In this work, we used the same technique to create 3D suitability models, as depicted in Fig. 3. It entails a three-step method consisting of (1) elementary attribute selection, (2) elementary criteria specification and evaluation and (3) aggregation."

Other: Geographical Information System (ArcGIS, QGIS, etc.)

ICGC (Spain / Catalonia)

NA

GSI (Ireland)

NA

GeoZS (Slovenia)

Field validation of the modelled results

ISPRA (Italy)

Multicriteria GIS-based analysis

GTK (Finland)

We do not actually make coastal vulnerability analysis at GTK. However, we consider following DST's useful: EMODnet Central Portal for marine data, VELMU map portal for Finnish Marine Inventory data, HELCOM data service, GIS Desktop. For geological parameter see above.

GSD (Cyprus)

NA

GEUS (Denmark)

ArcGIS Pro

HSGME (Greece)

Geographic Information Systems

LNEG (Portugal)

SIG (ArcGIS Pro, ESRI)

ISOR (Iceland)

GIS systems and reporting (e.g., for surface geology mapping, DEMs, aerial photography, historical records, etc.)

BGS (United Kingdom)

We use standard geospatial tools GIS, bespoke scripts (Python, MATLAB, QGIS, ...). We use sensitivity analysis to evaluate how uncertainty in the geological data might result in the 4D coastal landscape evolution and therefore uncertainty around the coastal vulnerability assessments.

Are the parameters weighted and/or standardised. If so, how (4)?

AGS (Albania)

Our parameters are standardised by our scientific government institution, Albanian Geological Survey

BRGM (France)

/

HGI-CGS (Croatia)

No

RBINS-GSB (Belgium)

Yes, in the creation of the sediment dataset, the voxel model and the DSS of the subsurface of the Belgian part of the North Sea.

Kint et al. (2020): "Lithological data and associated metadata were harmonized and standardized to facilitate the generation of seamless seabed maps (Van Lancker and van Heteren 2013) following internationally proposed or agreed guidelines (e.g. Geo-Seas for geological and geophysical data (van Heteren 2010), SeaDataNet for oceanographic data, and INSPIRE for spatial information). To ensure machine-readability, interoperability and compatibility of the data, lithological descriptions available as text were transferred to code.

Hademenos et al. (2018): "To model offshore aggregate resources, a methodological workflow was developed based on the voxel modelling approach of Stafleu et al. (2011) and expanded with seismic data. It comprises the following steps: (1a) Standardisation and lithological classification of borehole descriptions; (1b, 3) Delineation of seismic acoustic facies and their seismostratigraphical interpretation; (2) Stratigraphic interpretation of the boreholes; (4) Construction of the 2D stratigraphical layer model; (5) Assignment of lithostratigraphical units to the 3D voxel model; (6) 3D interpolation of lithological class within each lithostratigraphical unit; (7) Assessment of the information entropy of the model."

De Tré et al. (2018): "A scientific solution for data quality assessment using (geographic) multi-criteria decision-making based on LSP suitability models relies on the identification and specification of elementary data quality aspects for the elementary attributes that are
involved in the decision-making process. For each elementary data quality aspect, a corresponding elementary quality criterion is specified. Evaluation of these elementary quality criteria for a given voxel in a geographical voxel space yields elementary confidence scores for that voxel. These elementary confidence scores are then aggregated to an overall confidence degree by applying a novel, extended version of the LSP aggregation structure. Every LSP aggregator is extended so that it takes both suitability degrees and confidence degrees as arguments and computes a couple that consists of an aggregated suitability degree and an aggregated confidence degree. The aggregated suitability degree is computed in exactly the same way as in regular suitability modelling. For the aggregated confidence degree, a weighted sum of the input confidence degrees is computed, with the weights reflecting the impact of the corresponding input suitability degrees on the computation
of the aggregated suitability degree. In our future research, we aim to study alternatives for the weighted sum aggregation in order to further improve the semantic properties of the aggregation, so that this aggregation even better reflects and complements expert reasoning."

ICGC (Spain / Catalonia)

No

GSI (Ireland)

Parameters are standardised using discrete vulnerability categories.

GeoZS (Slovenia)

The parameters are weighted, but we cannot disclose details due to contractual obligations.

ISPRA (Italy)

NA

GTK (Finland)

NA

GSD (Cyprus)

NA

GEUS (Denmark)

The parameters are not standardised or weighted but are instead represented with an economic value, which makes them comparable. Some socio-economic parameters have a higher economic value than others, which relates to a weighting of the parameters.

HSGME (Greece)

Yes. Each different area will require a different weighting of the parameters, and a standard answer cannot be given that will be case-independent. As many input parameters among those already mentioned are to be included and with as much accuracy and detail as possible, in order for the weighting and the final outputs to be proper and accurate. How they are standardised depends upon: the availability and accuracy of existing data; the time and budget available to collect the missing data; local conditions (e.g. weather issues) that may hinder or facilitate the collection of additional data; the time available to process the data and run the necessary models in detail; the integrity of the equipment and materials available in the field and in the post-field analyses.

LNEG (Portugal)

No

ISOR (Iceland)

No

BGS (United Kingdom)
For the 4D coastal landscape evolution modelling, we use the geological parameters described above to create a simulation model or a digital representation of a physical reality on which elevation is a key control on the vulnerability, and we do not standardise or weight the parameters.

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

AGS (Albania)
No, we don't apply Artificial Neutral Networks

BRGM (France)
Yes

HGI-CGS (Croatia)
No

RBINS-GSB (Belgium)
Yes

ICGC (Spain / Catalonia)
No

GSI (Ireland)
No

GeoZS (Slovenia)
No

ISPRA (Italy)
NA

GTK (Finland)
No

GSD (Cyprus)
NA

GEUS (Denmark)
NA

HSGME (Greece)
Sometimes but usually no

LNEG (Portugal)
No

ISOR (Iceland)
No

BGS (United Kingdom)
Yes

If yes! How and with what objective?
If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

AGS (Albania)
No, we don't have considered yet on using these tools.

BRGM (France)

Research works of Jeremy ROHMER (BRGM; j.rohmer@brgm.fr) (e.g. https://brgm.hal.science/hal-02386579v1/file/Rohmer_EAAI_HAL.pdf or https://hal.science/hal-02380692/document)

PhD thesis in progress at BRGM: Mirna BADILLO (2024 - 2027) "An integrated approach to assessing the impact of compound climate risks in the context of small islands". In the frame of the FUTURISKS project. Supervisors: Virginie DUVAT (La Rochelle university), Goneri LE COZANNET (BRGM) and Jeremy ROHMER (BRGM)

Previous works within BRGM teams, for example the article: Bulteau et al., 2015 (https://doi.org/10.1016/j.geomorph.2014.09.002; https://www.sciencedirect.com/science/article/pii/S0169555X14004607?via%3Dihub)

HGI-CGS (Croatia)

No

RBINS-GSB (Belgium)

De Mol (2019): "In the Bayesian interpretation (based on Bayes' theory of Bayesian inference but actually pioneered by Laplace), probability is a subjective indicator of belief. Different agents might assign different probabilities to different outcomes and there is no reason for someone to believe one agent over the other. Bayesian probabilities further also rely on the assumption that agents are perfectly rational [3, 21], though evidence has shown that this claim is doubtful [17]. This interpretation is often applied in the context of betting games, to set payout rates for outcomes in correspondence to their perceived probability of occurring, which is immediate evidence that perceived probabilities can be used to turn a profit and are not necessarily fair. Au contraire, this interpretation relies on the idea that the true likeliness of the outcomes can be hidden behind slightly manipulated probabilities in order to trick gamblers into entering an unfair game, the lottery being a prime example thereof.

ICGC (Spain / Catalonia)

NA

GSI (Ireland)

We have considered to include Bayesian network methods to forecast coastal vulnerability

GeoZS (Slovenia)

We have not yet considered the latter as we follow a pre-defined methodology. Additionally, we do not have adequate in-house knowledge.

ISPRA (Italy)

NA

GTK (Finland)

NA

GSD (Cyprus)

NA

GEUS (Denmark)

NA

HSGME (Greece)

Artificial Neural Networks have been used in runoff erosion hazard assessment, but the plan is to apply them in coastal vulnerability as well

LNEG (Portugal)

So far, we were focused on understanding the past variability of the shoreline, but we are considering using Artificial Neural Networks or a Bayesian Network in the future, to predict coastal vulnerability

ISOR (Iceland)

We have to implement a DSS tool, but have to define our coastal types, CVI, or MSP first. The environmental components have to be defined and what industries assessments have to be conducted.

BGS (United Kingdom)

we use seasonal trend decomposition tools for time series analysis to extract the pattern of motion.

Additional comments concerning DSTs and information layers / parameters.

AGS (Albania)

-

BRGM (France)

/

HGI-CGS (Croatia)

NA

RBINS-GSB (Belgium)

-

ICGC (Spain / Catalonia)

NA

GSI (Ireland)

NA

GeoZS (Slovenia)

NA

ISPRA (Italy)

NA

GTK (Finland)

We do not actually make coastal vulnerability analysis at GTK

GSD (Cyprus)

NA

GEUS (Denmark)

In the current analytical work it is assumed that existing dikes are stable and that they will not deteriorate. A tool is under development which should address this optimistic assumption. Based on parameters on the strength of the dike.

HSGME (Greece)

NA

LNEG (Portugal)

DSAS enables a user to calculate rate-of-change statistics from multiple historical shoreline positions, so the input parameter is shoreline position, which is achieved through the analysis of historical aerial photographs and ortophoto maps, geology and digital terrain models.

ISOR (Iceland)

For Iceland, we are still figuring out, how to establish a cross-institute workflow to develop a coastal vulnerability assessment strategy, before we can defined the implementation, monitoring strategies, documentation, and finally DSS / DST approaches.

BGS (United Kingdom)

Please notice that we have defined two types of DSTs that are currently actively in use by BGS staff. One for assessing subsidence and another one (CoastalME) to assess vulnerability and risk.

Decision Support Indices and other outputs

What outputs do you produce to evaluate the geology in relation to coastal vulnerability (5)? Why these outputs?

AGS (Albania)

We produce coastal maps, surfaces of erosion and accumulation during the seashore and the bathymetry of the sea and lagoon.

BRGM (France)

/

HGI-CGS (Croatia)

Mostly shapefiles. So far, we didn't produce any indices. For EMODnet Coastal migration/Coastal resilience we used EROSION classes to classify lithology, then reclassified to areas with prograding, retrograding or stable coastline, and low or high resilience.

RBINS-GSB (Belgium)

De Tré et al. (2018): "Key to the decision support tool used in TILES is the creation of 3D suitability models. As input, a 3D voxel model of the subsurface of the Belgian part of the North Sea is being constructed. Each voxel is currently fixed in size (length and width 200 m, height 1 m). The model currently includes voxels that range from 4 m above mean sea level to 75 m below it.

Van Lancker et al. (2019): "Main DSS attributes relate to the integrated data, information and knowledge, the 3D geological models and some first output from 4D process models. Advanced criteria-evaluation techniques were developed to support the construction of specialized geographical maps of the sea region under investigation. Such maps, hereafter called 'suitability maps', are able to show geological boundaries, distributions of particular resource qualities, and the resource estimation at various cut-off grades, all calculated in a time-efficient manner encouraging online use of the tool. Additionally, user functions of the BPNS, as available from the Marine Atlas (Belgian Marine Data Centre), were incorporated: infrastructure (e.g. pipelines; electricity and telecommunication cables; windmills; navigation routes), human activity (e.g. tourism, safety), legal status (e.g. areas reserved for special activities), economic development (e.g. expansion of industries). A user can make dynamically a series of tailor-made suitability maps that assist in resource assessments."

ICGC (Spain / Catalonia)

we create basic information for decision-making: topographic maps, DEMs, geological, orthophotos, bathymetry.

We also generate geothematic products https://www.icgc.cat/ca/Ambits-tematics/Litoral-Dinamica-de-la-costa:

-We document the effects of storms on the coast(https://www.icgc.cat/ca/Eines-i-visors/Visors/Evolucio-de-la-costa

-Geomorphological maps of storm surge flooding (pending publication)

-Permanent flooding map https://visors.icgc.cat/inundacio-permanent/

-Danger and risk studies of flooding and erosion https://visors.icgc.cat/sidl/#10.9/40.6786/0.6722

-Cartography of slope movements along the entire coast of Catalonia (pending publication)

GSI (Ireland)

Geomorphology classes, cliff type, coastal slope, shoreline change rates

GeoZS (Slovenia)

Mass-movement susceptibility maps

ISPRA (Italy)

NA

GTK (Finland)

We do not actually make coastal vulnerability analysis at GTK, but we produce information about the seabed geological structures, composition, and processes, and parameters for the environmental assessments like information on acid sulphate soils (ASS).

GSD (Cyprus)

Key outputs for evaluating geology in relation to coastal vulnerability:
Geologic maps: Show rock types and structures.
Topographic maps: Illustrate landforms and elevation.
Bathymetric maps: Map seafloor depth and topography.
Seafloor sediment maps: Show sediment distribution.
Shoreline change maps: Track coastal changes over time.
Coastal Vulnerability Index (CVI) maps: Assess overall vulnerability.
Hazard maps: Identify areas at risk from specific hazards.

Why these outputs?
Geology influences coastal stability and erosion.
Topography affects wave energy and flooding.
Bathymetry impacts wave patterns and sediment transport.
Seafloor sediment determines seabed stability and erodibility.
Shoreline change tracks coastal trends.
Hazard maps pinpoint areas at risk for targeted management.
By combining these outputs, we can understand coastal vulnerability and develop effective management strategies.

GEUS (Denmark)

Interactive vulnerability maps in webgis:
Kystplanlægger (Eng: 'Coastal Planner'). Data layers in 100 x 100 m grid cells showing the susceptibility of erosion and flooding in 2020, 2070 and 2120 at 6 different events with respective return periods ranging from 50 to 10.000 years, while taking into account the effects of climate change (scenario: RCP8.5). Further it shows the vulnerability of the coast which considers the beforementioned susceptibility, the percentage risk of a given event as well as the economic cost of damage on infrastructure, property, livestock, crops and companies. Data is color-coded based on costs. A data layer with recommendations on mitigation strategy is also available.

HSGME (Greece)

All the data mentioned above are necessary for integrated coastal zone management, including application of mitigation strategies and protection measures. When unavailable and missing, these data should be collected or generated (e.g. using GIS), because they all affect the coastal zone evolution and the efficiency of any applied measure. Skipping or simply estimating any of those data is highly avoided, and accurate measurements are to be done to acquire them.

LNEG (Portugal)

We also use Coastal Vulnerability index, given by Abs[NSM/SCE], as a complement tool to the net shoreline movement (NSM) and the shoreline change rates (LRR) for specific time windows, as the Abs[NSM/SCE] highlights the areas that experienced higher oscillations of the shoreline.

ISOR (Iceland)

For now, these are coastal point assessments that are stored as GIS layers and its associated meta-data.

BGS (United Kingdom)

We have created a dataset called GeoCoast with an open and a premium version (https://www.bgs.ac.uk/datasets/geocoast-open/ & https://www.bgs.ac.uk/datasets/geocoast-premium/). GeoCoast Premium provides a range of geological and geomorphological properties that influence coastal vulnerability. They are provided as attributed 50 m grid cells around the coastline of Great Britain. The data has been developed from BGS databases and datasets, regional expertise and additional analytics to compile the essential baseline geo-information necessary to feed into coastal vulnerability analyses and assessments for resilience and adaptation. GeoCoast Open provides a range of historic images and diagrams extracted from our archives, memoirs and other publications that can provide a reference for coastal change. It also contains a detailed suite of statistical data based on the underlying datasets (GeoCoast Premium). These include, for example, percentage of county at threat from inundation and percentage of county coastline with high susceptibility to erosion. In addition, there is a tool to compare or share best practise at a regional scale and streamline the consideration of multiple underlying datasets through a simple, high-level scheme, presented as domains.

Do you have any experiences with indices as a measurement of the geology in relation to coastal vulnerability?

AGS (Albania)

Yes, we have experience with indices

BRGM (France)

Yes

HGI-CGS (Croatia)

No

RBINS-GSB (Belgium)

-

ICGC (Spain / Catalonia)

No

GSI (Ireland)

Yes

GeoZS (Slovenia)

No

ISPRA (Italy)

No

GTK (Finland)

No

GSD (Cyprus)

Yes,

GEUS (Denmark)

No

HSGME (Greece)

Yes

LNEG (Portugal)
No
ISOR (Iceland)
No
BGS (United Kingdom)
Yes

If yes! Please describe the indices.

AGS (Albania)
we have studied the ecosystems, habitats and infrastructure as indices for vulnerability.
BRGM (France)
For example the Vertical Land Motion (VLM) assessment: e.g. works in BRGM / Rémi THIEBLEMONT (r.thieblemont@brgm.fr) : https://doi.org/10.1029/2024EF004523 ; https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2024EF004523
HGI-CGS (Croatia)
No. Other colleagues used CVI (Coastal Vulnerability Index, Gornitz, V. (1991.): Global coastal hazards from future sea level rise. Palaeogeography, Palaeoclimatology, Palaeoecology (Global and Planetary Change Section), 89(4), 379–398. doi.org/10.1016/0031-0182(91)90173-O) to present coastal vulnerability (e.g. Benac, Čedomir, Andrea Tadić, Vedrana Petrović, Dado Jakupović, Gorana Ljubičić, Nino Krvavica i Igor Ružić. "Vulnerability of Krk Island Coasts." Hrvatske vode 29, br. 117 (2021): 187-200.)
RBINS-GSB (Belgium)
-
ICGC (Spain / Catalonia)
NA
GSI (Ireland)
We use a CVI modified from USGS index-based methodology (Thieler et al., (2000); Pendleton et al., (2010))
GeoZS (Slovenia)
NA
ISPRA (Italy)
NA
GTK (Finland)
NA
GSD (Cyprus)
One common index is the Coastal Vulnerability Index (CVI). It combines various factors like:

Geomorphology: Coastal landforms and their stability.
Shoreline change: Erosion or accretion rates.
Coastal slope: Steepness of the coastline.
Relative sea level rise: Rate of sea level increase.
Sediment type: Sand, mud, or rock, influencing erosion rates.
Rock type: Strength and resistance to weathering.
Fault activity: Potential for seismic hazards.

Using these indices, geological surveys can provide valuable insights for coastal management and planning.

GEUS (Denmark)

A Social Vulnerability Index was developed in relation to flooding and erosion. It relies on demographic information. Data is in 100x100 meter grid cells, and the index uses five key indicators that assess both susceptibility (negative factors) and resilience (positive factors) at the neighbourhood level. Key indicators: Age; Health, Socio-economic conditions: ability to receive and understand information; neighbourhood resilience (bonding factors). Indicators are weighted equally. The index is transformed to a 0-10 scale by use of Natural Breaks in ArcGIS Pro.
The economic vulnerability caused by erosion and flooding susceptibility is on a monetary scale divided in groups by Natural Breaks in ArcGIS Pro.

HSGME (Greece)

Previous (Holocene) changes and trends in the coastal zone, based on indices: (a) geomorphological ones (e.g. tidal notches, abrasion platforms, beachrocks); (b) archaeological ones (e.g. ancient harbours, cemeteries, temples, settlements and other constructions); (c) biological ones (e.g. Lithophaga holes and other biological marks); (d) sedimentological ones (involving sediment dating methods, such as U/Th, OSL, 14C etc.). Also, through boreholes in coastal lagoonal environments, where previous environmental, climatic and geomorphological conditions can be reconstructed.

LNEG (Portugal)

NA

ISOR (Iceland)

NA

BGS (United Kingdom)

Version 1 of the CVI consists of four data layers in Geographic Information System (GIS) format that identify areas susceptible to flooding and coastal erosion in Great Britain within 1km of the British coast. This data has been produced by geologists including engineering and coastal specialists and information specialists at the British Geological Survey. The separate layers listed below and are briefly explained in the reference shown below: #1) Erosion susceptibility, #2) Cliff top height, #3) geological indicators of flooding, #4) groundwater flooding REF: Jenkins, G.O.; Mee, K.; Richardson, J.F.M.; Lee, K.A.; Westhead, R.K.; Carter, G.D.O.; Hurst, M.D.. 2016 User guide BGS Coastal Vulnerability Index version 1. Nottingham, UK, British Geological Survey, 16pp. (OR/16/039) (Unpublished) https://nora.nerc.ac.uk/id/eprint/521681

Additional comments concerning DSIs and other outputs.

AGS (Albania)

-

BRGM (France)

/

HGI-CGS (Croatia)

NA

RBINS-GSB (Belgium)

-

ICGC (Spain / Catalonia)

We are currently working on a CVI, but I don't not know when it will be finished.

GSI (Ireland)

NA

GeoZS (Slovenia)

NA

ISPRA (Italy)

NA

GTK (Finland)

NA

GSD (Cyprus)

NA

GEUS (Denmark)

A second version of Kystplanlægger is under development (hopefully ready in 2027). In the new version it should be possible to draw a line representing a dike, assign a height to the dike and then compute the mitigation effect it will have.

HSGME (Greece)

NA

LNEG (Portugal)

No additional comments.

ISOR (Iceland)

There is a clear understanding that the EMODnet Geology coastal ribbon assessment is just a start. A countrywide study should be conducted based on published standards, e.g. Furlan, E., Dalla Pozza, P., Michetti, M., Torresan, S., Critto, A., Marcomini, A. (2021), Development of a Multi-Dimensional Coastal Vulnerability Index: assessing vulnerability to inundation scenarios in the Italian coast. Sci. Total Environ. 144650.

BGS (United Kingdom)

BGS started using indices (e.g. CVI) and then moved to a database (GeoCoast) as this is found more useful by our stakeholders.

21. Annex V – Part 2: Inventory

The workflows described by the GSOs in the questionnaire were integrated in the schematic diagram visualising the conceptual model of a generic DSS and its components. This was done both in the cases where a DSS was applied in an assessment of geology in relation to offshore windfarm siting and in the cases where a DSS was not applied. This integration revealed that the conceptual model exhibited limitations when trying to fit a broad spectrum of workflows to the model. Hence, the model and schematic diagram is a guiding framework, but it cannot always stand alone. Please refer to the text which accompanies the figures for the individual GSOs for an elaboration of the individual workflows and thus also a diversification of the different approaches.

AGS (Albania)

The conceptual approach of AGS (Albania) is shown in the schematic diagram in Figure 22.

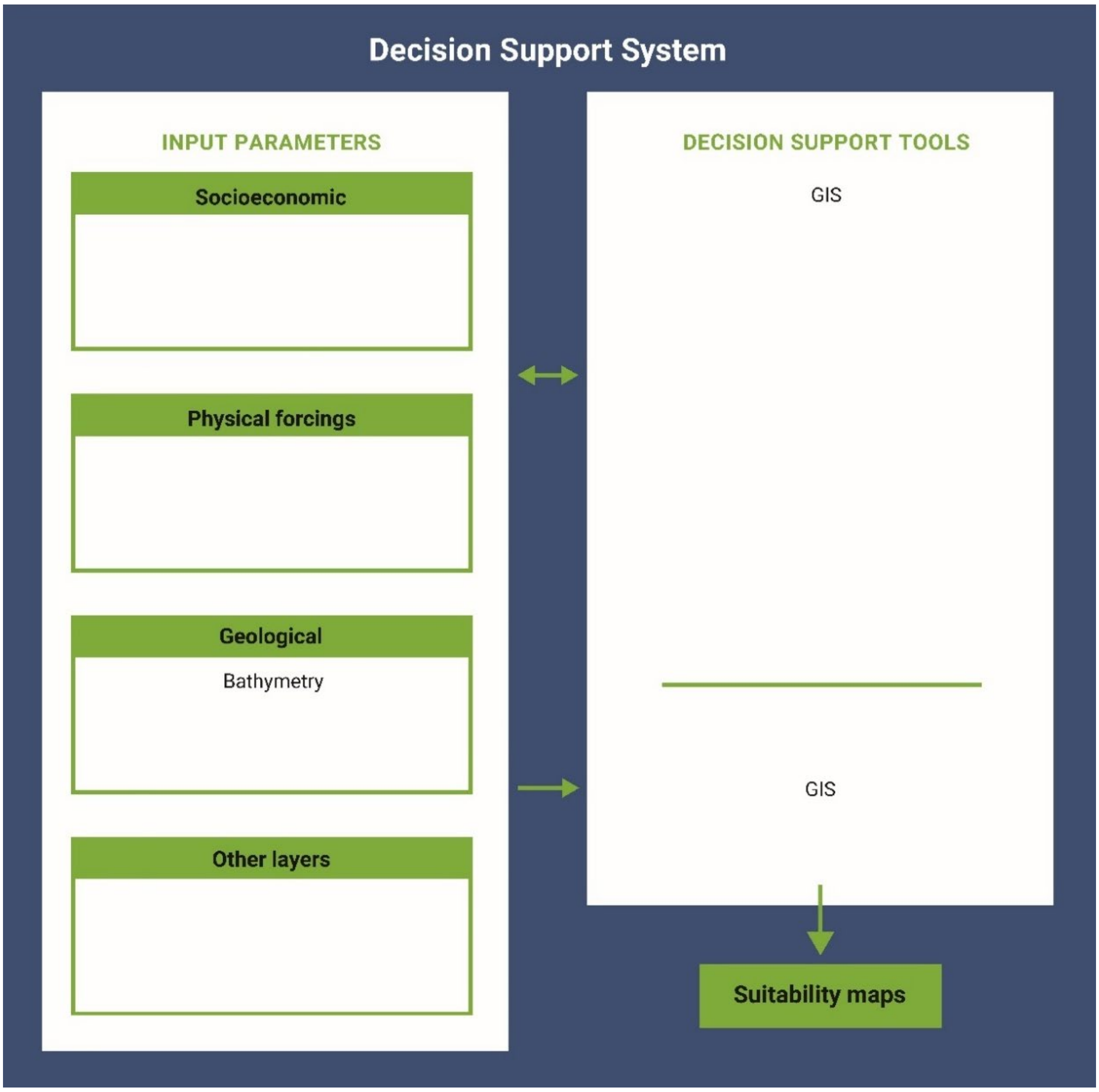

Figure 22. Conceptual approach to offshore windfarm siting in Albania based on questionnaire filled in by AGS.

AGS reported that they currently do not use DSSs for offshore windfarm siting. ArcGIS is the primary DST, which AGS uses to create suitability maps illustrating water depth and maps indicating if the area in question fulfils the requirements for building offshore windfarms. The relevant parameters are standardised in the process of making the suitability maps.

BRGM (France)

The conceptual approach of BRGM (France) is shown in the schematic diagram in Figure 23.

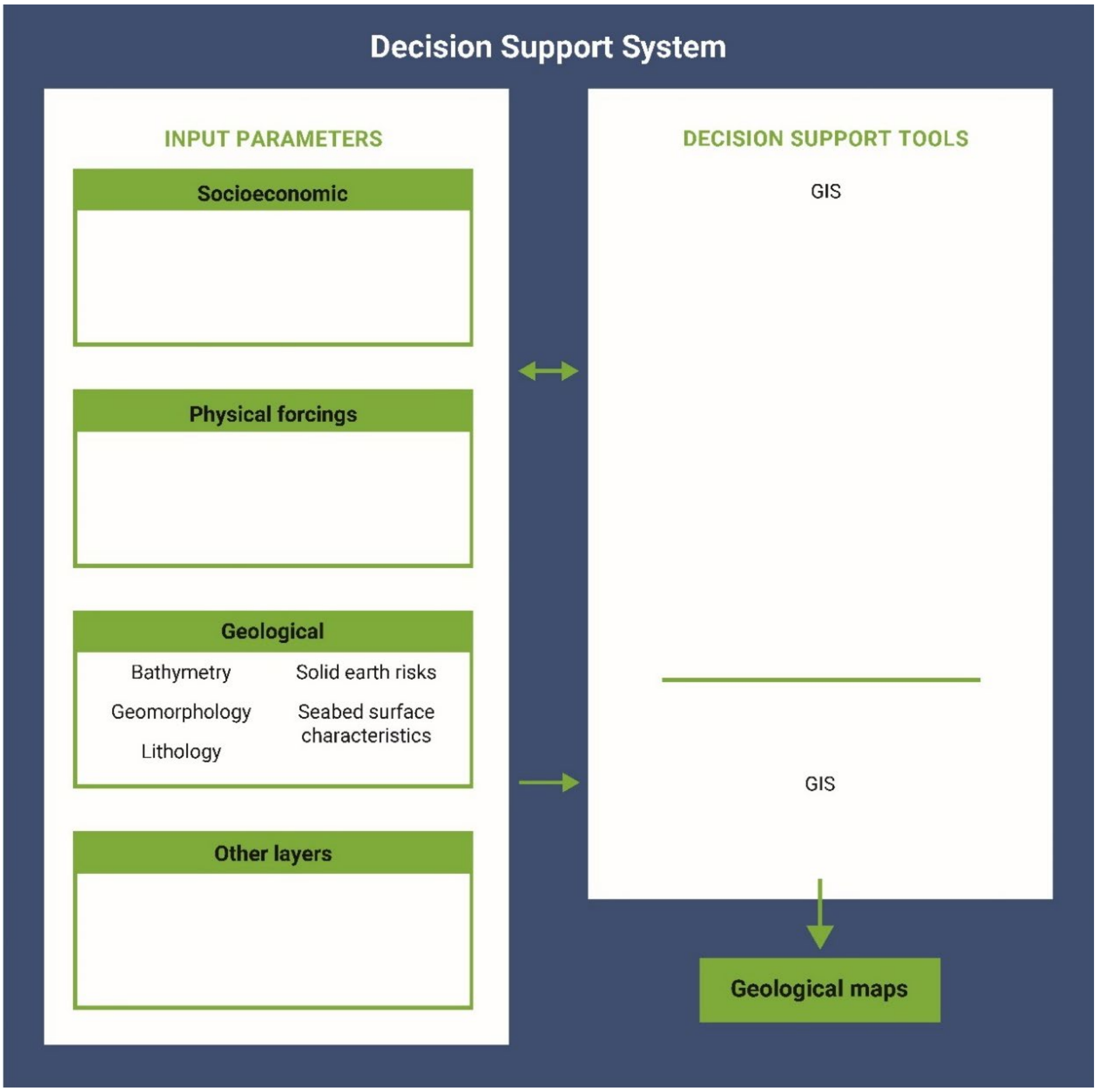

Figure 23. Conceptual approach to offshore windfarm siting in France based on questionnaire filled in by BRGM.

BRGM does not apply a DSS for offshore windfarm siting but contributes by providing key geological and environmental data.
BRGM utilises GIS tools (e.g., ArcGIS, QGIS) as all available information can be spatially visualised.
Their role primarily involves supplying bathymetric data, geological maps, structural geology, and seismic data to support site selection and planning efforts.

HGI-CGS (Croatia)

The conceptual approach of HGI-CGS (Croatia) is shown in the schematic diagram in Figure 24.

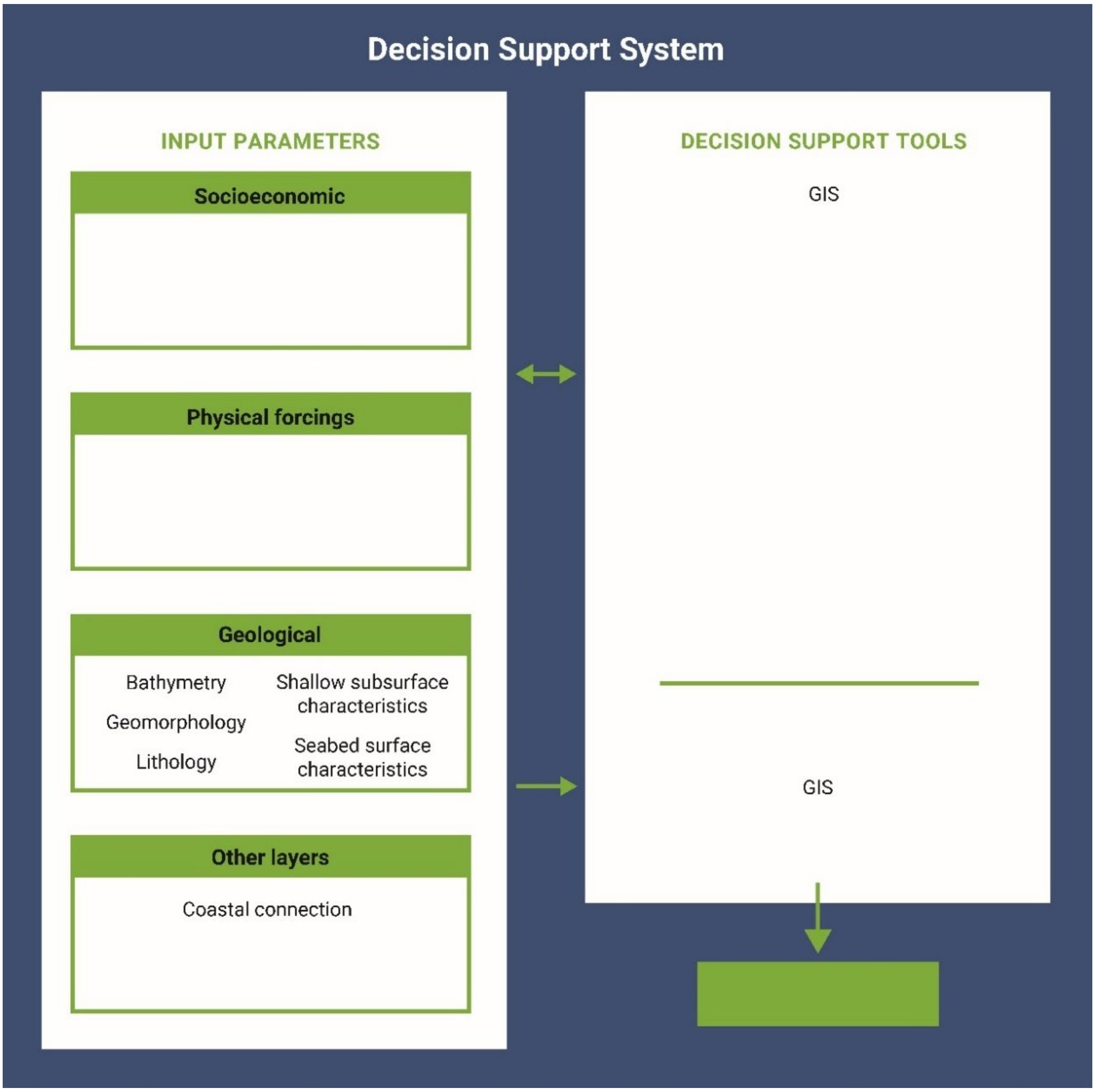

Figure 24. Conceptual approach to offshore windfarm siting in Croatia based on questionnaire filled in by HGI-CGS.

HGI-CGS does not currently use DSSs in relation to offshore windfarm siting and has no experience in the field of offshore windfarm siting. They do however state the use of GIS to analyse parameters.

RBINS-GSB (Belgium)

The conceptual approach of RBINS-GSB (Belgium) is shown in the schematic diagram in Figure 25.

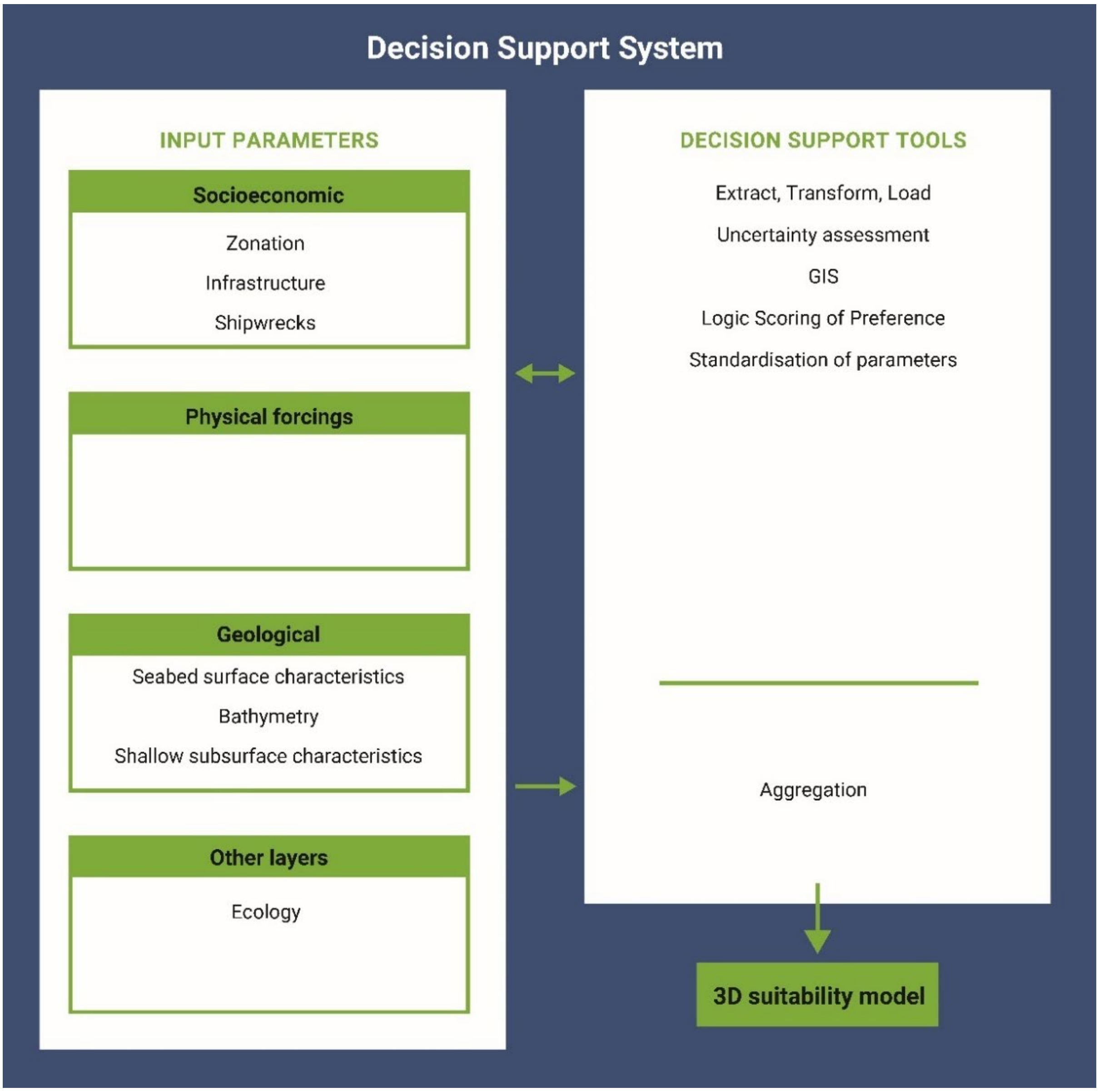

Figure 25. Conceptual approach to offshore windfarm siting in Belgium based on questionnaire filled in by RBINS-GSB.

RBINS-GSB uses the TILES DSS to assess subsurface lithology and geology in the Belgian part of the North Sea. The DSS integrates various geological datasets into a voxel model, providing three-dimensional representations of the seabed. The TILES DSS incorporates multiple IT components to support data integration from multiple databases and other data sources and both a DST and a visualisation tool (De Tré et al., 2018). These models are essential for understanding geological risks and informing MSP. The system also includes methods for evaluating uncertainty in geological data by providing confidence scores to help users assess the reliability of the information, as described by Kint et al. (2020).

Geographic Multi-Criteria Decision Making (MCDM) tools are employed to process large volumes of geological data. These tools create suitability models that help decision-makers in MSP. The MCDM approach involves an Extract, Transform, and Load (ETL) process to integrate data from multiple sources, ensuring that the system provides accurate and up-to-date information (De Tré et al., 2018). Kint et al. (2020) highlighted the importance of standardising lithological data to improve the quality and reliability of the outputs.

The output of the DSS is 3D suitability models that aggregates suitability degrees of individual geological parameters, such as lithology, bathymetry, and sediment composition (Figure 25) (Hademenoes et al., 2019).

The DSS and DST applications are evaluated based on several criteria, including ease of use, accuracy, and adaptability. Additionally, RBINS-GSB has explored the use of Bayesian Networks to incorporate probabilistic reasoning into offshore windfarm siting, as discussed by De Mol et al. (2019).

Further reading

De Mol, R., De Tré, G., Pelta, D. A., Cabrera, I. P., Verdegay, J. L., Yager, R. R., Ojeda-Aciego, M., Medina, J., Bouchon-Meunier, B., Cabrera, I. P., Yager, R. R., & Pelta, D. A. (2018). Applying suitability distributions in a geological context. In Information Processing and Management of Uncertainty in Knowledge-Based Systems. Theory and Foundations (Vol. 853, pp. 278–288). Springer International Publishing AG. https://doi.org/10.1007/978-3-319-91473-2_24

De Tré, G., De Mol, R., van Heteren, S., Stafleu, J., Chademenos, V., Missiaen, T., Kint, L., Terseleer, N., Van Lancker, V., Carrara, P., & Bordogna, G. (2018). Data quality assessment in volunteered geographic decision support. In Mobile Information Systems: Leveraging Volunteered Geographic Information for Earth Observation (Vol. 4, pp. 173–192). Springer International Publishing AG. https://doi.org/10.1007/978-3-319-70878-2_9

Hademenos, V., Stafleu, J., Missiaen, T., Kint, L., & Van Lancker, V. R. M. (2019). 3D subsurface characterisation of the Belgian Continental Shelf: A new voxel modelling approach. Netherlands Journal of Geosciences, 98. https://doi.org/10.1017/njg.2018.18

Kint, L., Hademenos, V., De Mol, R., Stafleu, J., van Heteren, S., & Van Lancker, V. (2021). Uncertainty assessment applied to marine subsurface datasets. Quarterly Journal of Engineering Geology and Hydrogeology, 54(1), 1–. https://doi.org/10.1144/qjegh2020-028

ICGC (Spain / Catalonia)

The conceptual approach of ICGC (Spain / Catalonia) is shown in the schematic diagram in Figure 26.

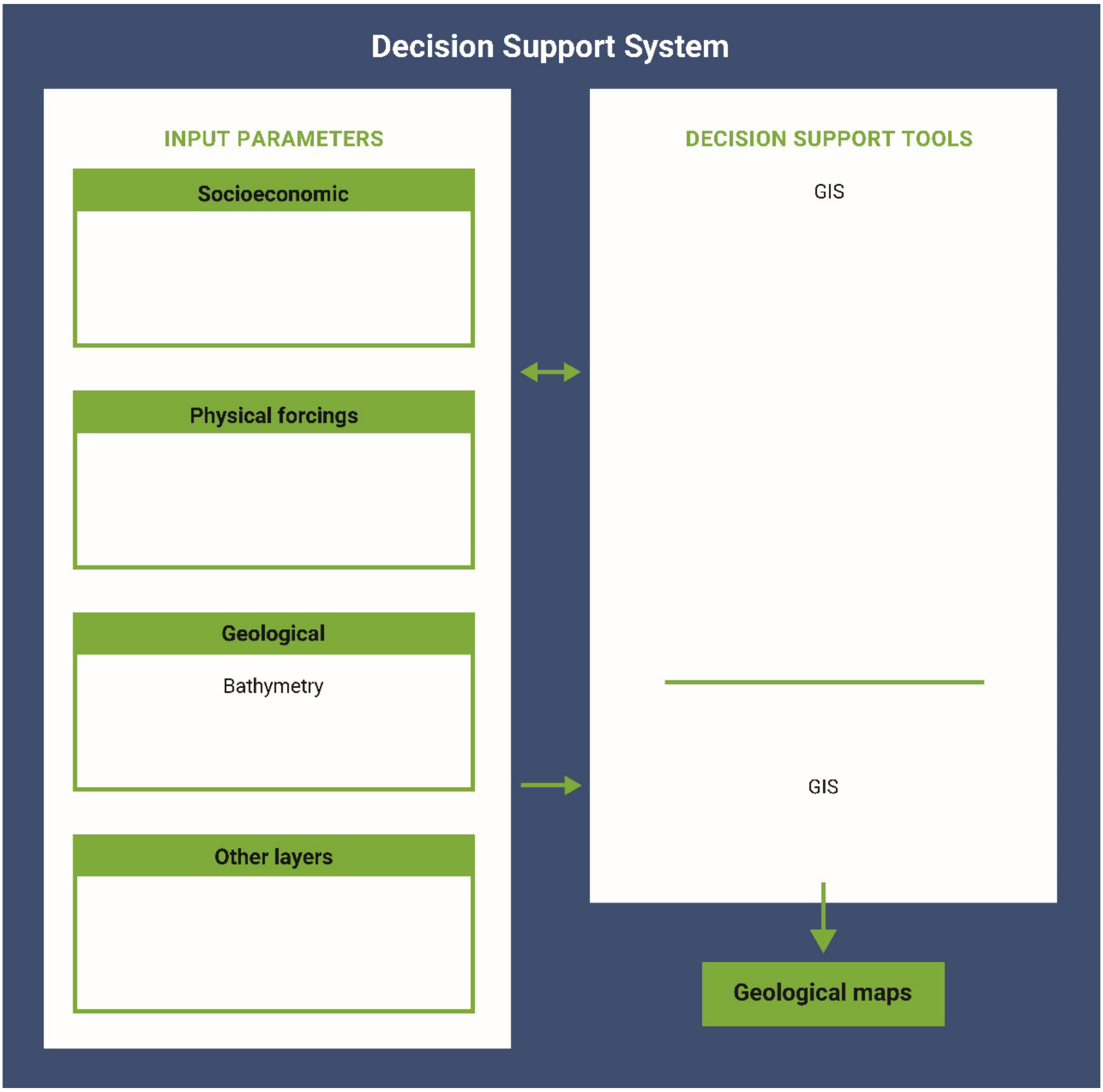

Figure 26. Conceptual approach to offshore windfarm siting in Spain based on questionnaire filled in by ICGC.

ICGC does not currently utilise DSSs for offshore windfarm siting. The same applies for the Geological and Mining Institute of Spain (IGME). ICGC focus on producing geothematic outputs, such as bathymetric and geological maps.

GSI (Ireland)

The conceptual approach of GSI (Ireland) is shown in the schematic diagram in Figure 27.

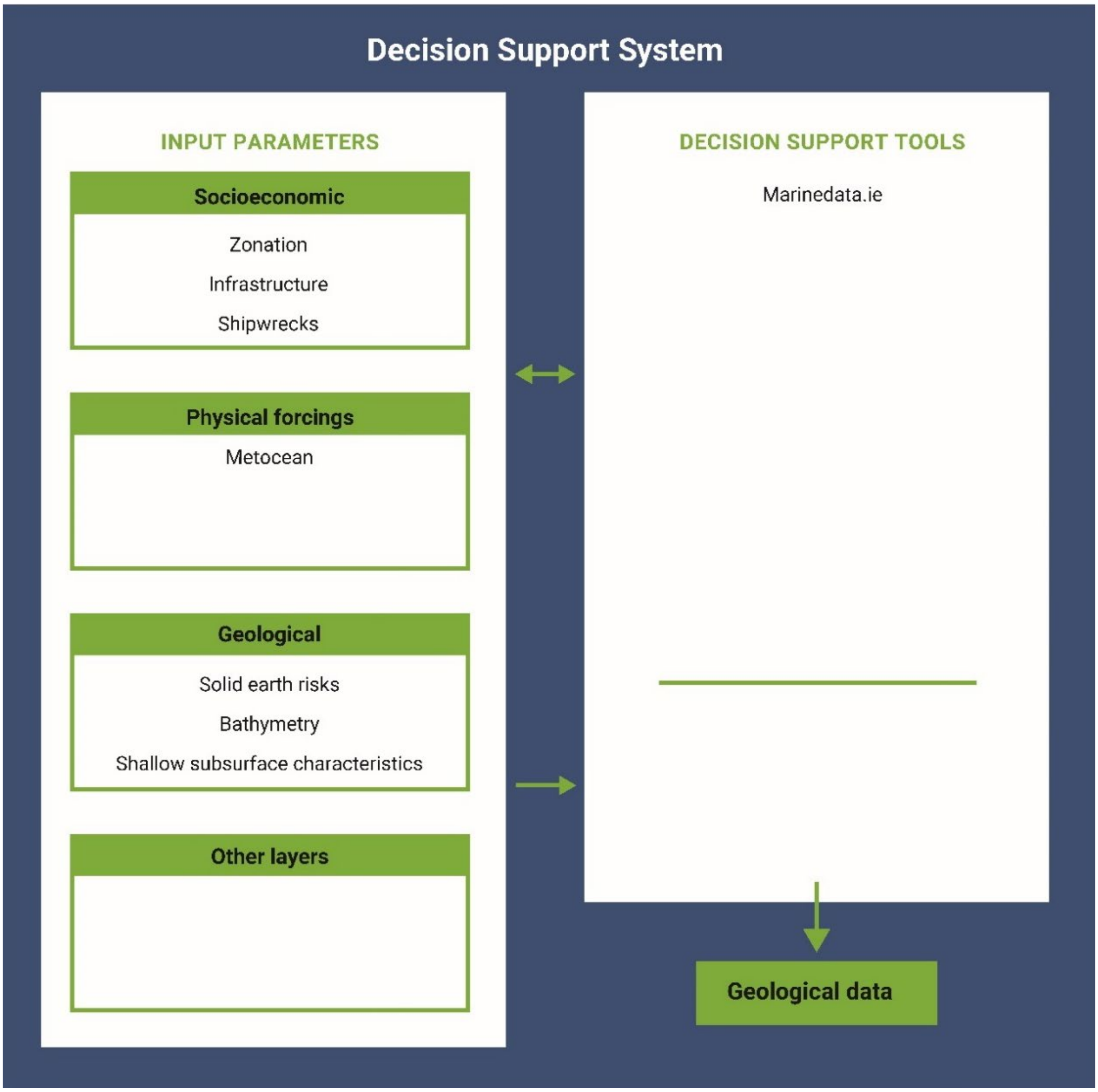

Figure 27. Conceptual approach to offshore windfarm siting in Ireland based on questionnaire filled in by GSI.

GSI employs a DSS in the form of an online, map-based interface (GIS viewer) showcasing geological and non-geological data to support decision making in offshore windfarm siting and other marine spatial planning activities. The primary DST applied in marine spatial planning is MarinePlan.ie. A tool specifically designed for offshore renewable energies are under development, which is proposed to include weighting and/or standardisation of parameters. The output of the work undertaken by GSI in cooperation with the Department of the Environment, Climate and Communications is geophysical data which is provided to the industry who evaluate the data at auction stage.

ISPRA (Italy)

The conceptual approach of ISPRA (Italy) is shown in the schematic diagram in Figure 28.

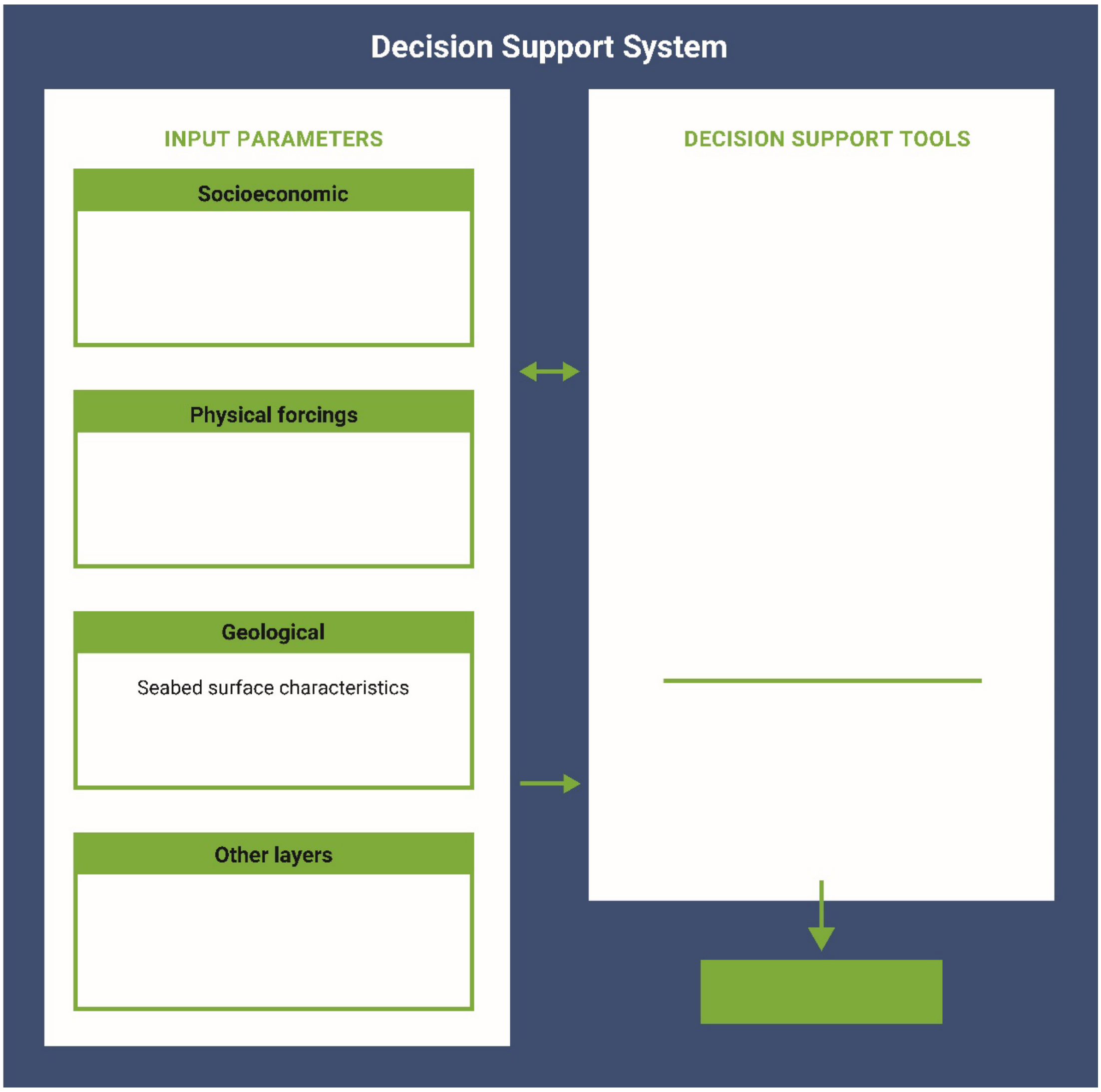

Figure 28. Conceptual approach to offshore windfarm siting in Italy based on questionnaire filled in by ISPRA.

ISPRA does not employ DSSs for offshore windfarm siting. ISPRA provides technical support to the Ministry of the Environment in the environmental impact assessment of offshore windfarms.

Further reading

Azzellino, A., Kofoed, J. P., Lanfredi, C., Margheritini, L., & Pedersen, M. L. (2013). A Marine Spatial Planning framework for the optimal siting of Marine Renewable Energy Installations: two Danish case studies. *Journal of Coastal Research*, *65*(sp2), 1623–1628. https://doi.org/10.2112/SI65-274.1

GTK (Finland)

The conceptual approach of GTK (Finland) is shown in the schematic diagram in Figure 29.

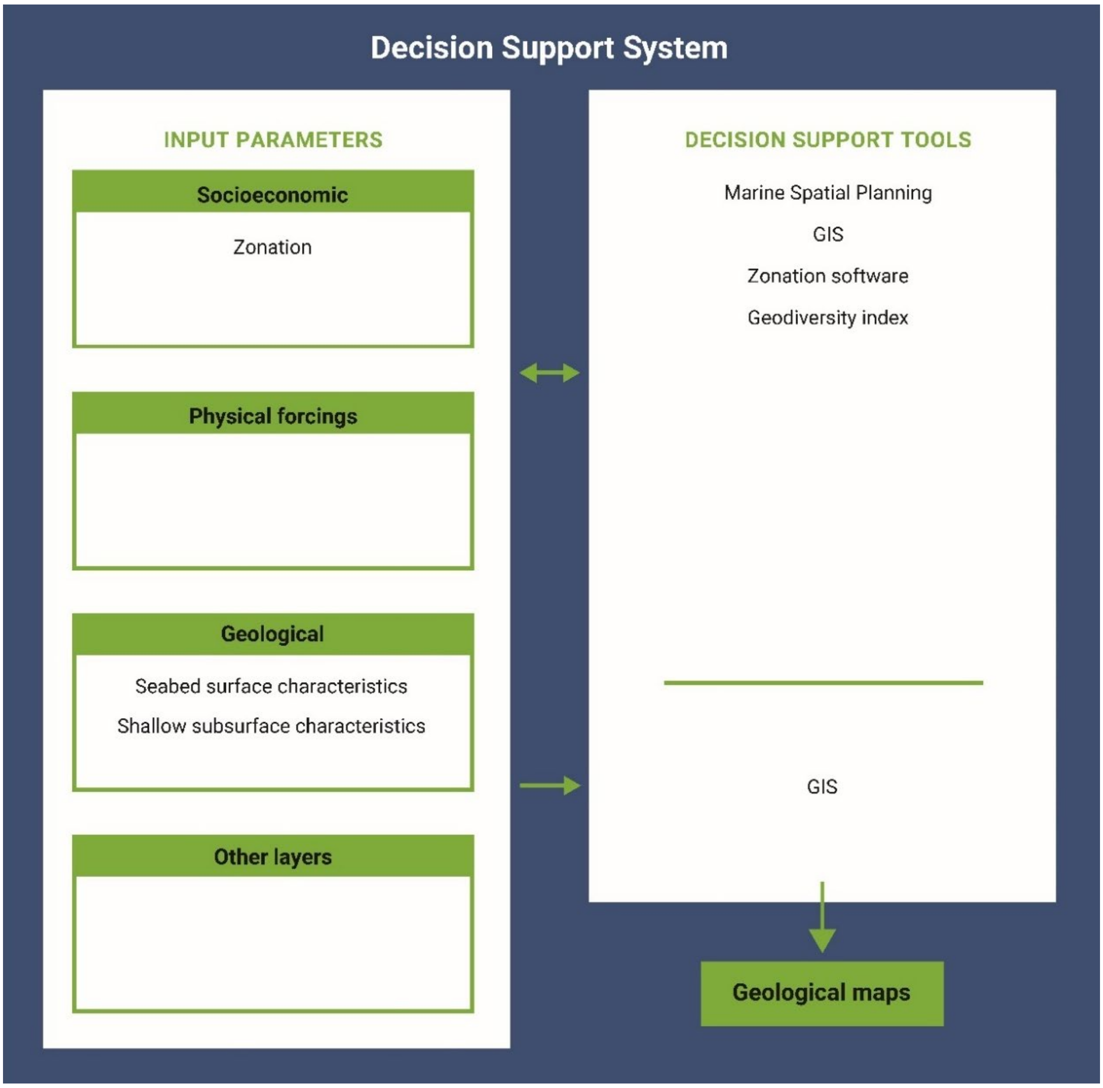

Figure 29. Conceptual approach to offshore windfarm siting in Finland based on questionnaire filled in by GTK.

GTK does not utilise DSSs for offshore windfarm siting. Work is primarily done within the frameworks of MSP, environmental impact assessments (EIA), and strategic planning initiatives.
Zonation Software is widely applied in Finland for prioritising areas for conservation or development. This tool helps identify suitable sites for offshore wind farms by balancing ecological sensitivity and development goals (Virtanen et al. 2022). GIS is also used.
GTK provides geological information on seabed surface and subsurface composition and structures for offshore windfarm planning companies and geological data at different scales for e.g. background information and offshore windfarm siting studies. A Geodiversity index was developed which helps to inform planners and decision-makers about the dynamics of the seabed, abiotic conservation values, and potential areas with high biodiversity (Kaskela & Kotilainen, 2017).

Further reading

Kaskela, A. M., & Kotilainen, A. T. (2017). Seabed geodiversity in a glaciated shelf area, the Baltic Sea. Geomorphology, 295, 419-435. https://doi.org/10.1016/j.geomorph.2017.07.014

Virtanen, E. A., Lappalainen, J., Nurmi, M., Viitasalo, M., Tikanmäki, M., Heinonen, J., Atlaskin, E., Kallasvuo, M., Tikkanen, H., & Moilanen, A. (2022). Balancing profitability of energy production, societal impacts and biodiversity in offshore wind farm design. *Renewable and Sustainable Energy Reviews, 158*, 112087. https://doi.org/10.1016/j.rser.2022.112087

GSD (Cyprus)

The conceptual approach of GSD (Cyprus) is shown in the schematic diagram in Figure 30.

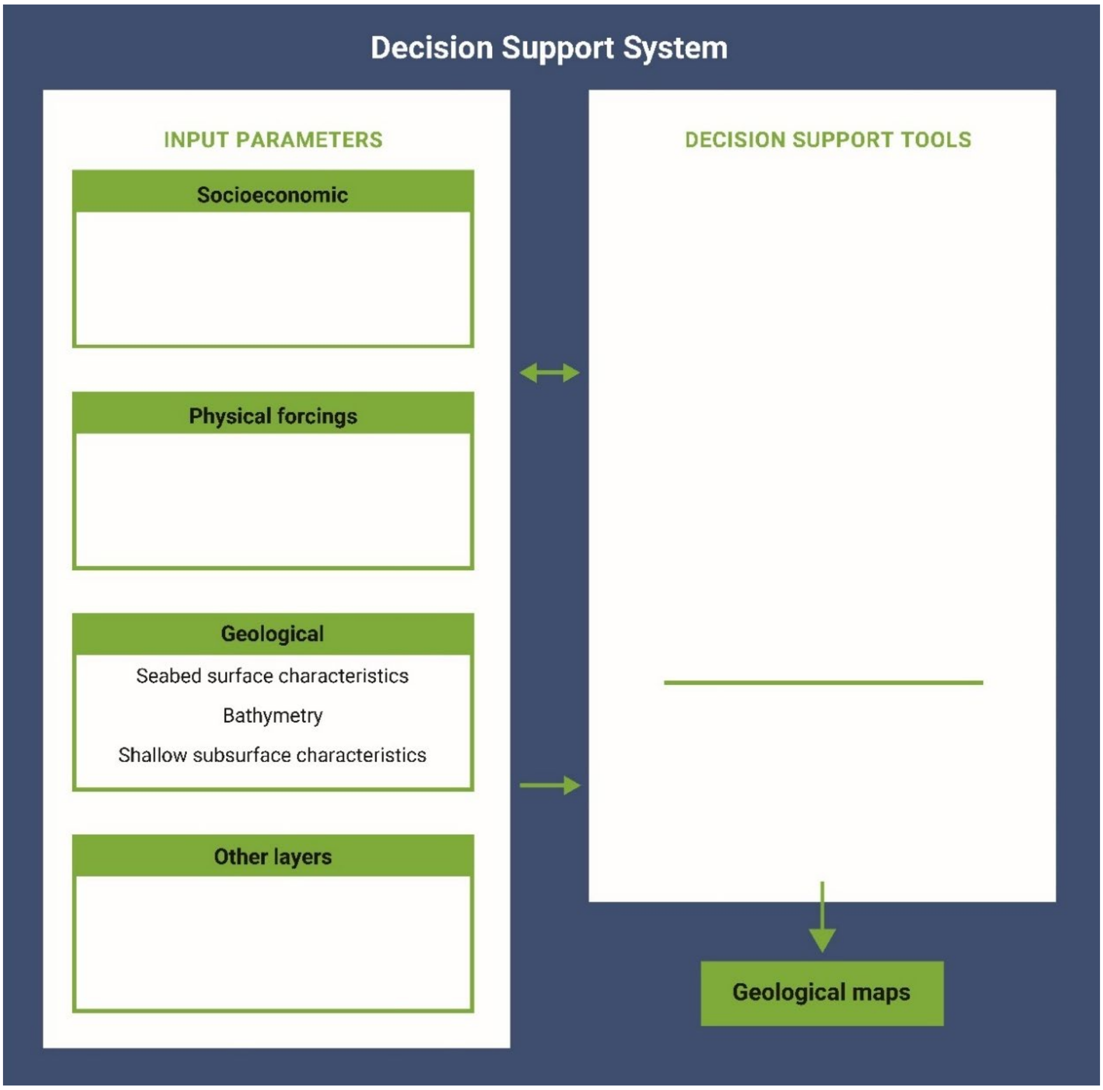

Figure 30. Conceptual approach to offshore windfarm siting in Cyprus based on questionnaire filled in by GSD.

GSD does not currently utilise DSSs for offshore windfarm siting and is not aware of other institutions in the country using such systems. GSD produces a variety of maps to evaluate geology in relation to offshore windfarm siting. These include geologic maps of subsurface geology, subsurface structures, bathymetric maps and seabed sediment maps. Further, Environmental Impact Assessments (EIAs) are also made to analyse environmental impacts and ensure sustainable development.

GEUS (Denmark)

The conceptual approach of GEUS (Denmark) is shown in the schematic diagram in Figure 31.

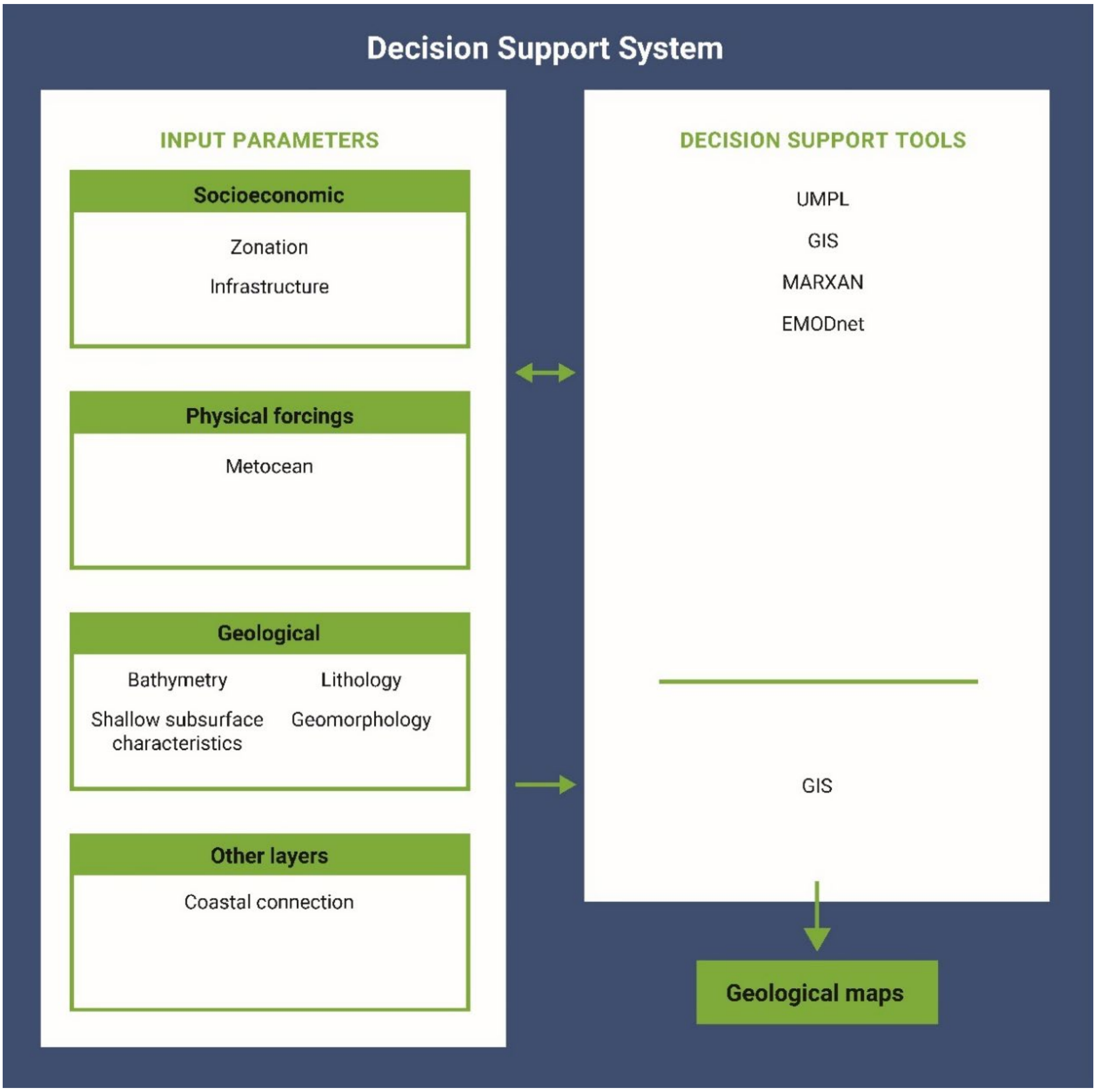

Figure 31. Conceptual approach to offshore windfarm siting in Denmark based on questionnaire filled in by GEUS.

In Denmark, a DSS has not been developed for application in relation to offshore windfarm siting. However, Göke et al. (2018) applied the DSS MARXAN in the western Baltic Sea for offshore windfarm siting. DSTs applied are GIS and a wind distribution model (UMPL). The outputs from MARXAN are suitability maps. In other windfarm projects, background information would be geological maps on seabed lithology, geomorphology and the shallow subsurface composition, strength and structures. Additionally, screenings for marine archaeological hot spots are performed focusing on the development of the distribution of land and sea (paleo-landscapes) after the last deglaciation (Jensen et al., 2025). Another tool to be mentioned is the EMODnet Central Portal.

Further reading

Göke, C., Dahl, K., & Mohn, C. (2018). Maritime spatial planning supported by systematic site selection: Applying Marxan for offshore wind power in the western Baltic Sea. PLoS ONE, 13(3), e0194362. https://doi.org/10.1371/journal.pone.0194362

Jensen, J. B., Bennike, O., Christensen, N., Vangkilde-Pedersen, T. (2025). Screening of seabed geological conditions for the offshore wind farm area Kattegat II and the adjacent cable corridor area: Desk study for Energinet. GEUS. Danmarks og Grønlands Geologiske Undersøgelse Rapport Vol. 2023 No. 33 https://doi.org/10.22008/gpub/34700

GSEU

LNEG (Portugal)

The conceptual approach of LNEG (Portugal) is shown in the schematic diagram in Figure 32.

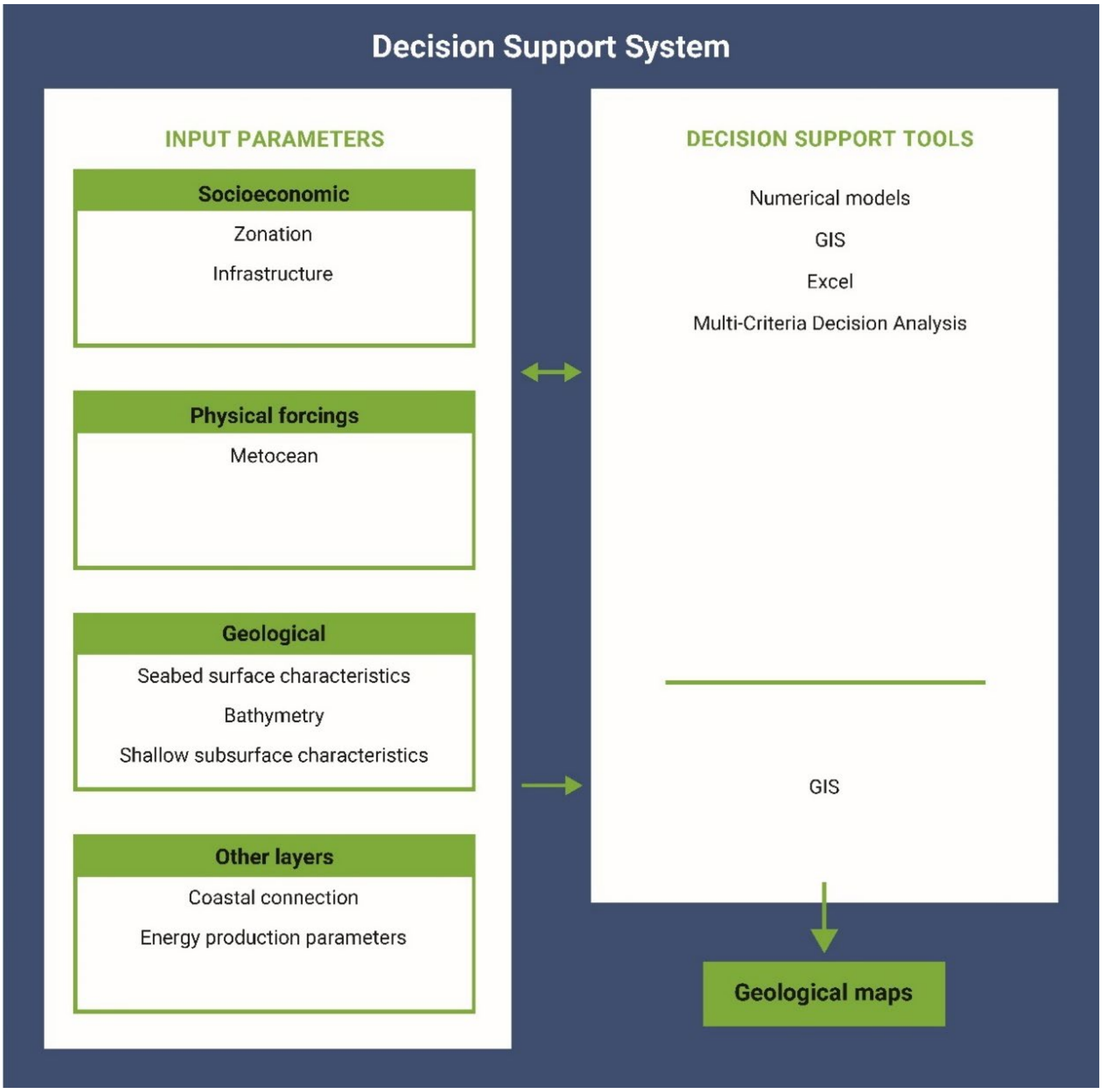

Figure 32. Conceptual approach to offshore windfarm siting in Portugal based on questionnaire filled in by LNEG.

LNEG actively utilises DSSs. Key DSTs include ArcGIS Pro and numerical tools for energy simulation according to the technology in question. In some cases, Multi-Criteria Decision Analysis is also used, although for specific cases, and Excel or other similar software to build point layers. Parameters are weighted and/or standardised using GIS.

Outputs include geological maps of seabed substrate, pre-quaternary geology, landslides, slopes, seabed dynamics, bathymetry and structures (faults, strike-slips etc.).

ISOR (Iceland)

The conceptual approach of ISOR (Iceland) is shown in the schematic diagram in Figure 33.

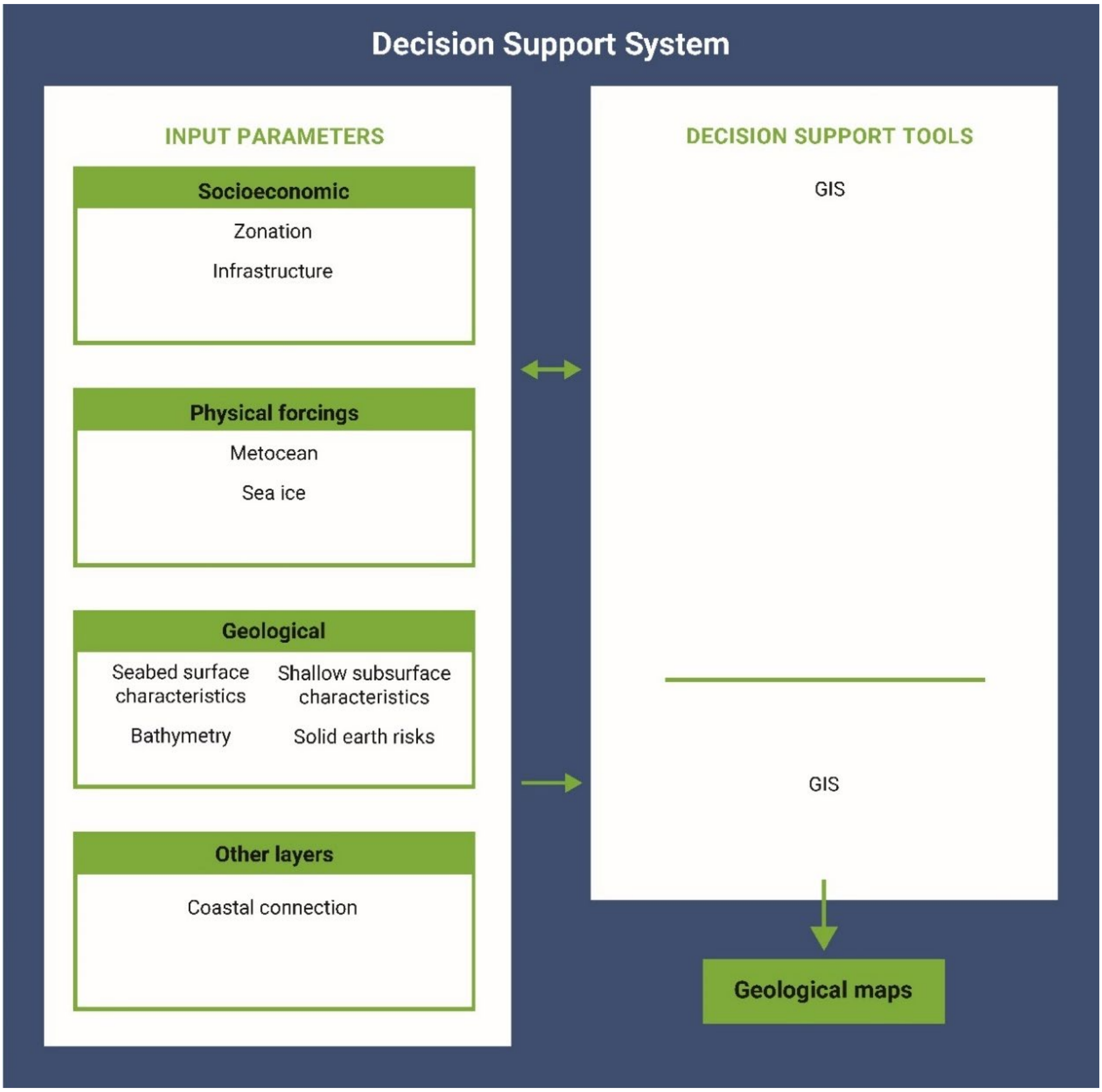

Figure 33. Conceptual approach to offshore windfarm siting in Iceland based on questionnaire filled in by ISOR.

ISOR does not utilise DSSs in relation to offshore windfarm siting. A national collaboration seeks to make the first general assessment of feasibility of offshore wind farming.
GIS is the primary tool applied, and it is used for overlay analysis of multiple data sources. The outputs include parameter specific maps, and risk tables for a nationwide overview.

22. Annex VI – Part2: Questionnaire Responses per GSO

The input that was provided via a questionnaire by the partners in T5.4 as well as other partners in WP5 is shown below, subdivided according to GSOs and decision support modules (DSS, DST, DSI), respectively. Any typos in the input to the questionnaires were corrected.

AGS (Albania)

Do you or does your institute have expertise in DSS for evaluating the geology in relation to optimal offshore windfarm siting?

No

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

No we are not aware of other institution

Which DSSs do you work with in projects concerning optimal offshore windfarm siting (1)?

we don't have

What is the purpose of the DSSs?

we don't have

What is the domain: local, regional, national or international?

we don't have

How do you evaluate the DSS?

we don't have

Additional comments concerning DSSs.

we don't have

Which geological parameters / information layers do you deem relevant in relation to optimal offshore windfarm siting (3)?

The depth of the sea is the parameter that indicates, and we have a key study zone where it can be an offshore windfarm , The Cape of Rodon, North West Adriatic Sea

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

we don't use DST

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to optimal offshore windfarm siting (4)?

We use ARCH GIS

Are the parameters weighted and/or standardised. If so, how (4)?

Yes the parameters are standarised by our institution

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

No we don't apply

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

No we have not considered yet

Additional comments concerning DSTs and information layers / parameters.

-

What outputs do you produce to evaluate the geology in relation to optimal offshore windfarm siting (5)? Why these outputs?

We produce datas for the depth of the shelf and we evaluate the zone which it complete the conditions for building offshore windfarms

Do you have any experiences with indices as a measurement of the geology in relation to optimal offshore windfarm siting?

No we have some datas but not something completed

If yes! Please describe the indices.

-

Additional comments concerning DSIs and other outputs.

-

BRGM (France)

Do you or does your institute have expertise in DSS for evaluating the geology in relation to optimal offshore windfarm siting?

No

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

In France, we are in contact with people working on offshore windfarm sitting in these structures:
- Cerema => Neil ALLONCLE (Neil.alloncle@cerema.fr / Head of maritime and coastal planning in Cerema)
- France Energies Marines (https://www.france-energies-marines.org/) => Maëlle NEXER (maelle.nexer@france-energies-marines.org) or contact (contact@france-energies-marines.org)
- Shom (French hydrographic office) => Aurélien GANGLOFF (aurelien.gangloff@shom.fr)

Some websites of interest :
- https://www.eoliennesenmer.fr/ (Cerema) ; https://www.eoliennesenmer.fr/observatoire/presentation
- projects SIMCELT (https://maritime-spatial-planning.ec.europa.eu/projects/supporting implementation-maritime-spatial-planning-celtic-seas ; https://www.marei.ie/project/simcelt/), SIMNORAT, SIMWESTMED, etc. (Shom ; https://www.shom.fr/fr/liste-actualites/europe-le-shom-partenaire-des-projets-med-osmosis-et-msp-med) => link to the Strategic Façade Documents

Which DSSs do you work with in projects concerning optimal offshore windfarm siting (1)?

We help provide data (bathymetry, geological maps, structural geology, seismic data) for projects at potential/planned sites in France.

(contact for BRGM : Fabien PAQUET (f.paquet@brgm.fr ; involved in WP5.2)

What is the purpose of the DSSs?

/

What is the domain: local, regional, national or international?

at local, regional ou national scales

How do you evaluate the DSS?

/

Additional comments concerning DSSs.

To be checked: we don't know whether these are actually DSS that have been set up, or whether they are simply interactive maps / GIS tools that display the various activities and data sets available in the areas concerned.

Which geological parameters / information layers do you deem relevant in relation to optimal offshore windfarm siting (3)?

- nature of the seabed (rocky/soft), bathymetry, marine sediments, marine dune dynamics => Shom
- marine seismic data (faults, etc.), geological maps, structural geology => BRGM

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

/

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to optimal offshore windfarm siting (4)?

GIS tools (ArcGIS, QGIS, and so on), where all available information can be viewed: geology, tides, winds, currents, swell, environmental restrictions (regulatory zones), birdlife (migratory corridors), benthic habitats, shipping lanes and fisheries, etc.

Are the parameters weighted and/or standardised. If so, how (4)?

/

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

/

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

/

Additional comments concerning DSTs and information layers / parameters.

/

What outputs do you produce to evaluate the geology in relation to optimal offshore windfarm siting (5)? Why these outputs?

/

Do you have any experiences with indices as a measurement of the geology in relation to optimal offshore windfarm siting?

/

If yes! Please describe the indices.

/

Additional comments concerning DSIs and other outputs.

/

HGI-CGS (Croatia)

Do you or does your institute have expertise in DSS for evaluating the geology in relation to optimal offshore windfarm siting?

NO

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

NA

Which DSSs do you work with in projects concerning optimal offshore windfarm siting (1)?

NA

What is the purpose of the DSSs?

NA

How do you evaluate the DSS?

NA

Additional comments concerning DSSs.

NA

Which geological parameters / information layers do you deem relevant in relation to optimal offshore windfarm siting (3)?

lithology, geomorphology, distance to the coast, bathymetry, sediment distribution, subsurface data

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

NONE

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to optimal offshore windfarm siting (4)?

ArcGIS

Are the parameters weighted and/or standardised. If so, how (4)?

NO

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

NO

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

NA

Additional comments concerning DSTs and information layers / parameters.

NA

What outputs do you produce to evaluate the geology in relation to optimal offshore windfarm siting (5)? Why these outputs?

None. We so far have no expirience in offshore windfarm siting.

Do you have any experiences with indices as a measurement of the geology in relation to optimal offshore windfarm siting?

NO

If yes! Please describe the indices.

NA

Additional comments concerning DSIs and other outputs.

NA

RBINS-GSB (Belgium)

Do you or does your institute have expertise in DSS for evaluating the geology in relation to optimal offshore windfarm siting?

Yes

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

Vera Van Lancker (vvanlancker@naturalsciences.be); Lars Kint (lkint@naturalsciences.be)

Subsurface lithology and geology in the Belgian part of the North Sea (Hademenos et al. 2018) + Uncertainty assessment (Kint et al. 2020)

Which DSSs do you work with in projects concerning optimal offshore windfarm siting (1)?

TILES DSS (http://www.bmdc.be/tiles-dss/) Currently not available

What is the purpose of the DSSs?

A decision support application opens up the voxel model for specific requests on lithology, geology and uncertainty information in areas of interest in the Belgian part of the North Sea.

What is the domain: local, regional, national or international?

National

How do you evaluate the DSS?

Easy querrying, visualisation and download of 3D subsurface sediments for areas of interest in the Belgian part of the North Sea.

Additional comments concerning DSSs.

Long-term support and maintenance of a DSS is needed through long-term or updated coding language, software, etc.

Which geological parameters / information layers do you deem relevant in relation to optimal offshore windfarm siting (3)?

Manual TILES dss (2020):

- Most common lithological classes
- Heterogeneity of the lithological class
- (average) probability
- (average) entropy
- Most common lithostratigraphy
- (average) borehole density
- (average) percentage of the lithological class
- (average) quality

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

De Tré et al. (2018): "Geographic MCDM relies on the availability of several IT components, including databases and other data resources, a data integration component, a decision support tool and a visualization tool. Data from different sources are used for evaluating the decision criteria. In a first step, each data source is subject to a kind of Extract, Transform and Load (ETL) process, which extracts the relevant data from the source, transforms it into the correct format and prepares it as input for the decision support tool. For main data sources that do not change often, like 3D lithological classification models, ETL is done in advance. In the next step, the integrated input data are processed by the decision support tool. In TILES, an LSP-based approach is used for the computation of suitability degrees for a 3D suitability model. This model is enriched with metadata expressing the confidence that experts have in the computed suitability degrees. The enriched suitability model is loaded into dedicated visualization software for easily accessible presentation to the decision-maker."

De Tré et al. (2018):"The simplified attribute tree shown emphasizes that for a marine exploitation decision (root node), one has to consider data that are related to the lithology, bathymetry, ecology, restricted areas and locations of shipwrecks. As a measure of lithology, the probabilities for different kinds of sediment (in the example limited to fine sand, coarse sand and clay) are considered. A restricted area can be a military zone or an area where power supplies, pipelines or telecommunication lines are located."

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to optimal offshore windfarm siting (4)?

De Tré et al. (2018): "In our previous research, we studied 2D suitability maps constructed using the LSP approach [16]. In this work, we used the same technique to create 3D suitability models, as depicted in Fig. 3. It entails a three-step method consisting of (1) elementary attribute selection, (2) elementary criteria specification and evaluation and (3) aggregation."

Other: Geographical Information System (ArcGIS, QGIS, etc.)

Are the parameters weighted and/or standardised. If so, how (4)?

Yes, in the creation of the sediment dataset, the voxel model and the DSS of the subsurface of the Belgian part of the North Sea.

Kint et al. (2020): "Lithological data and associated metadata were harmonized and standardized to facilitate the generation of seamless seabed maps (Van Lancker and van Heteren 2013) following internationally proposed or agreed guidelines (e.g. Geo-Seas for geological and geophysical data (van Heteren 2010), SeaDataNet for oceanographic data, and INSPIRE for spatial information). To ensure machine-readability, interoperability and compatibility of the data, lithological descriptions available as text were transferred to code.

Hademenos et al. (2018): "To model offshore aggregate resources, amethodological workflow was developed based on the voxel modelling approach of Stafleu et al. (2011) and expanded with seismic data. It comprises the following steps: (1a) Standardisation and lithological classification of borehole descriptions; (1b, 3) Delineation of seismic acoustic facies and their seismostratigraphical interpretation; (2) Stratigraphic interpretation of the boreholes; (4) Construction of the 2D stratigraphical layer model; (5) Assignment of lithostratigraphical units to the 3D voxel model; (6) 3D interpolation of lithological class within each lithostratigraphical unit; (7) Assessment of the information entropy of the model."

De Tré et al. (2018): "A scientific solution for data quality assessment using (geographic) multi-criteria decision-making based on LSP suitability models relies on the identification and specification of elementary data quality aspects for the elementary attributes that are involved in the decision-making process. For each elementary data quality aspect, a corresponding elementary quality criterion is specified. Evaluation of these elementary quality criteria for a given voxel in a geographical voxel space yields elementary confidence scores for that voxel. These elementary confidence scores are then aggregated to an overall confidence degree by applying a novel, extended version of the LSP aggregation structure. Every LSP aggregator is extended so that it takes both suitability degrees and confidence degrees as arguments and computes a couple that consists of an aggregated suitability degree and an aggregated confidence degree. The aggregated suitability degree is computed in exactly the same way as in regular suitability modelling. For the aggregated confidence degree, a weighted sum of the input confidence degrees is computed, with the weights reflecting the impact of the corresponding input suitability degrees on the computation of the aggregated suitability degree. In our future research, we aim to study alternatives for the weighted sum aggregation in order to further improve the semantic properties of the aggregation, so that this aggregation even better reflects and complements expert reasoning."

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

Yes

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

De Mol (2019): "In the Bayesian interpretation (based on Bayes' theory of Bayesian inference but actually pioneered by Laplace), probability is a subjective indicator of belief. Different agents might assign different probabilities to different outcomes and there is no reason for someone to believe one agent over the other. Bayesian probabilities further also rely on the assumption that agents are perfectly rational [3, 21], though evidence has shown that this claim is doubtful [17]. This interpretation is often applied in the context of betting games, to set payout rates for outcomes in correspondence to their perceived probability of occurring, which is immediate evidence that perceived probabilities can be used to turn a profit and are not necessarily fair. Au contraire, this interpretation relies on the idea that the true likeliness of the outcomes can be hidden behind slightly manipulated probabilities in order to trick gamblers into entering an unfair game, the lottery being a prime example thereof.

Additional comments concerning DSTs and information layers / parameters.

-

What outputs do you produce to evaluate the geology in relation to optimal offshore windfarm siting (5)? Why these outputs?

De Tré et al. (2018): "Key to the decision support tool used in TILES is the creation of 3D suitability models. As input, a 3D voxel model of the subsurface of the Belgian part of the North Sea is being constructed. Each voxel is currently fixed in size (length and width 200 m, height 1 m). The model currently includes voxels that range from 4 m above mean sea level to 75 m below it.

Van Lancker et al. (2019): "Main DSS attributes relate to the integrated data, information and knowledge, the 3D geological models and some first output from 4D process models. Advanced criteria-evaluation techniques were developed to support the construction of specialized geographical maps of the sea region under investigation. Such maps, hereafter called 'suitability maps', are able to show geological boundaries, distributions of particular resource qualities, and the resource estimation at various cut-off grades, all calculated in a time-efficient manner encouraging online use of the tool. Additionally, user functions of the BPNS, as available from the Marine Atlas (Belgian Marine Data Centre), were incorporated: infrastructure (e.g. pipelines; electricity and telecommunication cables; windmills; navigation routes), human activity (e.g. tourism, safety), legal status (e.g. areas reserved for special activities), economic development (e.g. expansion of industries). A user can make dynamically a series of tailor-made suitability maps that assist in resource assessments."

Do you have any experiences with indices as a measurement of the geology in relation to optimal offshore windfarm siting?

-

If yes! Please describe the indices.

-

Additional comments concerning DSIs and other outputs.

-

ICGC (Spain / Catalonia)

Do you or does your institute have expertise in DSS for evaluating the geology in relation to optimal offshore windfarm siting?

No

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

No, i'm not aware of any.

Which DSSs do you work with in projects concerning optimal offshore windfarm siting (1)?

None

What is the purpose of the DSSs?

NA

What is the domain: local, regional, national or international?

NA

How do you evaluate the DSS?

NA

Additional comments concerning DSSs.

NA

Which geological parameters / information layers do you deem relevant in relation to optimal offshore windfarm siting (3)?

Bathymetry

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

NA

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to optimal offshore windfarm siting (4)?

NA

Are the parameters weighted and/or standardised. If so, how (4)?

No

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

No

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

NA

Additional comments concerning DSTs and information layers / parameters.

NA

What outputs do you produce to evaluate the geology in relation to optimal offshore windfarm siting (5)? Why these outputs?

Bathymetry

Do you have any experiences with indices as a measurement of the geology in relation to optimal offshore windfarm siting?

No

If yes! Please describe the indices.

NA

Additional comments concerning DSIs and other outputs.

NA

GSI (Ireland)

Do you or does your institute have expertise in DSS for evaluating the geology in relation to optimal offshore windfarm siting?

Yes

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

Jo Coloe, Offshore Energy, Department of the Environment, Climate and Communications jo.coloe@decc.gov.ie; Eoin Mac Craith eoin.maccraith@gsi.ie

Which DSSs do you work with in projects concerning optimal offshore windfarm siting (1)?

An online, map-based interface (GIS Viewer and dashboard)

What is the purpose of the DSSs?

This viewer will make available data which provides value in the (DMAP) decision-making process and in future ORESS auctions and related/supporting spatial marine data/information.

What is the domain: local, regional, national or international?

National

How do you evaluate the DSS?

Stakeholder workshops with feedback

Additional comments concerning DSSs.

Would like further iterations to potentially develop into a cumulative effects/ weighting framework/tool

Which geological parameters / information layers do you deem relevant in relation to optimal offshore windfarm siting (3)?

Administrative (anchorage areas, pilot boarding locations and restricted areas), Aquaculture, Aviation – interference with flight radars, Commercial fisheries, Designated sites – European sites, Ramsar, UNESCO, NHAs, Fish and shellfish, Industrial – shoreline construction, commercial fishing and harbour facilities, and offshore piles, Marine habitats, Marine historic environment, Marine infrastructure – oil and gas pipelines, submarine cables, Marine mammals, Military, Obstructions and wrecks, Ornithology & bats, Seascape and landscape, Shipping and navigation, Tourism and recreation, Biodiversity, Bathymetry, Seismic activity, Type of ground condition, Significant wave height, Tidal currents, Extreme wind gust & mean wind speed, Submarine cables, LCOE, Military practice, danger and other no-go areas, Location of oil and gas activity, Aggregate and material extraction areas, Underwater archaeology – UXO, Pipelines, Ports, piers, marinas, Population and human health, Cultural heritage, Tourism and recreation, Archaeological heritage, Rivers and lakes

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

Currently marineplan.ie is the DST used for general marine spatial planning, the tool in process will be specifically for ORE.

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to optimal offshore windfarm siting (4)?

Geology evaluated by industry at auction stage

Are the parameters weighted and/or standardised. If so, how (4)?

No but propose to down the line with this ORE digital tool.

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

No

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

Considering for the future - time and resources would delay this phase

Additional comments concerning DSTs and information layers / parameters.

NA

What outputs do you produce to evaluate the geology in relation to optimal offshore windfarm siting (5)? Why these outputs?

Government-led geophysical surveys provide data to industry

Do you have any experiences with indices as a measurement of the geology in relation to optimal offshore windfarm siting?

No

If yes! Please describe the indices.

NA

Additional comments concerning DSIs and other outputs.

NA

GeoZS (Slovenia)

Do you or does your institute have expertise in DSS for evaluating the geology in relation to optimal offshore windfarm siting?

No

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

We are not aware

Which DSSs do you work with in projects concerning optimal offshore windfarm siting (1)?

NA

What is the purpose of the DSSs?

NA

What is the domain: local, regional, national or international?

NA

How do you evaluate the DSS?

NA

Additional comments concerning DSSs.

NA

Which geological parameters / information layers do you deem relevant in relation to optimal offshore windfarm siting (3)?

NA

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

NA

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to optimal offshore windfarm siting (4)?

NA

Are the parameters weighted and/or standardised. If so, how (4)?

NA

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

NA

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

NA

Additional comments concerning DSTs and information layers / parameters.

NA

What outputs do you produce to evaluate the geology in relation to optimal offshore windfarm siting (5)? Why these outputs?

NA

Do you have any experiences with indices as a measurement of the geology in relation to optimal offshore windfarm siting?

NA

If yes! Please describe the indices.

NA

Additional comments concerning DSIs and other outputs.

NA

ISPRA (Italy)

Do you or does your institute have expertise in DSS for evaluating the geology in relation to optimal offshore windfarm siting?

No

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

No

Which DSSs do you work with in projects concerning optimal offshore windfarm siting (1)?

NAWhat is the purpose of the DSSs?

NA

What is the domain: local, regional, national or international?

NA

How do you evaluate the DSS?

NA

Additional comments concerning DSSs.

NA

Which geological parameters / information layers do you deem relevant in relation to optimal offshore windfarm siting (3)?

Nature of the seabed (rocky/soft)

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

NA

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to optimal offshore windfarm siting (4)?

NA

Are the parameters weighted and/or standardised. If so, how (4)?

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

NA

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

NA

Additional comments concerning DSTs and information layers / parameters.

NA

What outputs do you produce to evaluate the geology in relation to optimal offshore windfarm siting (5)? Why these outputs?

NA

Do you have any experiences with indices as a measurement of the geology in relation to optimal offshore windfarm siting?

NA

If yes! Please describe the indices.

NA

Additional comments concerning DSIs and other outputs.

NA

GTK (Finland)

Do you or does your institute have expertise in DSS for evaluating the geology in relation to optimal offshore windfarm siting?

No

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

We have expertise in geology at GTK, but not in DSS's regarding offshore windfarm siting. In Finland, decision support systems (DSSs) and tools for offshore wind farm siting are primarily used within the frameworks of Marine Spatial Planning (MSP), environmental impact assessments (EIA), and strategic planning initiatives. These systems integrate data on environmental, social, and economic factors to identify suitable areas for offshore wind farms. Regarding MSPs, Regional Councils are responsible for preparing and implementing MSPs at the regional level in Finland. Ministry of the Environment oversees MSP processes and ensures alignment with national and EU-level strategies. Finnish Environment Institute (SYKE) provide scientific support and data for MSP processes. ELY Centres (Centres for Economic Development, Transport and the Environment) are responsible for coordinating and reviewing EIA processes for offshore projects. Metsähallitus is responsible for site selection in government-owned sea areas within the territorial waters of Finland.

Which DSSs do you work with in projects concerning optimal offshore windfarm siting (1)?

GTK has done commissioned surveys and provided geological information on seabed surface and subsurface composition and structures for some OWF planning companies including Metsähallitus.

What is the purpose of the DSSs?

Finland's MSP processes include frameworks that integrate multi-use considerations and zoning for offshore activities, including wind energy. The MSP system incorporates ecological values, shipping routes, fisheries, and biodiversity protection zones. GIS-based tools are commonly used to visualize and analyze spatial data, ensuring compatibility of offshore wind farm locations with other marine uses. EIA processes are mandatory for OWF projects in Finland. These assessments rely on DSS elements to evaluate potential impacts on marine ecosystems including the seabed, bird and fish populations, and coastal habitats. Tools for cumulative impact assessment are also used to consider combined effects of multiple wind farms or other marine activities

What is the domain: local, regional, national or international?

For MSPs - regional, for EIAs - (inter)national (if close to borders*)/regional/local

How do you evaluate the DSS?

MSPs are evaluated based on the public consultations on the planned proposals.

Additional comments concerning DSSs.

*) Espoo Convention

Which geological parameters / information layers do you deem relevant in relation to optimal offshore windfarm siting (3)?

Seabed surface and subsurface composition and structures, geological parameters derivated from geological interpretations include e.g., thickness of unconsolidated sediments, depth of the bedrock surface, thickness of soft sediments, depth of the hard substrate.

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

We do not actually make OWF siting at GTK. However, we consider following DST's useful: GIS Desktop. For parameters that have been used by others in Finland see e.g. Virtanen et al. 2022. Unfortunately, the (full coverage) seabed geological parameters were missing/not available that time.

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to optimal offshore windfarm siting (4)?

Zonation Software is widely applied in Finland for prioritizing areas for conservation or development. This tool helps identify suitable sites for offshore wind farms by balancing ecological sensitivity and development goals (Virtanen et al. 2022). Unfortunately, the (full coverage) seabed geological parameters were missing/not available that time.

Are the parameters weighted and/or standardised. If so, how (4)?

For parameters see e.g., Virtanen et al. 2022

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

No

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

NA

Additional comments concerning DSTs and information layers / parameters.

E.A. Virtanen, J. Lappalainen, M. Nurmi, M. Viitasalo, M. Tikanmäki, J. Heinonen, E. Atlaskin, M. Kallasvuo, H. Tikkanen, A. Moilanen, 2022. Balancing profitability of energy production, societal impacts

and biodiversity in offshore wind farm design. Renewable and Sustainable Energy Reviews, 158, 2022, 112087, https://doi.org/10.1016/j.rser.2022.112087.

What outputs do you produce to evaluate the geology in relation to optimal offshore windfarm siting (5)? Why these outputs?

We do not actually make OWF siting at GTK. However, GTK has done commissioned surveys and provided geological information on seabed surface and subsurface composition and structures for OWF planning companies including Metsähallitus. GTK provides geological data at different scales for e.g. background information and OWF siting studies.

Do you have any experiences with indices as a measurement of the geology in relation to optimal offshore windfarm siting?

Yes

If yes! Please describe the indices.

Besides parameters mentioned above, Geodiversity index is one of the indices developed and provided by GTK (e.g. Kaskela & Kotilainen, 2017).

Additional comments concerning DSIs and other outputs.

Kaskela, A.M., Kotilainen, A.T., 2017. Seabed geodiversity in a glaciated shelf area, the Baltic Sea. Geomorphology, 295, 419–435.

GSD (Cyprus)

Do you or does your institute have expertise in DSS for evaluating the geology in relation to optimal offshore windfarm siting?

no

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

no

Which DSSs do you work with in projects concerning optimal offshore windfarm siting (1)?

NA

What is the purpose of the DSSs?

NA

What is the domain: local, regional, national or international?

NA

How do you evaluate the DSS?

NA

Additional comments concerning DSSs.

NA

Which geological parameters / information layers do you deem relevant in relation to optimal offshore windfarm siting (3)?

NA

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

NA

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to optimal offshore windfarm siting (4)?

NA

Are the parameters weighted and/or standardised. If so, how (4)?

NA

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

NA

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

NA

Additional comments concerning DSTs and information layers / parameters.

NA

What outputs do you produce to evaluate the geology in relation to optimal offshore windfarm siting (5)? Why these outputs?

Key geological outputs for offshore windfarm siting:
Bathymetric maps: Map seafloor depth for suitable water depth.
Seabed sediment maps: Identify foundation suitability and scour risks.
Geological surveys: Assess subsurface geology for foundation stability and potential hazards.
Geophysical surveys: Map subsurface structures for cable routing and obstacle identification.
Environmental Impact Assessments (EIAs): Evaluate environmental impacts and ensure sustainable development.

Why these outputs?
Bathymetry: Ensures sufficient water depth.
Seabed sediment: Determines foundation type and scour risks.
Geology: Assesses foundation stability and potential hazards.
Geophysics: Identifies obstacles and suitable cable routes.
EIAs: Mitigates environmental impacts.
Combining these outputs helps identify optimal sites for offshore wind farms.

Do you have any experiences with indices as a measurement of the geology in relation to optimal offshore windfarm siting?

no

If yes! Please describe the indices.

NA

Additional comments concerning DSIs and other outputs.

NA

GEUS (Denmark)

Do you or does your institute have expertise in DSS for evaluating the geology in relation to optimal offshore windfarm siting?

No

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

NA

Which DSSs do you work with in projects concerning optimal offshore windfarm siting (1)?

NA

What is the purpose of the DSSs?

NA

What is the domain: local, regional, national or international?

NA

How do you evaluate the DSS?

NA

Additional comments concerning DSSs.

No DSSs are applied by governmental agencies in relation to Offshore Windfarm Siting.

Which geological parameters / information layers do you deem relevant in relation to optimal offshore windfarm siting (3)?

Depth, Wind, Shipping lanes, Marine protected areas, distance to grid, shoreline visual effect, substrate, subsurface composition, thickness of unconsolidated sediments, geomorphology, lithology

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

GIS, EMODnet Central Portal

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to optimal offshore windfarm siting (4)?

NA

Are the parameters weighted and/or standardised. If so, how (4)?

The parameters are weighted

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

No

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

NA

Additional comments concerning DSTs and information layers / parameters.

NA

What outputs do you produce to evaluate the geology in relation to optimal offshore windfarm siting (5)? Why these outputs?

Geological maps

Do you have any experiences with indices as a measurement of the geology in relation to optimal offshore windfarm siting?

No

If yes! Please describe the indices.

NA

Additional comments concerning DSIs and other outputs.

NA

HSGME (Greece)

Do you or does your institute have expertise in DSS for evaluating the geology in relation to optimal offshore windfarm siting?

No

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

HEREMA (Hellenic Hydrocarbons and Energy Resources Management Company), contact@herema.gr

Which DSSs do you work with in projects concerning optimal offshore windfarm siting (1)?

NA

What is the purpose of the DSSs?

NA

What is the domain: local, regional, national or international?

NA

How do you evaluate the DSS?

NA

Additional comments concerning DSSs.

NA

Which geological parameters / information layers do you deem relevant in relation to optimal offshore windfarm siting (3)?

NA

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

NA

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to optimal offshore windfarm siting (4)?

NA

Are the parameters weighted and/or standardised. If so, how (4)?

NA

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

NA

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

NA

Additional comments concerning DSTs and information layers / parameters.

NA

What outputs do you produce to evaluate the geology in relation to optimal offshore windfarm siting (5)? Why these outputs?

NA

Do you have any experiences with indices as a measurement of the geology in relation to optimal offshore windfarm siting?

NA

If yes! Please describe the indices.

NA

Additional comments concerning DSIs and other outputs.

NA

LNEG (Portugal)

Do you or does your institute have expertise in DSS for evaluating the geology in relation to optimal offshore windfarm siting?

Yes

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

At LNEG we have expertise in Geology and Energy areas with experienced people in using support tools for siting of RES projects. In the Geology area we have Lidia Quental and Sílvia Nave and in the Energy Area we have Teresa Simões. Expertise is related with the several aspects of both mentioned areas and in the development of GIS methodologies to meet the siting objectives.

Which DSSs do you work with in projects concerning optimal offshore windfarm siting (1)?

For OWC siting we use essentially GIS (ArcGIS Pro or similar) and numerical tools for energy simulation according to the technology we wish to analyse. In some cases, MCDA analysis is also used, although for specific cases.

What is the purpose of the DSSs?

The purpose is mostly the identification of suitable areas for the installation of offshore Wind Turbines, considering the different type of technologies - fixed and floating foundations. Also, it is meant to estimate the offshore wind capacity that can be installed in the identified areas - Technical potential.

What is the domain: local, regional, national or international?

The teams have developed work for Regional, National and International domains.

How do you evaluate the DSS?

Each used tool in the DSS is validated whenever possible with experimental data. In the GIS the layers are carefully verified in what concerns the quality of the data and are cross checked against data from experimental campaigns whenever they are available. In addition, the data that is used on the DSS is provided by the competent authorities in the areas they represent and follow strict quality control rules. The final results obtained from the DSS are checked and compared to real case studies with similar characteristics.

Additional comments concerning DSSs.

No additional comments

Which geological parameters / information layers do you deem relevant in relation to optimal offshore windfarm siting (3)?

Bathymetry and type of seabed. Faults. Reef areas. Socioeconomic parameters such has tourism areas, visibility buffers representation, fisheries areas, aquaculture and other. Environmental protected areas. Military zones and navigation channels. Energy production and wind potential parameters (Energy, wind speed, Power density and weibull parameters for the height one wishes to perform the studies. Underground cables location. Hydrographic basins.

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

GIS for mapped information. Numerical models to generate energy parameters' layers. Excel or other similar software to build point layers when needed and process into the suitable formats.

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to optimal offshore windfarm siting (4)?

SIG (ArcGIS Pro, ESRI) or/and QGIS

Are the parameters weighted and/or standardised. If so, how (4)?

Yes, when applicable. We use GIS to make the necessary transformations to the different parameters.

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

No

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

In the work we have been developing, the methodologies have proved to be efficient to meet the objectives. However, it is a possibility that we can consider in the future.

Additional comments concerning DSTs and information layers / parameters.

No additional comments.

What outputs do you produce to evaluate the geology in relation to optimal offshore windfarm siting (5)? Why these outputs?

Seabed substrate, pre-quaternary geology, landslides, slopes, seabed dynamics, bathymetry and structures (faults, strike-slips,...). These parameters give a very good picture of the areas under analysis and are valuable informations for project phase. On the same way, bathymetry and type of seabed are crucial for decision making and for the type of technology that can be installed.

Do you have any experiences with indices as a measurement of the geology in relation to optimal offshore windfarm siting?

No

If yes! Please describe the indices.

NA

Additional comments concerning DSIs and other outputs.

Other conditionants/restrictions can be considered, especially those referred in line 10 of this questionnaire and that are related with submarine occurrences, like submarine cables, aquaculture structures, patrimony - archaeology and environmental, natural and artificial reefs, or similar. The impacts of climate changes are of high importance and can be subject to further analysis in the future. In addition, representation (map) of extreme winds is relevant for decision making in what concerns installation areas (and of course for risks assessment). In summary, climate changes and other extreme events (Tsunamis, for example) should be taken into account in the short-medium term on the DSS and related analysis.

ISOR (Iceland)

Do you or does your institute have expertise in DSS for evaluating the geology in relation to optimal offshore windfarm siting?

No

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

No, ISOR is working directly for the government with the MET-Office, the Road Administration, the Hydrographic Institute, the National Energy Authority of Iceland, the Natural History Institute, and the Environmental Institute to assess for the first time a general feasibility of offshore windfarming.

Which DSSs do you work with in projects concerning optimal offshore windfarm siting (1)?

We are working closely with the GSEU WP5.2 group, the BGS, and GEUS to develop a decision-making tool that is suitable for Iceland.

What is the purpose of the DSSs?

As a first path, define areas suitable for offshore wind farming in general. As a second path - define areas that have been flagged as generally ideal for the specific type of windfarming (soft sediment monopile, gravel pack, hardground, or floating platforms).

What is the domain: local, regional, national or international?

National (1st phase); Regional (2nd phase)

How do you evaluate the DSS?

Compare the GSEU system and published work / examples to the Icelandic setting and review with partners that have gone through that process already.

Additional comments concerning DSSs.

Through the collaboration of ISOR with the National Energy Authority of Iceland, it has become clear that we need to have clear regulations and decision flow paths established before any licensing for windfarm assessments can be issued.

Which geological parameters / information layers do you deem relevant in relation to optimal offshore windfarm siting (3)?

Water depth; substrate type; sediment thickness; coastal type; coastal dynamic changes; existing infrastructure (cables, pipelines, tunnels, air traffic); environmental protection areas; shipping lane; fishing grounds; other resource areas; high geo-risk areas (volcanism, tectonics, glacial floods, storm surges, etc.); weather conditions (wind, wave hight, sea ice, ocean currents).

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

For the national and large-scale assessment, consistent national datasets are: bathymetry for most area, substrate type, coastal type, geo-hazards, cables, ship traffic, protection areas, weather conditions.

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to optimal offshore windfarm siting (4)?

GIS map overlay and reporting, presentations.

Are the parameters weighted and/or standardised. If so, how (4)?

No

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

No

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

WE are working closely with the GSEU WP5.2 group, the BGS, and GEUS to develop a decision-making tool that is suitable for Iceland. Here specifically look into the risk map suggestions by BGS to use hexagons in GIS to define each risk and be able to calculate an overall risk to exclude areas, and highlight areas for windfarm suitability.

Additional comments concerning DSTs and information layers / parameters.

Early days for Iceland and we are right so starting to consider to implement DSS based on windfarm licencing decisions studies. This is not even getting close to siting decision making.

What outputs do you produce to evaluate the geology in relation to optimal offshore windfarm siting (5)? Why these outputs?

Parameter specific maps in GIS, and risk tables for a nationwide overview.

Do you have any experiences with indices as a measurement of the geology in relation to optimal offshore windfarm siting?

No

If yes! Please describe the indices.

NA

Additional comments concerning DSIs and other outputs.

We following to a large degree the windfarm siting and risking workflow by GSEU WP5.2

23. Annex VII – Part 2: Questionnaire Responses about DSSs, DSTs and DSIs

Decision Support Systems

Do you or does your institute have expertise in DSS for evaluating the geology in relation to optimal offshore windfarm siting?

AGS (Albania)
No
BRGM (France)
No
HGI-CGS (Croatia)
NO
RBINS-GSB (Belgium)
Yes
ICGC (Spain / Catalonia)
No
GSI (Ireland)
Yes
GeoZS (Slovenia)
No
ISPRA (Italy)
No
GTK (Finland)
No
GSD (Cyprus)
no
GEUS (Denmark)
No
HSGME (Greece)
No
LNEG (Portugal)
Yes
ISOR (Iceland)
No

If yes! Who is the contact person? What is the field?

If no! Are you aware of any other institutes in your country working with DSS / DSI? If yes! Who is the contact person? What is the field?

AGS (Albania)

No we are not aware of other institution

BRGM (France)

In France, we are in contact with people working on offshore windfarm sitting in these structures:

- Cerema => Neil ALLONCLE (Neil.alloncle@cerema.fr / Head of maritime and coastal planning in Cerema)
- France Energies Marines (https://www.france-energies-marines.org/) => Maëlle NEXER (maelle.nexer@france-energies-marines.org) or contact (contact@france-energies-marines.org)
- Shom (French hydrographic office) => Aurélien GANGLOFF (aurelien.gangloff@shom.fr)

Some websites of interest :

- https://www.eoliennesenmer.fr/ (Cerema) ; https://www.eoliennesenmer.fr/observatoire/presentation
- projects SIMCELT (https://maritime-spatial-planning.ec.europa.eu/projects/supporting-implementation-maritime-spatial-planning-celtic-seas ; https://www.marei.ie/project/simcelt/), SIMNORAT, SIMWESTMED, etc. (Shom ; https://www.shom.fr/fr/liste-actualites/europe-le-shom-partenaire-des-projets-med-osmosis-et-msp-med) => link to the Strategic Façade Documents

HGI-CGS (Croatia)

NA

RBINS-GSB (Belgium)

Vera Van Lancker (vvanlancker@naturalsciences.be); Lars Kint (lkint@naturalsciences.be)

Subsurface lithology and geology in the Belgian part of the North Sea (Hademenos et al. 2018) + Uncertainty assessment (Kint et al. 2020)

ICGC (Spain / Catalonia)

No, i'm not aware of any.

GSI (Ireland)

Jo Coloe, Offshore Energy, Department of the Environment, Climate and Communications jo.coloe@decc.gov.ie; Eoin Mac Craith eoin.maccraith@gsi.ie

GeoZS (Slovenia)

We are not aware

ISPRA (Italy)

No

GTK (Finland)

We have expertise in geology at GTK, but not in DSS's regarding offshore windfarm siting. In Finland, decision support systems (DSSs) and tools for offshore wind farm siting are primarily used within the frameworks of Marine Spatial Planning (MSP), environmental impact assessments (EIA), and strategic planning initiatives. These systems integrate data on environmental, social, and economic factors to identify suitable areas for offshore wind farms. Regarding MSPs, Regional Councils are responsible for preparing and implementing MSPs at the regional level in Finland. Ministry of the Environment oversees MSP processes and ensures alignment with national and EU-level strategies. Finnish Environment Institute (SYKE) provide scientific support and data for MSP processes. ELY Centres (Centres for Economic Development, Transport and the Environment) are responsible for coordinating and reviewing EIA processes for offshore projects. Metsähallitus is responsible for site selection in government-owned sea areas within the territorial waters of Finland.

GSD (Cyprus)
no
GEUS (Denmark)
NA
HSGME (Greece)
HEREMA (Hellenic Hydrocarbons and Energy Resources Management Company), contact@herema.gr
LNEG (Portugal)
At LNEG we have expertise in Geology and Energy areas with experienced people in using support tools for siting of RES projects. In the Geology area we have Lidia Quental and Sílvia Nave and in the Energy Area we have Teresa Simões. Expertise is related with the several aspects of both mentioned areas and in the development of GIS methodologies to meet the siting objectives.
ISOR (Iceland)
No, ISOR is working directly for the government with the MET-Office, the Road Administration, the Hydrographic Institute, the National Energy Authority of Iceland, the Natural History Institute, and the Environmental Institute to assess for the firat time a general feasibility of offshore windfarming.

Which DSSs do you work with in projects concerning optimal offshore windfarm siting (1)?

AGS (Albania)
we don't have
BRGM (France)
We help provide data (bathymetry, geological maps, structural geology, seismic data) for projects at potential/planned sites in France.
(contact for BRGM : Fabien PAQUET (f.paquet@brgm.fr ; involved in WP5.2)
HGI-CGS (Croatia)
NA
RBINS-GSB (Belgium)
TILES DSS (http://www.bmdc.be/tiles-dss/) Currently not available
ICGC (Spain / Catalonia)
None
GSI (Ireland)
An online, map-based interface (GIS Viewer and dashboard)
GeoZS (Slovenia)
NA
ISPRA (Italy)
Marine Spatial Planning (MSP) frameworks (Azzellino et al., 2013);
GTK (Finland)
GTK has done commissioned surveys and provided geological information on seabed surface and subsurface composition and structures for some OWF planning companies including Metsähallitus.
GSD (Cyprus)
NA
GEUS (Denmark)
NA
HSGME (Greece)
NA

LNEG (Portugal)

For OWC siting we use essencially GIS (ArcGIS Pro or similar) and numerical tools for energy simulation according to the technology we wish to analyse. In some cases, MCDA analysis is also used, although for specific cases.

ISOR (Iceland)

We are working closely with the GSEU WP5.2 group, the BGS, and GEUS to develope a decision-making tool that is suitable for Iceland.

What is the purpose of the DSSs?

AGS (Albania)

we don't have

BRGM (France)

/

HGI-CGS (Croatia)

NA

RBINS-GSB (Belgium)

A decision support application opens up the voxel model for specific requests on lithology, geology and uncertainty information in areas of interest in the Belgian part of the North Sea.

ICGC (Spain / Catalonia)

NA

GSI (Ireland)

This viewer will make available data which provides value in the (DMAP) decision-making process and in future ORESS auctions and related/supporting spatial marine data/information.

GeoZS (Slovenia)

NA

ISPRA (Italy)

To identify optimal locations for offshore windfarms while minimizing environmental and socio-economic impacts.

GTK (Finland)

Finland's MSP processes include frameworks that integrate multi-use considerations and zoning for offshore activities, including wind energy. The MSP system incorporates ecological values, shipping routes, fisheries, and biodiversity protection zones. GIS-based tools are commonly used to visualize and analyze spatial data, ensuring compatibility of offshore wind farm locations with other marine uses. EIA processes are mandatory for OWF projects in Finland. These assessments rely on DSS elements to evaluate potential impacts on marine ecosystems including the seabed, bird and fish populations, and coastal habitats. Tools for cumulative impact assessment are also used to consider combined effects of multiple wind farms or other marine activities

GSD (Cyprus)

NA

GEUS (Denmark)

NA

HSGME (Greece)

NA

LNEG (Portugal)
The purpose is mostly the identification of suitable areas for the instalation of offshore Wind Turbines, considering the different type of technologies - fixed and floating foundations. Also, it is meant to estimate the offshore wind capacity that can be installed in the identified areas - Technical potential.
ISOR (Iceland)
As a first path, define areas suitable for offshore wind farming in general. As a second path - define areas that have been flagged as generally ideal for the specific type of windfarming (soft sediment monopile, gravel pack, hardground, or floating platforms).

What is the domain: local, regional, national or international?

AGS (Albania)
we don't have
BRGM (France)
at local, regional ou national scales
RBINS-GSB (Belgium)
National
ICGC (Spain / Catalonia)
NA
GSI (Ireland)
National
GeoZS (Slovenia)
NA
ISPRA (Italy)
Regional
GTK (Finland)
For MSPs - regional, for EIAs - (inter)national (if close to borders*)/regional/local
GSD (Cyprus)
NA
GEUS (Denmark)
NA
HSGME (Greece)
NA
LNEG (Portugal)
The teams have developed work for Regional, National and International domains.
ISOR (Iceland)
National (1st phase); Regional (2nd phase)

How do you evaluate the DSS?

AGS (Albania)
we don't have
BRGM (France)
/

HGI-CGS (Croatia)

NA

RBINS-GSB (Belgium)

Easy querrying, visualisation and download of 3D subsurface sediments for areas of interest in the Belgian part of the North Sea.

ICGC (Spain / Catalonia)

NA

GSI (Ireland)

Stakeholder workshops with feedback

GeoZS (Slovenia)

NA

ISPRA (Italy)

NA

GTK (Finland)

MSPs are evaluated based on the public consultations on the planned proposals.

GSD (Cyprus)

NA

GEUS (Denmark)

NA

HSGME (Greece)

NA

LNEG (Portugal)

Each used tool in the DSS is validated whenever possible with experimental data. In the GIS the layers are carefully verified in what concerns the quality of the data and are cross checked against data from experimental campaigns whenever they are available. In addition the data that is used on the DSS is provided by the competent authorities in the areas they represent and follow strict quality control rules. The final results obtained from the DSS are checked and compared to real case studies with similar characteristics.

ISOR (Iceland)

Compare the GSEU system and published work / examples to the Icelandic setting and review with partners that have gone through that process already.

Additional comments concerning DSSs.

AGS (Albania)

we don't have

BRGM (France)

To be checked: we don't know whether these are actually DSS that have been set up, or whether they are simply interactive maps / GIS tools that display the various activities and data sets available in the areas concerned.

HGI-CGS (Croatia)

NA

RBINS-GSB (Belgium)

Long-term support and maintenance of a DSS is needed through long-term or updated coding language, software, etc.

ICGC (Spain / Catalonia)

NA

GSI (Ireland)

Would like further iterations to potentially develop into a cumulative effects/ weighting framework/tool

GeoZS (Slovenia)

NA

ISPRA (Italy)

NA

GTK (Finland)

*) Espoo Convention

GSD (Cyprus)

NA

GEUS (Denmark)

No DSSs are applied by governmental agencies in relation to Offshore Windfarm Siting.

HSGME (Greece)

NA

LNEG (Portugal)

No additional comments

ISOR (Iceland)

Through the collaboration of ISOR with the National Energy Authority of Iceland, it has become clear that we need to have clear regulations and decision flow pathes established before any licensing for windfarm assessments can be issued.

Decision Support Tools and parameters

Which geological parameters / information layers do you deem relevant in relation to optimal offshore windfarm siting (3)?

AGS (Albania)

The depth of the sea is the parameter that indicates , and we have a key study zone where it can be an offshore windfarm , The Cape of Rodon, North West Adriatic Sea

BRGM (France)

- nature of the seabed (rocky/soft), bathymetry, marine sediments, marine dune dynamics => Shom
- marine seismic data (faults, etc.), geological maps, structural geology => BRGM

HGI-CGS (Croatia)

lithology, geomorphology, distance to the coast, bathymetry, sediment distribution, subsurface data

RBINS-GSB (Belgium)

Manual TILES dss (2020):

- Most common lithological classes
- Heterogeneity of the lithological class
- (average) probability
- (average) entropy
- Most common lithostratigraphy
- (average) borehole density
- (average) percentage of the lithological class
- (average) quality

ICGC (Spain / Catalonia)

Bathymetry

GSI (Ireland)

Administrative (anchorage areas, pilot boarding locations and restricted areas), Aquaculture, Aviation – interference with flight radars, Commercial fisheries, Designated sites – European sites, Ramsar, UNESCO, NHAs, Fish and shellfish, Industrial – shoreline construction, commercial fishing and harbour facilities, and offshore piles, Marine habitats, Marine historic environment, Marine infrastructure – oil and gas pipelines, submarine cables, Marine mammals, Military, Obstructions and wrecks, Ornithology & bats, Seascape and landscape, Shipping and navigation, Tourism and recreation, Biodiversity, Bathymetry, Seismic activity, Type of ground condition, Significant wave height, Tidal currents, Extreme wind gust & mean wind speed, Submarine cables, LCOE, Military practice, danger and other no-go areas, Location of oil and gas activity, Aggregate and material extraction areas, Underwater archaeology – UXO, Pipelines, Ports, piers, marinas, Population and human health, Cultural heritage, Tourism and recreation, Archaeological heritage, Rivers and lakes

GeoZS (Slovenia)

NA

ISPRA (Italy)

Bathymetry (depth variations)

GTK (Finland)

Seabed surface and subsurface composition and structures, geological parameters derivated from geological interpretations include e.g., thickness of unconsolidated sediments, depth of the bedrock surface, thickness of soft sediments, depth of the hard substrate.

GSD (Cyprus)

NA

GEUS (Denmark)

Depth, Wind, Shipping lanes, Marine protected areas, distance to grid, shoreline visual effect, substrate, subsurface composition, thickness of unconsolidated sediments, geomorphology, lithology

HSGME (Greece)

NA

LNEG (Portugal)

Bathymetry and type of seabed. Faults. Reef areas. Socioeconomic parameters such has tourism areas, visibility buffers representation, fisheries areas, aquaculture and other. Environmental protected areas. Military zones and navigation channels. Energy production and wind potential parameters (Energy, wind speed, Power density and weibull parameters for the height one whishes to perform the studies. Underground cables location. Hydrographic basins.

ISOR (Iceland)

Water depth; substrate type; sediment thickness; coastal type; coastal dynamic changes; existing infrastructure (cables, pipelines, tunnels, air traffic); environmental protection areas; shipping lane; fishing grounds; other resource areas; high geo-risk areas (volcanism, tectonics, glacial floods, storm surges, etc.); weather conditions (wind, wave hight, sea ice, ocean currents).

Which DSTs do you use to process already existing data or newly gathered data to extract relevant parameters (2)? And which parameters are extracted with the given DSTs (3)?

AGS (Albania)

we don't use DST

BRGM (France)

/

HGI-CGS (Croatia)

NONE

RBINS-GSB (Belgium)

De Tré et al. (2018): "Geographic MCDM relies on the availability of several IT components, including databases and other data resources, a data integration component, a decision support tool and a visualization tool. Data from different sources are used for evaluating the decision criteria. In a first step, each data source is subject to a kind of Extract, Transform and Load (ETL) process, which extracts the relevant data from the source, transforms it into the correct format and prepares it as input for the decision support tool. For main data sources that do not change often, like 3D lithological classification models, ETL is done in advance. In the next step, the integrated input data are processed by the decision support tool. In TILES, an LSP-based approach is used for the computation of suitability degrees for a 3D suitability model. This model is enriched with metadata expressing the confidence that experts have in the computed suitability degrees. The enriched suitability model is loaded into dedicated visualization software for easily accessible presentation to the decision-maker."

De Tré et al. (2018):"The simplified attribute tree shown emphasizes that for a marine exploitation decision (root node), one has to consider data that are related to the lithology, bathymetry, ecology, restricted areas and locations of shipwrecks. As a measure of lithology, the probabilities for different kinds of sediment (in the example limited to fine sand, coarse sand and clay) are considered. A restricted area can be a military zone or an area where power supplies, pipelines or telecommunication lines are located."

ICGC (Spain / Catalonia)

NA

GSI (Ireland)

Currently marineplan.ie is the DST used for general marine spatial planning, the tool in process will be specifically for ORE.

GeoZS (Slovenia)

NA

ISPRA (Italy)

GTK (Finland)

We do not actually make OWF siting at GTK. However, we consider following DST's useful: GIS Desktop. For parameters that have been used by others in Finland see e.g. Virtanen et al. 2022. Unfortunately the (full coverage) seabed geological parameters were missing/not available that time.

GSD (Cyprus)

NA

GEUS (Denmark)

GIS, EMODnet Central Portal

HSGME (Greece)

NA

LNEG (Portugal)

GIS for mapped information. Numerical models to generate energy parameters' layers. Excel or other similar software to build point layers when needed and process into the suitable formats.

ISOR (Iceland)

For the national and large scale assessment, consistent national datasets are: bathymetry for most area, substrate type, coastal type, geo-hazards, cables, ship traffic, protection areas, weather conditions.

When all relevant parameters are gathered what tools do you then use to analyse / evaluate the geology in relation to optimal offshore windfarm siting (4)?

AGS (Albania)

We use ARCH GIS

BRGM (France)

GIS tools (ArcGIS, QGIS, and so on), where all available information can be viewed: geology, tides, winds, currents, swell, environmental restrictions (regulatory zones), birdlife (migratory corridors), benthic habitats, shipping lanes and fisheries, etc.

HGI-CGS (Croatia)

ArcGIS

RBINS-GSB (Belgium)

De Tré et al. (2018): "In our previous research, we studied 2D suitability maps constructed using the LSP approach [16]. In this work, we used the same technique to create 3D suitability models, as depicted in Fig. 3. It entails a three-step method consisting of (1) elementary attribute selection, (2) elementary criteria specification and evaluation and (3) aggregation."

Other: Geographical Information System (ArcGIS, QGIS, etc.)

ICGC (Spain / Catalonia)

NA

GSI (Ireland)

Geology evaluated by industry at auction stage

GeoZS (Slovenia)

NA

ISPRA (Italy)

NA

GTK (Finland)

Zonation Software is widely applied in Finland for prioritizing areas for conservation or development. This tool helps identify suitable sites for offshore wind farms by balancing ecological sensitivity and development goals (Virtanen et al. 2022). Unfortunately the (full coverage) seabed geological parameters were missing/not available that time.

GSD (Cyprus)

NA

GEUS (Denmark)

NA

HSGME (Greece)

NA

LNEG (Portugal)

SIG (ArcGisPro, ESRI) or/and QGIS

ISOR (Iceland)

GIS map overlay and reporting, presentations.

Are the parameters weighted and/or standardised. If so, how (4)?

AGS (Albania)

Yes the parametrs are standarised by our institution

BRGM (France)

/

HGI-CGS (Croatia)

NO

RBINS-GSB (Belgium)

Yes, in the creation of the sediment dataset, the voxel model and the DSS of the subsurface of the Belgian part of the North Sea.

Kint et al. (2020): "Lithological data and associated metadata were harmonized and standardized to facilitate the generation of seamless seabed maps (Van Lancker and van Heteren 2013) following internationally proposed or agreed guidelines (e.g. Geo-Seas for geological and geophysical data (van Heteren 2010), SeaDataNet for oceanographic data, and INSPIRE for spatial information). To ensure machine-readability, interoperability and compatibility of the data, lithological descriptions available as text were transferred to code.

Hademenos et al. (2018): "To model offshore aggregate resources, amethodological workflow was developed based on the voxel modelling approach of Stafleu et al. (2011) and expanded with seismic data. It comprises the following steps: (1a) Standardisation and lithological classification of borehole descriptions; (1b, 3) Delineation of seismic acoustic facies and their seismostratigraphical interpretation; (2) Stratigraphic interpretation of the boreholes; (4) Construction of the 2D stratigraphical layer model; (5) Assignment of lithostratigraphical units to the 3D voxel model; (6) 3D interpolation of lithological class within each lithostratigraphical unit; (7) Assessment of the information entropy of the model."

De Tré et al. (2018): "A scientific solution for data quality assessment using (geographic) multi-criteria decision-making based on LSP suitability models relies on the identification and specification of elementary data quality aspects for the elementary attributes that are involved in the decision-making process. For each elementary data quality aspect, a corresponding elementary quality criterion is specified. Evaluation of these elementary quality criteria for a given voxel in a geographical voxel space yields elementary confidence scores for that voxel. These elementary confidence scores are then aggregated to an overall confidence degree by applying a novel, extended version of the LSP aggregation structure. Every LSP aggregator is extended so that it takes both suitability degrees and confidence degrees as arguments and computes a couple that consists of an aggregated suitability degree and an aggregated confidence degree. The aggregated suitability degree is computed in exactly the same way as in regular suitability modelling. For the aggregated confidence degree, a weighted sum of the input confidence degrees is computed, with the weights reflecting the impact of the corresponding input suitability degrees on the computation of the aggregated suitability degree. In our future research, we aim to study alternatives for the weighted sum aggregation in order to further improve the semantic properties of the aggregation, so that this aggregation even better reflects and complements expert reasoning."

ICGC (Spain / Catalonia)

No

GSI (Ireland)

No but propose to down the line with this ORE digital tool.

GeoZS (Slovenia)

NA

ISPRA (Italy)

GTK (Finland)

For parameters see e.g., Virtanen et al. 2022

GSD (Cyprus)

NA

GEUS (Denmark)

The parameters are weighted

HSGME (Greece)

NA

LNEG (Portugal)

Yes when applicable. We use GIS to make the necessary transformations to the different parameters.

ISOR (Iceland)

No

Do you apply Artificial Neural Networks or a Bayesian Network in your analyses?

AGS (Albania)

No we don't apply

BRGM (France)

/

HGI-CGS (Croatia)

NO

RBINS-GSB (Belgium)

Yes

ICGC (Spain / Catalonia)

No

GSI (Ireland)

No

GeoZS (Slovenia)

NA

ISPRA (Italy)

NA

GTK (Finland)

No

GSD (Cyprus)

NA

GEUS (Denmark)

No

HSGME (Greece)

NA

LNEG (Portugal)

No

ISOR (Iceland)

No

If yes! How and with what objective?

If no! Have you considered using one of the beforementioned tools and what stopped you from applying them?

AGS (Albania)

No we have not considered yet

BRGM (France)

/

HGI-CGS (Croatia)

NA

RBINS-GSB (Belgium)

De Mol (2019): "In the Bayesian interpretation (based on Bayes' theory of Bayesian inference but actually pioneered by Laplace), probability is a subjective indicator of belief. Different agents might assign different probabilities to different outcomes and there is no reason for someone to believe one agent over the other. Bayesian probabilities further also rely on the assumption that agents are perfectly rational [3, 21], though evidence has shown that this claim is doubtful [17]. This interpretation is often applied in the context of betting games, to set payout rates for outcomes in correspondence to their perceived probability of occurring, which is immediate evidence that perceived probabilities can be used to turn a profit and are not necessarily fair. Au contraire, this interpretation relies on the idea that the true likeliness of the outcomes can be hidden behind slightly manipulated probabilities in order to trick gamblers into entering an unfair game, the lottery being a prime example thereof.

ICGC (Spain / Catalonia)

NA

GSI (Ireland)

Considering for the future - time and resources would delay this phase

GeoZS (Slovenia)

NA

ISPRA (Italy)

NA

GTK (Finland)

NA

GSD (Cyprus)

NA

GEUS (Denmark)

NA

HSGME (Greece)

NA

LNEG (Portugal)

In the work we have been developing, the methodologies have proved to be efficicient to meet the objectives. However, it is a possibility that we can consider in the future.

ISOR (Iceland)

WE are working closely with the GSEU WP5.2 group, the BGS, and GEUS to develope a decision-making tool that is suitable for Iceland. Here specifically look into the the risk map suggestions by BGS to use hexagons in GIS to define each risk and be able to calculate an overall risk to exclude areas, and highlight areas for windfarm suitability.

Additional comments concerning DSTs and information layers / parameters.

AGS (Albania)

-

BRGM (France)

/

HGI-CGS (Croatia)

NA

RBINS-GSB (Belgium)

-

ICGC (Spain / Catalonia)

NA

GSI (Ireland)

NA

GeoZS (Slovenia)

NA

ISPRA (Italy)

NA

GTK (Finland)

E.A. Virtanen, J. Lappalainen, M. Nurmi, M. Viitasalo, M. Tikanmäki, J. Heinonen, E. Atlaskin, M. Kallasvuo, H. Tikkanen, A. Moilanen, 2022. Balancing profitability of energy production, societal impacts and biodiversity in offshore wind farm design. Renewable and Sustainable Energy Reviews, 158, 2022, 112087, https://doi.org/10.1016/j.rser.2022.112087.

GSD (Cyprus)

NA

GEUS (Denmark)

NA

HSGME (Greece)

NA

LNEG (Portugal)

No additional comments.

ISOR (Iceland)

Early days for Iceland and we are right so starting to consider to implement DSS based on windfarm licencing decisions studies. This is not even getting close to siting decision making.

Decision Support Indices and other outputs

What outputs do you produce to evaluate the geology in relation to optimal offshore windfarm siting (5)? Why these outputs?

AGS (Albania)

We produce datas for the depth of the shelf and we evaluate the zone which it complete the conditions for building offshore windfarms

BRGM (France)

/

HGI-CGS (Croatia)

None. We so far have no expirience in offshore windfarm siting.

RBINS-GSB (Belgium)

De Tré et al. (2018): "Key to the decision support tool used in TILES is the creation of 3D suitability models. As input, a 3D voxel model of the subsurface of the Belgian part of the North Sea is being constructed. Each voxel is currently fixed in size (length and width 200 m, height 1 m). The model currently includes voxels that range from 4 m above mean sea level to 75 m below it.

Van Lancker et al. (2019): "Main DSS attributes relate to the integrated data, information and knowledge, the 3D geological models and some first output from 4D process models. Advanced criteria-evaluation techniques were developed to support the construction of specialized geographical maps of the sea region under investigation. Such maps, hereafter called 'suitability maps', are able to show geological boundaries, distributions of particular resource qualities, and the resource estimation at various cut-off grades, all calculated in a time-efficient manner encouraging online use of the tool. Additionally, user functions of the BPNS, as available from the Marine Atlas (Belgian Marine Data Centre), were incorporated: infrastructure (e.g. pipelines; electricity and telecommunication cables; windmills; navigation routes), human activity (e.g. tourism, safety), legal status (e.g. areas reserved for special activities), economic development (e.g. expansion of industries). A user can make dynamically a series of tailor-made suitability maps that assist in resource assessments."

ICGC (Spain / Catalonia)

Bathymetry

GSI (Ireland)

Government-led geophysical surveys provide data to industry

GeoZS (Slovenia)

NA

ISPRA (Italy)

Vulnerability maps based on Environmental Impact Indices

GTK (Finland)

We do not actually make OWF siting at GTK. However, GTK has done commissioned surveys and provided geological information on seabed surface and subsurface composition and structures for OWF planning companies including Metsähallitus. GTK provides geological data at different scales for e.g. background information and OWF siting studies.

GSD (Cyprus)

Key geological outputs for offshore windfarm siting:
Bathymetric maps: Map seafloor depth for suitable water depth.
Seabed sediment maps: Identify foundation suitability and scour risks.

Geological surveys: Assess subsurface geology for foundation stability and potential hazards.
Geophysical surveys: Map subsurface structures for cable routing and obstacle identification.
Environmental Impact Assessments (EIAs): Evaluate environmental impacts and ensure sustainable development.

Why these outputs?
Bathymetry: Ensures sufficient water depth.
Seabed sediment: Determines foundation type and scour risks.
Geology: Assesses foundation stability and potential hazards.
Geophysics: Identifies obstacles and suitable cable routes.
EIAs: Mitigates environmental impacts.
Combining these outputs helps identify optimal sites for offshore wind farms.

GEUS (Denmark)

Geological maps

HSGME (Greece)

NA

LNEG (Portugal)

Seabed substrate, pre-quaternary geology, landslides, slopes, seabed dynamics, bathymetry and structures (faults, strike-slips,...). These parameters give a very good picture of the areas under analysis and are valuable informations for project phase. On the same way, bathymetry and type of seabed are crutial for decision making and for the type of technology that can be installed.

ISOR (Iceland)

Parameter specific maps in GIS, and risk tables for a nationawide overview.

Do you have any experiences with indices as a measurement of the geology in relation to optimal offshore windfarm siting?

AGS (Albania)

No we have some datas but not something completed

BRGM (France)

/

HGI-CGS (Croatia)

NO

RBINS-GSB (Belgium)

-

ICGC (Spain / Catalonia)

No

GSI (Ireland)

No

GeoZS (Slovenia)

NA

ISPRA (Italy)

NA

GTK (Finland)

Yes

GSD (Cyprus)
no
GEUS (Denmark)
No
HSGME (Greece)
NA
LNEG (Portugal)
No
ISOR (Iceland)
No

If yes! Please describe the indices.
AGS (Albania)
-
BRGM (France)
/
HGI-CGS (Croatia)
NA
RBINS-GSB (Belgium)
-
ICGC (Spain / Catalonia)
NA
GSI (Ireland)
NA
GeoZS (Slovenia)
NA
ISPRA (Italy)
NA
GTK (Finland)
Besides parameters mentioned above, Geodiversity index is one of the indices developed and provided by GTK (e.g. Kaskela & Kotilainen, 2017).
GSD (Cyprus)
NA
GEUS (Denmark)
NA
HSGME (Greece)
NA
LNEG (Portugal)
NA
ISOR (Iceland)
NA
Additional comments concerning DSIs and other outputs.

AGS (Albania)

-

BRGM (France)

/

HGI-CGS (Croatia)

NA

RBINS-GSB (Belgium)

-

ICGC (Spain / Catalonia)

NA

GSI (Ireland)

NA

GeoZS (Slovenia)

NA

ISPRA (Italy)

NA

GTK (Finland)

Kaskela, A.M., Kotilainen, A.T., 2017. Seabed geodiversity in a glaciated shelf area, the Baltic Sea. Geomorphology, 295, 419–435.

GSD (Cyprus)

NA

GEUS (Denmark)

NA

HSGME (Greece)

NA

LNEG (Portugal)

Other conditionants/restrictions can be considered, especially those referred in line 10 of this questionnaire and that are related with submarine occurences, like submarine cables, aquaculture structures, patrimony - archaelogy and environmental, natural and artificial reefs, or similar. The impacts of climate changes are of high importance and can be subject to further analysis in the future. In addition, representation (map) of extreme winds is relevant for decision making in what concerns installation areas (and of course for risks assessment). In summary, climate changes and other extreme events (Tsunamis, for example) should be taken into account in the short-medium term on the DSS and related analysis.

ISOR (Iceland)

We following to a large degree the windfarm siting and risking workflow by GSEU WP5.2

24. Part 1 – References

Aucelli, P. P. C., Di Paola, G., Rizzo, A., & Rosskopf, C. M. (2018). Present day and future scenarios of coastal erosion and flooding processes along the Italian Adriatic coast: The case of Molise region. Environmental Earth Sciences, 77(10), 1–19. https://doi.org/10.1007/s12665-018-7535-y

Barzehkar, M., Parnell, K.E., Soomere, T., Dragovich, D., Engström, J. (2021), Decision support tools, systems and indices for sustainable coastal planning and management: A review. Ocean and Coastal Management 212.

Barzehkar, M., Parnell, K., & Soomere, T. (2025). Incorporating a machine learning approach into an established decision support system for coastal vulnerability in the Eastern Baltic Sea. Journal of Coastal Research, 113(sp1), 58–62. https://doi.org/10.2112/JCR-SI113-012.1

British Geological Survey. (2022). User guide: BGS GeoCoast V1. British Geological Survey Open Report, OR/21/001, 48pp.

Bruno, M. F., Saponieri, A., Molfetta, M. G., & Damiani, L. (2020). The DPSIR approach for coastal risk assessment under climate change at regional scale: The case of Apulian coast (Italy). Journal of Marine Science and Engineering, 8(7), 531. https://doi.org/10.3390/jmse8070531

Bulteau, T., Baills, A., Petitjean, L., Garcin, M., Palanisamy, H., & Le Cozannet, G. (2015). Gaining insight into regional coastal changes on La Réunion island through a Bayesian data mining approach. Geomorphology, 228(228), 134–146. https://doi.org/10.1016/j.geomorph.2014.09.002

Coelho, C., Narra, P., Marinho, B., & Lima, M. (2020). Coastal management software to support the decision-makers to mitigate coastal erosion. Journal of Marine Science and Engineering, 8(1), 37. https://doi.org/10.3390/jmse8010037

Davies, W. T. R. (2012). Applying a coastal vulnerability index (CVI) to the Westfjords, Iceland: A preliminary assessment. (MSc thesis). University of Akureyri, Ísafjörður.

De Mol, R., De Tré, G., Pelta, D. A., Cabrera, I. P., Verdegay, J. L., Yager, R. R., Ojeda-Aciego, M., Medina, J., Bouchon-Meunier, B., & Cabrera, I. P. (2018). Applying suitability distributions in a geological context. In Information Processing and Management of Uncertainty in Knowledge-Based Systems. Theory and Foundations (Vol. 853, pp. 278–288). Springer International Publishing. https://doi.org/10.1007/978-3-319-91473-2_24

De Serio, F., Armenio, E., Mossa, M., & Petrillo, A. F. (2018). How to define priorities in coastal vulnerability assessment. Geosciences, 8(11), 415. https://doi.org/10.3390/geosciences8110415

De Tré, G., De Mol, R., van Heteren, S., Stafleu, J., Chademenos, V., Missiaen, T., Kint, L., Terseleer, N., Van Lancker, V., Carrara, P., & Bordogna, G. (2018). Data quality assessment in volunteered geographic decision support. In Mobile Information Systems Leveraging Volunteered Geographic Information for Earth Observation (Vol. 4, pp. 173–192). Springer International Publishing. https://doi.org/10.1007/978-3-319-70878-2_9

Di Luccio, D., Aucelli, P. P. C., Di Paola, G., Pennetta, M., Berti, M., Budillon, G., Florio, A., & Benassai, G. (2023). An integrated approach for coastal cliff susceptibility: The case study of Procida Island (southern Italy). Science of the Total Environment, 855, 158759. https://doi.org/10.1016/j.scitotenv.2022.158759

Durap, A. (2024). Mapping coastal resilience: A GIS-based Bayesian network approach to coastal hazard identification for Queensland's dynamic shorelines. Anthropocene Coasts, 7(1). https://doi.org/10.1007/s44218-024-00060-y

Furlan, E., Pozza, P. D., Michetti, M., Torresan, S., Critto, A., & Marcomini, A. (2021). Development of a multi-dimensional coastal vulnerability index: Assessing vulnerability to inundation scenarios in the Italian coast. Science of the Total Environment, 772, 144650. https://doi.org/10.1016/j.scitotenv.2020.144650

Göke, C., Dahl, K., & Mohn, C. (2018). Maritime spatial planning supported by systematic site selection: Applying Marxan for offshore wind power in the western Baltic Sea. PLoS ONE, 13(3), e0194362. https://doi.org/10.1371/journal.pone.0194362

Hademenos, V., Stafleu, J., Missiaen, T., Kint, L., & Van Lancker, V. R. M. (2019). 3D subsurface characterisation of the Belgian Continental Shelf: A new voxel modelling approach. Netherlands Journal of Geosciences, 98. https://doi.org/10.1017/njg.2018.18

Haryani, D., Pitandovo, A. B., & Nugroho, L. E. (2024). A QGIS-based information system for the coastal vulnerability classification with ANN method. 2024 10th International Conference on Smart Computing and Communication (ICSCC), 33–38. https://doi.org/10.1109/ICSCC62041.2024.10690739

Hinkel, J.; Nicholls, R.J.; Tol, R.S.J.; Wang, Z.B.; Hamilton, J.M.; Boot, G.; Vafeidis, A.T.; McFadden, L.; Ganopolski, A.; Klein, R.J.T. (2013), A global analysis of erosion of sandy beaches and sea-level rise: An application of DIVA. Glob. Planet. Change, 111, 150–158.

IPCC. (2021). Climate Change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M. I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J. B. R., Maycock, T. K., Waterfield, T., Yelekçi, O., Yu, R., & Zhou, B. (Eds.)]. Cambridge University Press. https://doi.org/10.1017/9781009157896

Jäger, W. S., Christie, E. K., Hanea, A. M., den Heijer, C., & Spencer, T. (2018). A Bayesian network approach for coastal risk analysis and decision making. Coastal Engineering, 134, 48–61. https://doi.org/10.1016/j.coastaleng.2017.05.004

Jemec Auflič, M., Šinigoj, J., Krivic, M., Podboj, M., Peternel, T., & Komac, M. (2016). Landslide prediction system for rainfall-induced landslides in Slovenia. MaspreM Geologija, 59(2), 259–271.

Jenkins, G. O., Mee, K., Richardson, J. F. M., Lee, K. A., Westhead, R. K., Carter, G. D. O., & Hurst, M. D. (2016). User guide BGS Coastal Vulnerability Index version 1. British Geological Survey, OR/16/039, 16pp.

Kint, L., Hademenos, V., De Mol, R., Stafleu, J., van Heteren, S., & van Lancker, V. (2021). Uncertainty assessment applied to marine subsurface datasets. Quarterly Journal of Engineering Geology and Hydrogeology, 54(1), 1–. https://doi.org/10.1144/qjegh2020-028

Komac, M., Jež, J., Dang, K., Sassa, K., Arbanas, Ž., Yamagishi, H., McSaveney, M., Casagli, N., & Guzzetti, F. (2018). TXT-tool 1.386-2.1 Landslide Susceptibility Assessment Method. In Landslide Dynamics: ISDR-ICL Landslide Interactive Teaching Tools (pp. 133–138). Springer International Publishing AG. https://doi.org/10.1007/978-3-319-57774-6_9

Nourdi, N. F., Raphael, O., Achab, M., Loudi, Y., Rudant, J.-P., Minette, T. E., Kambia, P., Claude, N. J., & Romaric, N. (2024). Integrated Assessment of Coastal Vulnerability in the Bonny Bay: A Combination of Traditional Methods (Simple and AHP) and Machine Learning Approach. Estuaries and Coasts, 47(8), 2670–2695. https://doi.org/10.1007/s12237-024-01362-7

Pagano, M., Fernetti, M., Busetti, M., Ghribi, M., & Camerlenghi, A. (2023). Multicriteria GIS-based analysis for the evaluation of the vulnerability of the marine environment in the Gulf of Trieste (north-eastern Adriatic Sea) for sustainable blue economy and maritime spatial planning. People and Nature, 5(6), 2006–2025. https://doi.org/10.1002/pan3.10537

Pantusa, D., D'Alessandro, F., Frega, F., Francone, A., & Tomasicchio, G. R. (2022). Improvement of a coastal vulnerability index and its application along the Calabria Coastline, Italy. Scientific Reports, 12(1), 21959–21959. https://doi.org/10.1038/s41598-022-26374-w

Patrício, J., Elliott, M., Mazik, K., Papadopoulou, K. N., & Smith, C. J. (2016). DPSIR—Two decades of trying to develop a unifying framework for marine environmental management? Frontiers in Marine Science, 3, 177.

Payo, A., Favis-Mortlock, D., Dickson, M., Hall, J. W., Hurst, M. D., Walkden, M. J. A., Townend, I., Ives, M. C., Nicholls, R. J., & Ellis, M. A. (2017). Coastal Modelling Environment version 1.0: A framework for integrating landform-specific component models in order to simulate decadal to centennial morphological changes on complex coasts. Geoscientific Model Development, 10(7), 2715–2740. https://doi.org/10.5194/gmd-10-2715-2017

Pendleton, E.A., Barras, J.A., Williams, S.J., & Twichell, D.C. (2010). Coastal vulnerability assessment of the Northern Gulf of Mexico to sea-level rise and coastal change. U.S. Geological Survey Open-File Report 2010-1146, at https://pubs.usgs.gov/of/2010/1146/

Peternel, T., Jemec Auflič, M., Krivic, M., Kumelj, Š., Domej, G., & Šinigoj, J. (2024). MASPREM - The Slovenian landslide forecasting and warning system. Conference paper. Congress of the CAIAG 20th anniversary - Past achievements and future challenges of applied geosciences in Central Asia.

Poelhekke, L., Jäger, W. S., van Dongeren, A., Plomaritis, T. A., McCall, R., & Ferreira, Ó. (2016). Predicting coastal hazards for sandy coasts with a Bayesian Network. Coastal Engineering, 118, 21–34. https://doi.org/10.1016/j.coastaleng.2016.08.011

Plomaritis, T. A., Costas, S., & Ferreira, Ó. (2018). Use of a Bayesian Network for coastal hazards, impact, and disaster risk reduction assessment at a coastal barrier (Ria Formosa, Portugal). Coastal Engineering, 134, 134–147. https://doi.org/10.1016/j.coastaleng.2017.07.003

Ramieri, E., Hartley, A., Barbanti, A., Santos, F. D., Gomes, A., Hilden, M., Laihonen, P., Marinova, N., & Santini, M. (2011). Methods for assessing coastal vulnerability to climate change (ETC CCA Technical Paper 1/2011). European Environment Agency.

Reisinger, A., Howden, M., Vera, C., et al. (2020). The concept of risk in the IPCC Sixth Assessment Report: A summary of cross-working group discussions. Intergovernmental Panel on Climate Change, Geneva, Switzerland, pp. 15.

Rizzo, A., Aucelli, P., Gracia, F., & Anfuso, G. (2018). A novel coastal susceptibility assessment method: Application to Valdelagrana area (SW Spain). Journal of Coastal Conservation, 22, 973–987.

Rohmer, J. (2020). Uncertainties in conditional probability tables of discrete Bayesian Belief Networks: A comprehensive review. Engineering Applications of Artificial Intelligence, 88, 103384. https://doi.org/10.1016/j.engappai.2019.103384

Rohmer, J., & Le Cozannet, G. (2019). Dominance of the mean sea level in the high-percentile sea levels time evolution with respect to large-scale climate variability: A Bayesian statistical approach. Environmental Research Letters, 14(1), 14008. https://doi.org/10.1088/1748-9326/aaf0cd

Ružić, I., Dugonjić Jovančević, S., Benac, Č., & Krvavica, N. (2019). Assessment of the Coastal Vulnerability Index in an area of complex geological conditions on the Krk Island, Northeast Adriatic Sea. Geosciences, 9(5), 219. https://doi.org/10.3390/geosciences9050219

Sanuy, M., Jiménez, J. A., & Plant, N. (2020). A Bayesian Network methodology for coastal hazard assessments on a regional scale: The BN-CRAF. Coastal Engineering, 157, 103627.

Sanuy, M., & Jiménez, J. A. (2021). Probabilistic characterisation of coastal storm-induced risks using Bayesian networks. Natural Hazards and Earth System Sciences, 21(1), 219–238. https://doi.org/10.5194/nhess-21-219-2021

Sayers, P. B., Hall, J. W., & Meadowcroft, I. C. (2002). Towards risk-based flood hazard management in the UK. Proceedings of the Institution of Civil Engineers: Civil Engineering, 150, 36–42. https://doi.org/10.1680/cien.2002.150.5.36

Thiéblemont, R., Le Cozannet, G., Nicholls, R. J., Rohmer, J., Wöppelmann, G., Raucoules, D., Michele, M., Toimil, A., & Lincke, D. (2024). Assessing current coastal subsidence at continental scale: Insights from Europe using the European Ground Motion Service. Earth's Future, 12(8). https://doi.org/10.1029/2024EF004523

Torrecillas, C., Payo, A., Cobos, M., Burke, H., Morgan, D., Smith, H., & Jenkins, G. O. (2024). Sediment Thickness Model of Andalusia's Nearshore and Coastal Inland Topography. Journal of Marine Science and Engineering, 12(2), 269. https://doi.org/10.3390/jmse12020269

Torresan, S., Critto, A., Rizzi, J., Zabeo, A., Furlan, E., & Marcomini, A. (2016). DESYCO: A decision support system for the regional risk assessment of climate change impacts in coastal zones. *Ocean & Coastal Management*, *120*, 49–63. https://doi.org/10.1016/j.ocecoaman.2015.11.003

Valchev, N., Eftimova, P., Andreeva, N., & Prodanov, B. (2017). Application of Bayesian Network as a tool for coastal flooding impact prediction at Varna Bay (Bulgaria, Western Black Sea). Proceedings of Conference on Coastal Engineering, 35, 14. https://doi.org/10.9753/icce.v35.management.14

van Dongeren, A., Ciavola, P., Martinez, G., Viavattene, C., De Kleermaeker, S., Ferreira, O., Costa, C., McCall, R., Lang, M., Samuels, P., & Klijn, F. (2016). RISC-KIT: Resilience-increasing strategies for coasts. E3S Web of Conferences, 7, 17001. https://doi.org/10.1051/e3sconf/20160717001

van Verseveld, H. C. W., van Dongeren, A. R., Plant, N. G., Jäger, W. S., & den Heijer, C. (2015). Modelling multi-hazard hurricane damages on an urbanized coast with a Bayesian Network approach. Coastal Engineering, 103, 1–14. https://doi.org/10.1016/j.coastaleng.2015.05.006

Wong-Parodi, G., Mach, K.J., Jagannathan, K., Sjostrom, K.D. (2020), Insights for developing effective decision support tools for environmental sustainability. Curr. Opin. Environ. Sustain. 42, 52–59.

Zanuttigh, B., Simcic, D., Bagli, S., Bozzeda, F., Pietrantoni, L., Zagonari, F., Hoggart, S., & Nicholls, R. J. (2014). THESEUS decision support system for coastal risk management. Coastal Engineering, 87, 218–239. https://doi.org/10.1016/j.coastaleng.2013.11.013

25. Part 2 – References

Abramic, A., García Mendoza, A., & Haroun, R. (2021). Introducing offshore wind energy in the sea space: Canary Islands case study developed under Maritime Spatial Planning principles. Renewable & Sustainable Energy Reviews, 145, 111119-. https://doi.org/10.1016/j.rser.2021.111119

Azzellino, A., Kofoed, J. P., Lanfredi, C., Margheritini, L., & Pedersen, M. L. (2013). A Marine Spatial Planning framework for the optimal siting of Marine Renewable Energy Installations: two Danish case studies. *Journal of Coastal Research*, *65*(sp2), 1623–1628. https://doi.org/10.2112/SI65-274.1

Barzehkar, M., Parnell, K.E., Soomere, T., Dragovich, D., Engström, J. (2021), Decision support tools, systems and indices for sustainable coastal planning and management: A review. Ocean and Coastal Management 212.

Barzehkar, M., Parnell, K., & Soomere, T. (2025). Incorporating a machine learning approach into an established decision support system for coastal vulnerability in the Eastern Baltic Sea. Journal of Coastal Research, 113(sp1), 58–62. https://doi.org/10.2112/JCR-SI113-012.1

Beuzen, T., Splinter, K. D., Marshall, L. A., Turner, I. L., Harley, M. D., & Palmsten, M. L. (2018). Bayesian Networks in coastal engineering: Distinguishing descriptive and predictive applications. *Coastal Engineering (Amsterdam)*, *135*, 16–30. https://doi.org/10.1016/j.coastaleng.2018.01.005

Dakin, N., van Heteren, S., Poyiadji, E., Ernstsen, V.B. and T5.2 GSO delegates (2024). Pan-european catalogue of key parameters for offshore windfarm siting v1. GSEU Report on Deliverable 5.3, 44 pp.

De Mol, R., De Tré, G., Pelta, D. A., Cabrera, I. P., Verdegay, J. L., Yager, R. R., Ojeda-Aciego, M., Medina, J., Bouchon-Meunier, B., & Cabrera, I. P. (2018). Applying suitability distributions in a geological context. In Information Processing and Management of Uncertainty in Knowledge-Based Systems. Theory and Foundations (Vol. 853, pp. 278–288). Springer International Publishing. https://doi.org/10.1007/978-3-319-91473-2_24

De Tré, G., De Mol, R., van Heteren, S., Stafleu, J., Chademenos, V., Missiaen, T., Kint, L., Terseleer, N., Van Lancker, V., Carrara, P., & Bordogna, G. (2018). Data quality assessment in volunteered geographic decision support. In Mobile Information Systems Leveraging Volunteered Geographic Information for Earth Observation (Vol. 4, pp. 173–192). Springer International Publishing. https://doi.org/10.1007/978-3-319-70878-2_9

Durap, A. (2024). Mapping coastal resilience: a Gis-based Bayesian network approach to coastal hazard identification for Queensland's dynamic shorelines. *Anthropocene Coasts*, *7*(1). https://doi.org/10.1007/s44218-024-00060-y

Furlan, E., Slanzi, D., Torresan, S., Critto, A., & Marcomini, A. (2020). Multi-scenario analysis in the Adriatic Sea: A GIS-based Bayesian network to support maritime spatial planning. *The Science of the Total Environment*, *703*, 134972–134972. https://doi.org/10.1016/j.scitotenv.2019.134972

Gill, A. B. (2005). Offshore renewable energy: ecological implications of generating electricity in the coastal zone. *The Journal of Applied Ecology*, *42*(4), 605–615. https://doi.org/10.1111/j.1365-2664.2005.01060.x

Gkeka-Serpetsidaki, P., Skiniti, G., Tournaki, S., & Tsoutsos, T. (2024). A Review of the Sustainable Siting of Offshore Wind Farms. *Sustainability*, *16*(14), 6036-. https://doi.org/10.3390/su16146036

Göke, C., Dahl, K., & Mohn, C. (2018). Maritime spatial planning supported by systematic site selection: Applying Marxan for offshore wind power in the western Baltic Sea. PLoS ONE, 13(3), e0194362. https://doi.org/10.1371/journal.pone.0194362

Gutierrez, B. T., Plant, N. G., & Thieler, E. R. (2011). A Bayesian network to predict coastal vulnerability to sea level rise. *Journal of Geophysical Research: Earth Surface*, *116*(F2). https://doi.org/10.1029/2010JF001891

Hademenos, V., Stafleu, J., Missiaen, T., Kint, L., & Van Lancker, V. R. M. (2019). 3D subsurface characterisation of the Belgian Continental Shelf: A new voxel modelling approach. Netherlands Journal of Geosciences, 98. https://doi.org/10.1017/njg.2018.18

Jensen, J. B., Bennike, O., Christensen, N., Vangkilde-Pedersen, T. (2025). Screening of seabed geological conditions for the offshore wind farm area Kattegat II and the adjacent cable corridor area: Desk study for Energinet. GEUS. Danmarks og Grønlands Geologiske Undersøgelse Rapport Vol. 2023 No. 33 https://doi.org/10.22008/gpub/34700

Kannen, A, Gee, K, Blazauskas, N, Cormier, R, Dahl, K, Göke, C, Morf, A, Ross, A, Schultz-Zehden, A (2016): BONUS BALTSPACE Deliverable 3.2: A Catalogue of Approaches and Tools for MSP.

Kaskela, A. M., & Kotilainen, A. T. (2017). Seabed geodiversity in a glaciated shelf area, the Baltic Sea. Geomorphology, 295, 419-435. https://doi.org/10.1016/j.geomorph.2017.07.014

Kint, L., Hademenos, V., De Mol, R., Stafleu, J., van Heteren, S., & van Lancker, V. (2021). Uncertainty assessment applied to marine subsurface datasets. Quarterly Journal of Engineering Geology and Hydrogeology, 54(1), 1–. https://doi.org/10.1144/qjegh2020-028

Lange, M., Burkhard, B., Garthe, S., Gee, K., Kannen, A., Lenhart, H., & Windhorst, W. (2010). Analyzing coastal and marine changes: Offshore wind farming as a case study. LOICZ Research & Studies No. 36. GKSS Research Center, Geesthacht.

Lloret, J., Turiel, A., Solé, J., Berdalet, E., Sabatés, A., Olivares, A., Gili, J.-M., Vila-Subirós, J., & Sardá, R. (2022). Unravelling the ecological impacts of large-scale offshore wind farms in the Mediterranean Sea. *The Science of the Total Environment*, *824*, 153803–153803. https://doi.org/10.1016/j.scitotenv.2022.153803

Martin, H., Spano, G., Küster, J. F., Collu, M., & Kolios, A. J. (2013). Application and extension of the TOPSIS method for the assessment of floating offshore wind turbine support structures. *Ships and Offshore Structures*, *8*(5), 477–487. https://doi.org/10.1080/17445302.2012.718957

Ouro, P., Fernandez, R., Armstrong, A., Brooks, B., Burton, R. R., Folkard, A., Ilic, S., Parkes, B., Schultz, D. M., Stallard, T., & Watson, F. M. (2024). Environmental impacts from large-scale offshore renewable-energy deployment. *Environmental Research Letters*, *19*(6), 63001-. https://doi.org/10.1088/1748-9326/ad4c7d

Patrício, J., Elliott, M., Mazik, K., Papadopoulou, K. N., & Smith, C. J. (2016). DPSIR—Two decades of trying to develop a unifying framework for marine environmental management? Frontiers in Marine Science, 3, 177.

Pınarbaşı, K., Galparsoro, I., Borja, Á., Stelzenmüller, V., Ehler, C.N., Gimpel, A. (2017). Decision support tools in marine spatial planning: Present applications, gaps and future perspectives. Marine Policy 83: 83-91.

Pınarbaşı, K., Galparsoro, I., Depellegrin, D., Bald, J., Pérez-Morán, G., & Borja, Á. (2019). A modelling approach for offshore wind farm feasibility with respect to ecosystem-based marine spatial planning. *The Science of the Total Environment*, *667*, 306–317. https://doi.org/10.1016/j.scitotenv.2019.02.268

Stefanakou, A. A., Nikitakos, N., Lilas, T., & Pavlogeorgatos, G. (2019). A GIS-based decision support model for offshore floating wind turbine installation. *International Journal of Sustainable Energy*, *38*(7), 673–691. https://doi.org/10.1080/14786451.2019.1579814

Stelzenmüller, V., Lee, J., South, A., Foden, J., & Rogers, S. I. (2013). Practical tools to support marine spatial planning: A review and some prototype tools. *Marine Policy*, *38*, 214–227. https://doi.org/10.1016/j.marpol.2012.05.038

Tercan, E., Tapkın, S., Latinopoulos, D., Dereli, M. A., Tsiropoulos, A., & Ak, M. F. (2020). A GIS-based multi-criteria model for offshore wind energy power plants site selection in both sides of the Aegean Sea. *Environmental Monitoring and Assessment*, *192*(10), 652–652. https://doi.org/10.1007/s10661-020-08603-9

Virtanen, E. A., Lappalainen, J., Nurmi, M., Viitasalo, M., Tikanmäki, M., Heinonen, J., Atlaskin, E., Kallasvuo, M., Tikkanen, H., & Moilanen, A. (2022). Balancing profitability of energy production, societal impacts and biodiversity in offshore wind farm design. *Renewable and Sustainable Energy Reviews, 158*, 112087. https://doi.org/10.1016/j.rser.2022.112087

Watts, M.E.; Ball, I.R.; Stewart, R.S.; Klein, C.J.; Wilson, K.; Steinback, C.; Lourival, R.; Kircher, L.; Possingham, H.P. (2009), Marxan with Zones: Software for optimal conservation based land- and sea-use zoning. Environ. Model. Softw., 24, 1513–1521.

Wong-Parodi, G., Mach, K.J., Jagannathan, K., Sjostrom, K.D. (2020), Insights for developing effective decision support tools for environmental sustainability. Curr. Opin. Environ. Sustain. 42, 52–59.