

Project GORSMART

Conducting a baseline study and preparing
a preliminary design for the GORSMART
smart buoy pilot project

Final report

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Abstract

The final report reflects the results of the baseline study for the GORSMART project. It includes the results of user needs mapping and analysis of technological solutions, as well as technical descriptions of proposed platforms in the Gulf of Riga and the Väinameri area. Preliminary concept for the development of up to three smart buoys and preliminary description of six (6) prototypes that meet the requirements of the GORSMART project and regional needs are presented. The solutions take into account the technical specifications of platform types and a larger network of smart buoys in the Estonian sea area designed within the project “Merehunt”. It is justified by the need to keep the smart buoy systems (“Merehunt” and GORSMART) compatible with each other.

The results presented are preliminary, and this report should be considered as a working document until the Project Evaluation Team approves it. The following experts from the Tallinn University of Technology were involved in the study and drafting the report: Stella-Theresa Luik, Villu Kikas, Nelli Rünk, Taavi Liblik and Urmas Lips.

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1. Introduction

The aim of the study is to develop a concept and a draft design for the GORSMART smart buoy network. The GORSMART project area encompasses the Gulf of Riga and the Väinameri region, including the areas near major cities (Pärnu, Kuressaare, and Riga), as well as the Irbe Strait, the Suur Strait, and the Pärnu shipping lanes. The main function of the smart buoys is to detect pollution and collect data on the state of the marine environment in the Gulf of Riga and the Väinameri area.

The following tasks were fulfilled during the study period of about three months.

Mapping and analysis of Estonian and Latvian user needs

Mapping the needs of various users was conducted. Potential users and responders included Estonian and Latvian authorities, research institutes, maritime and environmental institutions, ports, non-governmental organizations and local communities. In Estonia, the organizations that were contacted were the ones from which information was lacking in the “Merehunt” survey (e.g., Matsalu Nature Reserve, Väike Väina Society etc.).

Mapping of the user needs in Latvia was conducted through web-based surveys. The aim was to identify bottlenecks and shortcomings in existing marine environment monitoring solutions in the project area. Main expectations of users from a smart buoy network were inquired about. The results are presented in combination with a similar study (including web-based questionnaire and interviews) in Estonia which was carried out in the framework of the “Merehunt” project.

Technology and solutions analysis

An analysis of existing technological solutions was carried out, including sensors, platforms and data communication systems. The aim was to identify the most suitable technologies and sensors for marine environmental monitoring, including for detecting oil spills and monitoring the state of the sea. The user's needs for data and products were at the basis of the analysis. Different energy sources for smart buoys (including solar energy, wind energy, fuel cells, etc.) were considered. Communication technologies were analyzed, and the best solutions were suggested. The analysis took into account the results from the project "Merehunt". Sensors and solutions for oil spill detection were analyzed in more detail. Two potential methods for detecting oil pollution were studied. One is based on lidar technology, which is a ready-to-use solution but covers a very small area of the sea surface. The other one is based on camera (or thermal camera) technology. The latter needs some development before implementation.

Concept and initial design of smart buoys

A preliminary concept and design of smart buoys for environmental data collection and oil spill detection was developed. Platform types developed in the “Merehunt” project were adopted for the conditions in the GORSMART area, with a greater emphasis on oil spill detection. The following smart buoy potential capabilities were analyzed, and feasible solutions were offered:

- Oil spill detection. Besides sensor technologies to determine the existence of oil on the sea surface, solutions were considered to assess the extent and movement of the pollution, as well as identification and recording of the source of the pollution using cameras or other parameters measured by the platforms or information available from different sources.

- Marine environmental monitoring, including continuous monitoring of water temperature, salinity, pH level and dissolved oxygen content. Solutions for the determination of chemical pollutants, including the possible detection of cadmium, mercury, microplastics and other hazardous substances, were considered.
- Monitoring of marine ecosystems, including plankton (e.g. phytoplankton blooms), fish, seals and birds, as well as pressures on them (e.g. nutrient load).
- Underwater noise monitoring for the identification of natural and anthropogenic noise sources, including ship movements, development activities and mining. An analysis of potential data sources to monitor ship movements was conducted, including the use of unmanned and automated vehicles, various sensors or cameras on the platforms and external information sources, such as AIS.
- Monitoring of meteorological and oceanographic conditions, including parameters like wind speed and direction, wave height and direction, water level, and currents.

Concept and initial design of smart buoy network GORSMART

Prerequisites and requirements for the establishment of a smart buoy network in the Gulf of Riga and the Väinameri region for environmental data collection and oil spill detection were described. This activity considered the results and suggestions from the “Merehunt” project. It is suggested that in this relatively shallow sea area with ice conditions in winter, the solar panels are the primary energy source for the autonomous platforms.

Within the preliminary concept, locations of platforms, functionality, energy and communication solutions were recommended. The analysis suggests that 4G mobile networks can be used as the main communication system. The potential use of existing navigational buoys for the smart buoy network was considered. Potential solutions on data collection, data delivery and required level of processing are analyzed and proposed in the following areas: data transfer limitations, communication solutions and connectivity, capabilities and security, raw data delivery, identification of necessary processing levels in case the end user requires data in pre-processed form. The analysis takes into account the list of requirements and recommendations prepared by the “Merehunt” project consortium to secure the compatibility of the GORSMART network solutions with it.

Next steps and the basic requirements for the development of the smart buoy network

Based on the study results, a basic concept and design for a smart buoy network was developed. Technical specifications for the development of six prototype platforms for oil spill detection, environmental data collection and analysis were compiled.

This analysis included the following topics:

- The ability of smart buoys to respond and optimize their activities automatically according to the prevailing environmental conditions (weather, sea conditions, pollution). Real-time monitoring of smart buoys and dynamic response to changing or disruptive conditions.
- Ensuring the longest possible operational capability with automated systems, including in the event of interruptions.
- Level of automation and remote diagnostics. The possibilities of remote diagnostics of platforms, devices and sensors, and their maintenance, in case of failures were analyzed.
- Methodology for deploying and recovering smart buoys, for example, before ice formation or for regular maintenance.

- Different energy sources were analyzed, including different renewable energy sources (for example, wind, solar, waves, currents). The efficiency and durability of fuel cells and batteries, and the possibilities for storing energy in a long-term and environmentally friendly way were evaluated.

Cost estimation

The costs of the following alternative solutions, including the investments and costs for the maintenance of the system, were estimated:

- Pilot solution. A small-scale pilot project with the deployment and testing of a limited number of smart buoys. This includes the deployment and maintenance of 1-3 smart buoys, data transmission and basic monitoring systems. The solution is suitable for operational piloting in the initial phase, where it is necessary to collect initial data and assess the performance of the system. Integration with the “Merehunt” smart buoy network is foreseen. The time frame is 1-5 years from the start of the project.
- Medium solution. In addition to the pilot solution, it includes additional data analysis tools, an expanded monitoring network (construction of additional buoys) and improved integration with existing systems. The solution is suitable for post-pilot activities and for building a larger network. The time frame is 5-10 years from the start of the project.
- Complete solution. The most comprehensive solution, incorporating advanced technology, real-time data transmission, an extensive monitoring network and advanced data analysis. The solution would be part of the long-term concept of the “Merehunt” project. The time frame is 10-15 years from the start of the project.
- Alternative solution. Modular system, a public-private partnership, allowing for the gradual addition of new components and expansion of the network according to the needs of universities, maritime companies and public authorities. Time frame is 1-10 years from the start of the project, which may be divided into appropriate phases.
- Total cost of ownership estimates. The cost of ownership, administration and maintenance of the smart buoys developed during the study for the State Fleet was estimated. The total cost estimate includes the following items: Initial costs for the deployment of the smart buoys intended for piloting in 2025-2026; costs for the post-installation period in 2026-2028; ownership and maintenance costs in the post-project period 2028-2033, including recommendations and proposals for optimizing administrative and maintenance costs.

2. Results

2.1. Mapping and analysis of Estonian and Latvian user needs

Mapping the needs of various users was conducted. Potential users and responders included Estonian and Latvian authorities, research institutes, maritime and environmental institutions, ports, non-governmental organizations and local communities. In Estonia, organizations that had not responded to the 'Merehunt' survey were selected for contact.

Mapping of the user needs in Latvia was conducted through web-based surveys. The aim was to identify bottlenecks and shortcomings in existing marine environment monitoring solutions in the project area. Main expectations of users from a smart buoy network were inquired about. The results are presented in combination with a similar study (including a web-based questionnaire and interviews) in Estonia in the framework of the "Merehunt" project.

Since only five responses to the two questionnaires were received from Latvia, it was vital to consider carefully the responses from Estonia for the "Merehunt" project questionnaire, especially those from the GORSMART region. A total of 39 survey responses were received for the "Merehunt" web-based survey. Also, 16 interviews were conducted with a total of 43 respondents. The majority of respondents work in the fields of science, marine environmental protection, maritime transport and safety and security. The vast majority of state institutions (49%), as well as public legal entities (e.g. universities), private companies, non-profit associations and local governments, provided input to the survey. Responses were also received from foundations and private individuals.

According to the "Merehunt" survey results, forecasts are most needed for users to perform their tasks. Forecasts are essential for fieldwork planning, navigation, and other related activities. More than half of the respondents also need real-time data, and nearly 75% of the respondents want smart buoys to transmit data in real time. According to the survey, smart buoys would improve the (currently insufficient) temporal and spatial coverage of operational data. The availability of dense data is also extremely important for the development of mathematical models of the marine environment (including digital counterparts) and for improving the quality of model results.

Based on the "Merehunt" user survey, wave data is the most desired data from smart buoys. Water temperature, currents and meteorological parameters were noted more than 20 times. There is also great interest in salinity, dissolved oxygen content, turbidity, chlorophyll, video and image material, nutrient content, carbon cycle parameters, biological parameters and underwater sound. In some cases, pollution in general, radar information, air quality, suspended solids, CDOM, water level and video were noted as parameters of interest to be measured with smart buoys.

Two additional potential users were interviewed in Estonia regarding their needs in the GORSMART buoys network. They were the Matsalu Nature Reserve representatives (Environmental Board) and the Väike Väina Society. Specific needs were identified to deliver data on environmental conditions in Matsalu Bay, including monitoring of nutrient content, in the Väike Väin to record the present status and changes when the openings in the dam are constructed, i.e., the bridge will be built to improve the water exchange.

The following main user needs were compiled based on the answers from Latvia to the web-based questionnaire. The responders represented the Latvian Institute of Aquatic Ecology, Latvian

Environment, Geology and Meteorology Centre, Port of Liepaja and Freeport of Ventspils. All responders indicated that their primary need for marine data is primarily related to their professional activities (Fig. 1). Specifically, the needs were related to pollution detection and prevention through real-time data monitoring in maritime area surveillance. Also, the data needed for analyzing long-term trends in water quality, eutrophication, biodiversity, and the impacts of climate change and human activities on marine ecosystems was mentioned. The data are essential for fulfilling national and international reporting obligations, such as those related to the EU Marine Strategy Framework Directive (MSFD) and HELCOM assessments. Furthermore, marine data support applied research, the development of environmental indicators, and the implementation of sustainable management strategies for marine and coastal areas.

For what purpose do you need marine data or services based on such data?

5 responses



Figure 1. The purpose of marine data needs.

All responders indicated that near real-time data are needed for their professional activities. The following main shortcomings regarding the data availability were mentioned. Availability of marine data is rather scarce if we want to obtain data from other countries in the region (except if you have good contacts or are part of some data network, e.g. EMODnet). Information about data collected by other institutions within the country is not always freely available. Also, it is not always possible to ensure the quality of the marine data if the data source is another institution (the data quality procedure is not clear/defined). Since data come from different sources and different methods, instruments, and formats, data integration is complex.

It was mentioned that there is a general lack of in situ observations (both meteorological and hydrological observations). Different institutions are often unaware of similar activities carried out by other organizations. Restricted access due to commercial interests or unclear licensing can prevent broader use of data in public services. A doubt was expressed that it is almost impossible to cover all interests (from different institutions, stakeholders, etc.) and put them in one meaningful service.

All responders considered near real-time data delivery important or very important for their needs (Fig. 2). Specifically, it was mentioned that real-time data allows for assessing the conditions as soon as possible, resulting in more effective planning of different activities (producing forecasts, data sampling activities, notifying activities, etc.). The ability to receive and process data from smart buoys in real time greatly enhances responsiveness, accuracy, and effectiveness in both research and also operational marine activities.

How important is it for your tasks that data from smart buoys is received in real time (or near real time)?

5 responses

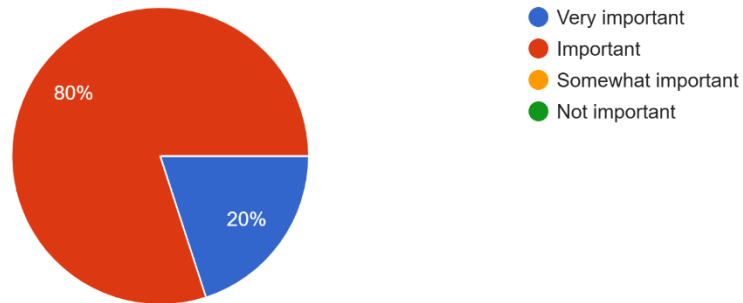


Figure 2. The importance of data delivered near real time.

Please select from the list below the parameters that smart buoys should measure to support your tasks. Select all parameters that are relevant to you.

5 responses

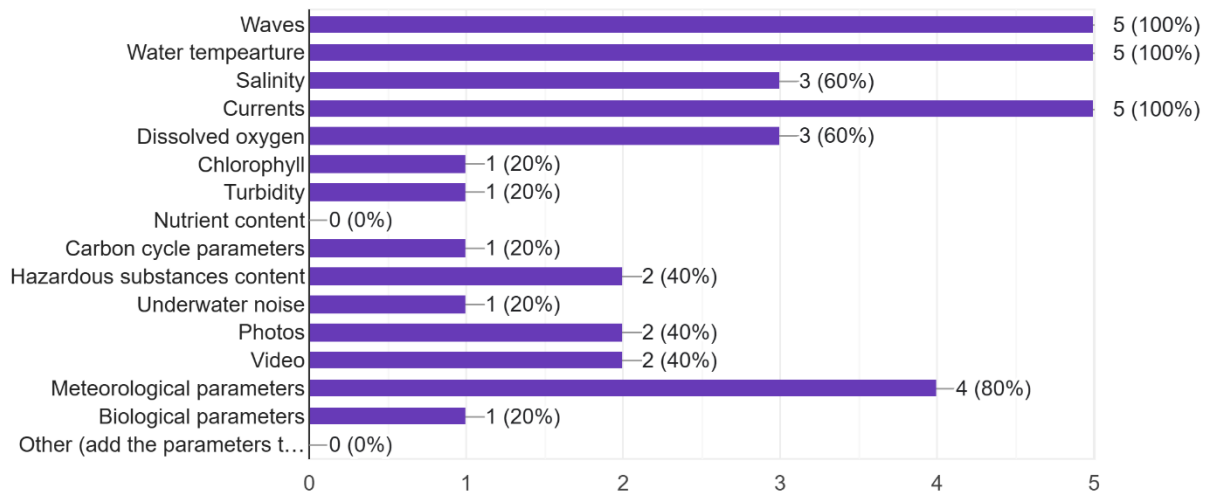


Figure 3. Parameters to be measured by smart buoys.

Similar to the “Merehunt” survey, the GORS MART survey identified the most desired parameters being waves, water temperature, currents and meteorological parameters (Fig. 3). Among the latter, wind speed and direction, and air temperature were indicated. Also, salinity and dissolved oxygen were mentioned by more than half of the responders. The other parameters included chlorophyll-a, turbidity, carbon cycle parameters (pH), underwater noise, and biological parameters (eDNA). Among hazardous substances, data on oil products and microplastics are

needed. Also similar to the “Merehunt” survey, users would like to have photos or a video stream available from the smart buoys.

In what format or level of processing would you prefer to receive the smart buoy data for performing your tasks?

5 responses

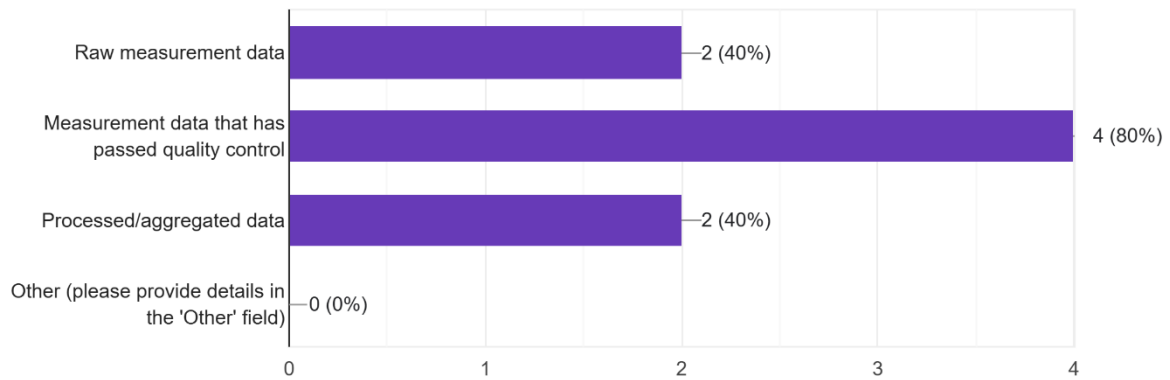


Figure 4. Preferred processing level of delivered data.

What is your preferred method for receiving smart buoy data?

5 responses

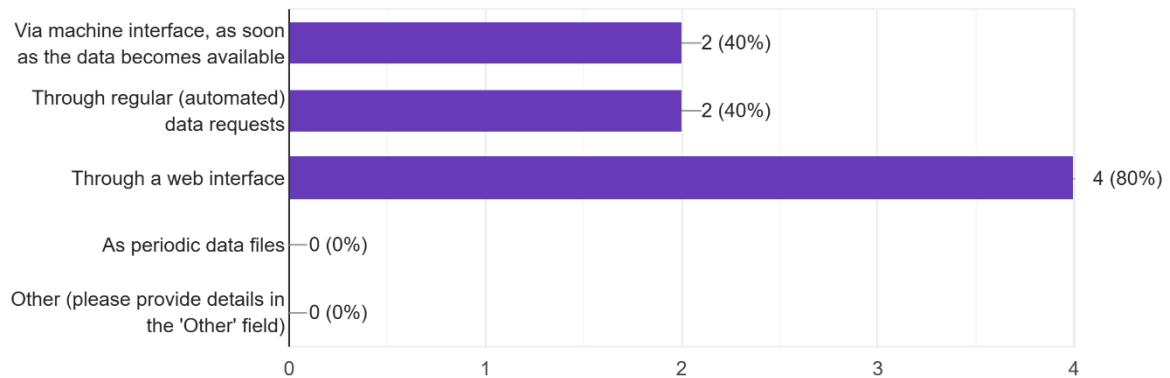


Figure 5. Preferred data harvesting methods.

Measurement data that passed quality control was the most needed data type regarding their processing level (Fig. 4). In addition, both raw data and aggregated data products are required by the users. Most of the users prefer to harvest data via a web interface (Fig. 5). Also, a machine interface that allows making data available as soon as possible and regular requests to receive data were mentioned.

One of the responders stated that establishing partnerships with research institutions and providing training to users can enhance the network's effectiveness and encourage broader data use.

2.2. Technology and solutions analysis

The aim was to carry out an analysis of existing technological solutions, including sensors, platforms and data communication systems, and analyze new marine environment monitoring technologies, including for detecting oil spills and accurately monitoring the state of the sea. For this analysis, the results of the mapping of existing marine monitoring technologies carried out by the "Merehunt" project were taken as a basis. Their study included the technical solutions used in the selected systems, and their advantages and disadvantages that were described and analyzed in five categories: platforms, sensor solutions, energy solutions, communication solutions and data management.

The SWOT analysis in the frames of the "Merehunt" compared the technological solutions by subtopics, such as platforms and their combinations, sensors, energy solutions, communication solutions and IT solutions. The SWOT analysis of the systems and solutions was based on information on the success and challenges of their implementation in the location of the systems and their potential implementation in the Baltic Sea environment.

The main results applicable in the GORS SMART area are as follows:

- All currently operating systems have been developed considering the needs of a very wide range of users and therefore also contain a wide range of platforms and sensors. This, in turn, means that both human resources (experts with different qualifications) and financial resources are needed to operate them.
- The strength of most systems is the ability to record a large number of parameters. Recording and real-time transmission of meteorological parameters is almost always necessary. The data is usually freely available to all users.
- The main weaknesses of the systems are the high costs of investment (including replacing platforms that have been damaged for some reason) and their operation.
- It is easier and cheaper to keep similar platforms (with similar sensors) in operation constantly, but then it is possible to satisfy a smaller number of potential users.
- A characteristic feature of existing systems is their joint management, use and improvement by the state, research institutions and private companies.

Regarding the sensors for smart buoys, it was concluded that sensors that meet the needs of all potential users are available on the market, and most of them are also suitable for use in the Baltic Sea conditions. The choice of sensors and their combinations also depends on the budget of subsequent development projects. For this, the investments and running costs required for the acquisition and future maintenance of sensors must be taken into account. However, oil spill detection sensors installed on smart buoys usually have a very small detection area or volume, which means a very low probability of detecting pollution. Existing systems do not use camera-based pollution detection methods, which will require additional development work.

In the present study, we considered these two types of technology for oil detection on the sea surface. An example of the sensors based on the lidar technology is produced by an Estonian-based company, LDI (<https://ldi.ee/products/row-oil-detector/>). Their sensor LDI ROW is a

popular sensor for use in applications where a high probability of oil pollution can be expected. More than 1000 sensors have been sold in more than 70 countries worldwide. The sensor can identify many different types of oil products, such as motor oils, turbine oils, vegetable oils, lubricant oils, hydraulic oils, mineral oils, fuel oils, marine diesel oils, crude oils, heating oils, gas oils, bunker fuels, diesel, gasoline, kerosene, and aviation fuels. Advantages of using this sensor on smart buoys include its detection range of 10 m above the sea surface, sensitivity of the detected film of 1-micron thickness, relatively small dimensions and weight, and low power consumption of 2W. The main challenge in using this sensor on the GORSMART platforms is its detection area. The sensor uses UV light, and the target area is defined by the width of the UV light beam (depending on the distance to the surface). Thus, it is feasible to use this sensor only in areas with a high probability of oil slicks (e.g. near harbors and areas with heavy ship traffic).

The other method is based on the use of cameras, including both visible and thermal cameras. The main challenge here is that in the visible range, this method is applicable only during daylight. When using a thermal camera, it can be mounted on masts or booms of vessels (crewed or unmanned) and surface buoys. If the camera is installed using a mechanical system that allows the camera to rotate horizontally and tilt vertically, then it can scan wide areas without needing to move the entire platform (like a drone or vessel). However, there are not readily available systems yet on the market, and for the use of this method, some development work is needed. In Estonia, a company that develops such systems is STRIXMARINE. In addition to the needed development work, this method has higher power consumption demands for an autonomous platform. However, it can cover a relatively large area to detect the oil spill and thus has a higher probability of hitting an oil spill than the LDI ROW sensor.

Nevertheless, both methods can be used alone or in combination with aerial surveys by drones. For example, if the smart buoy sensor identifies an anomalous sensor output, it may trigger the launch of a drone (by an operator or automatically) to survey a wider area. In principle, the drones can be hosted by smart buoys, but a more realistic solution in the near future would be the use of drones from land (e.g. nearby islands in the Väinameri area).

Aerial drones have been tested for oil spill detection in several countries, e.g. in Norway by the Norwegian Clean Seas Association for Operating Companies (NOFO), Portugal by the University of Porto and by the Coast Guard of the United States and Canada, as well as by the European Space Agency (ESA) in the project ARGOMARINE (Automatic Oil Spill Recognition and Geopositioning integrated in a Marine Monitoring Network).

Aerial drones can use the following methods and technologies to detect oil on the sea surface:

- RGB Cameras, which are mostly used for basic visual inspection and documentation.
- Thermal/Infrared Cameras that detect temperature differences. Oil slick on the sea surface can be detected, since oil heats differently than water.
- UV Cameras (similar to LDI sensor) detect oil that fluoresces under UV light.
- Hyperspectral Sensors can be used to identify oil composition and film thickness.
- Gas Sensors detect volatile organic compounds released from crude oil.

Solar energy, wind energy, wave energy and hydrogen-based technologies were considered as energy production solutions for smart buoys. Wave energy as an energy source for smart buoys was ruled out since it is still in the development and testing phase. See, for instance, PowerBuoy (Wind, Wave and Solar) under development by the Ocean Power Technologies (<https://oceanpowertechnologies.com/products/powerbuoys/wind-wave-solar/>). The same

conclusion applies to hydrogen-based solutions. There are companies in Estonia and Latvia testing this solution for maritime use, but the technology will not be available during the GORSMART project development phase in 2026-2027.

Regarding solar and wind energy, we rely on modeling carried out within the “Merehunt” project, taking into account the meteorological conditions in the sea area close to the GORSMART region (in the Gulf of Finland, where sufficient experience and measurements were available from recent years). Since energy production and storage systems are the main factors defining the size of the platform (surface buoy), which has implications for the costs of their construction and maintenance, the best solution would be to use solar panels. According to the modeling results, these platforms equipped with solar panels can be used for most of the year except during autumn-winter from November until January. If the year-round use of the platforms is needed, wind turbines have to be installed on buoys. Three types of buoys were suggested within the “Merehunt” project. The following solutions have been proposed for energy production: on the MEGA platform, energy is produced with solar panels and wind generators; on the MIDI and MINI platforms, energy is produced with solar panels.

Based on the analysis and additional on-site measurements within the “Merehunt” project, we can propose that the primary communication technology for all GORSMART platforms is communication via a mobile network. Starlink, as an alternative means of communication, can be considered, but it can increase energy consumption.

2.3. Concept and initial design of smart buoys

A preliminary concept and design for the development of smart buoys for environmental data collection and oil spill detection were created. It takes into account smart buoy solutions developed in the “Merehunt” project, adapting them for the conditions in the GORSMART area and with a greater emphasis on oil spill detection. In this section of the report, two main types of smart buoys for the GORSMART project are described, and their capabilities to carry sensors required by potential users are analyzed.

GORSMART smart buoys are platforms deployed in the Gulf of Riga area, which have sufficient autonomy to perform long-term, high-resolution measurements and transmit data in near real-time. The main platforms of the network are anchored buoys, but it is also possible to connect unmanned moving platforms on the sea surface, in the water column, in the air, or those installed on the seabed. To ensure the long-term independent operation of the platforms, they are equipped with a controller that performs the following main functions: collecting and processing data from sensors, controlling platform-related equipment, enabling data transmission, and facilitating two-way communication with shore infrastructure.

The GORSMART project will utilize the two platform types suggested by the study within the "Merehunt" project to ensure compatibility with the large system of smart buoys. The platforms are categorized into three types based on their capacity and size. One of the main considerations in determining the size of the platforms is the energy consumption of the devices and sensors planned for them. Appropriate modelling and calculations have been performed for all buoys to provide the platforms with sufficient capacity for energy production and storage. Within the GORSMART project, the use of two types of "Merehunt" platforms is proposed - MIDI and MINI buoys.

2.3.1. Large (MIDI) platform

The large platform corresponds to the "Merehunt" MIDI buoy, which is a high-capacity platform capable of carrying many devices and sensors. Energy is produced with solar panels. It requires that the platform should be in a different operational mode during the winter months or lifted out of the water. Interruption of measurements in winter is also related to ice conditions (depending on the location). The mass of the MIDI buoy is estimated at 500 kg.

Energy solutions. The platform produces the energy necessary for the operation of the devices with solar panels. A charging system installed on the platform allows data to be collected on the entire platform's energy solution, including battery voltage, panel output voltage, charging current, system consumption current, and more. The energy solution turns off devices or sensors when the battery voltage drops below a critical level, protecting the batteries and extending their life.

Communication solutions. The platform is equipped with a 4G modem. If 4G coverage at their installation locations is poor, they can be equipped with a satellite modem that offers a sufficient data exchange rate (for example, Starlink). The energy solution must consider this, as Starlink modems consume relatively large amounts of energy; therefore, the system must have the ability to turn the modem on and off cyclically.

Additional equipment related to the platform. The platform carries the profiling device and the sensors connected to it, and is connected to a current profiler that can be installed on the seabed or a wave buoy. The latter can be connected to the platform controller or be equipped with a separate controller and communication equipment.

Anchoring solutions. The platform is anchored with at least two anchor lines to ensure free movement of the profiling device throughout the water column. If devices are installed on the platform that require the buoy not rotating or maintain its position more accurately, it is recommended to anchor the platform with three anchor lines.

2.3.2. Small (MINI) platform

The small platform corresponds to the "Merehunt" MINI buoy, which is designed to measure surface layer and meteorological parameters and can be used for specific local needs. The buoy weighs no more than 120 kg. The main operating areas of platforms are the shallower parts of the coastal sea. These platforms operate during the ice-free period.

Energy solution. The platform generates the energy required for the equipment's operation using solar panels. A charging system installed on the platform enables the collection of data about the entire platform's energy solution, including battery voltage, panel output voltage, charging current, system consumption current, and more. The energy solution turns off devices or sensors when the battery voltage drops below a critical level, protecting the batteries and extending their life.

Communication solutions. The platform is equipped with a 4G modem. Since these platforms are designed for areas where mobile communications with sufficient reliability are guaranteed, no other communication solutions are provided for the platform.

Additional equipment. A current profiler installed on the seabed and a wave buoy can be connected to the platform. The latter can be connected to the platform controller or be equipped with a separate controller and communication equipment.

Anchoring solutions. The platform is anchored with a single anchor line. If the equipment requires the buoy not to rotate or to maintain its position more precisely, it is necessary to anchor the platform with at least two anchor lines.

2.3.3. Capabilities of smart buoys

The following smart buoy potential capabilities were analyzed and, if feasible, solutions are offered for them.

Oil spill detection. The most comprehensive approach for the detection of oil spills on the sea surface combines satellite, aerial, and surface-based methods. Satellite remote sensing mostly uses methods based on Synthetic Aperture Radar (SAR) technology. It discovers oil spills over large areas with time intervals, depending on flight schedules in a specific location (1-2 times a day in the Baltic). Limitations are mostly related to the frequency of getting images and the ability to detect only large spills (small spills could be left unnoticed). Aerial drones can employ cameras (in visual range or thermal cameras) and may be used to detect the extent of spills. Although this technology provides high-resolution mapping of spills, its limitations are related to the limited flight extent and duration. It can be applied in combination with satellite remote sensing and ground measurements. The latter can be arranged by vessels, autonomous buoys at fixed locations, drifters or autonomous vehicles.

Technologies applied in surface devices include thermal cameras (able to rotate and tilt), UV sensors, and fluorometers. This approach is mainly used to monitor known risk zones (ports, shipping lanes, pipelines, rigs). Its advantages are related to continuous operation and high reliability. However, it has only limited spatial coverage. Drifters with oil sensors can be applied to follow oil spills when they are detected (e.g. Pärt et al., 2024). The same is relevant for the surface vehicles, either crewed or unmanned. Underwater gliders are relatively slow, and their employment is feasible if other means are not available and the glider is in the area of interest. All these unmanned autonomous devices need to be transported to the area where a spill has been detected.

On the other hand, proposed GORSMART platforms deliver, in addition to the pollution detection data, also meteorological and oceanographic information. These data streams are highly relevant for combating oil spills, allowing more accurate prediction of the spread and movement of the pollution.

For the identification and recording of the source of the pollution, images and video stream from the buoys can be used. For this, images can be stored on the platform storage devices for a certain period (e.g. 7 days) and harvested if needed. Application of underwater noise data can be considered, but it still requires significant development to detect the vessels (their noise signatures) reliably.

Marine pollution and pollutant monitoring. Continuous monitoring of water temperature, salinity, and dissolved oxygen content is relatively common nowadays using autonomous buoys and other platforms. All suggested GORSMART buoys contain these sensors in the surface layer (on the buoy, except oxygen) and mostly also in the near-bottom layer. One platform in the Irbe

Strait is suggested to include also a profiling device with temperature, conductivity, chlorophyll a, turbidity and dissolved oxygen sensor.

Carbon system parameters like pH and pCO₂ were not required by the users in the GORSMART area (except for one answer). However, we consider these parameters very valuable for the climate change impact studies. None of the GORSMART buoys is proposed to include them. It is more relevant to have these sensors on the platform in the central Gulf of Riga (representing the entire sea area) as part of the “Merehunt” project pilot phase.

The use of autonomous platforms for the determination of chemical pollutants (including cadmium, mercury, microplastics and other hazardous substances) is not common. Direct measurements of concentrations of cadmium (Cd), mercury (Hg) and other hazardous substances are in the seawater in concentrations that can be detected only in a very close vicinity of their sources, e.g. waste water treatment plants, outfalls and construction sites with polluted sediments. We consider adding them to smart buoys as not feasible. However, testing of microplastic filtering devices can be discussed further. It will require more energy available at the platforms if a pump system is used.

The other option would be to apply passive samplers for hazardous substances and microplastics. Heavy metals, including Hg and Cd, can be detected using a method known as Diffusive Gradients in Thin Films (DGT). For detecting pharmaceuticals and pesticides in coastal areas, the Polar Organic Chemical Integrative Sampler (POCIS) can be used. Also, Semi-Permeable Membrane Devices (SPMD) can be applied for the detection of some hazardous substances. However, we consider these techniques still not available for operational use on autonomous platforms. A separate development project can be initiated instead of adding these technologies to the GORSMART platforms.

Monitoring of marine biological systems. Monitoring of fish, seals and birds using smart buoys is not feasible at present. Known methods employ underwater video or noise monitoring, video or radar monitoring with devices installed on fixed buoys. In principle, underwater noise recordings can be used to track marine mammals (as used in the Baltic Sea to count porpoises). It requires post-processing of hydrophone data that can be available from the smart buoys. Bird monitoring using radars is relatively standard. However, these systems require large amounts of energy and must be connected to the power grid.

Use of bioindicators to define pollution using smart buoys is also not feasible yet. Phytoplankton blooms can be detected using chlorophyll-a sensors. For the detection of surface blooms, a surface sensor of chlorophyll-a could be sufficient, which is planned for most GORSMART buoys. If cyanobacteria are the target group, a phycocyanin sensor must be added. It is not planned at the moment because it also requires additional and relatively expensive laboratory work to calibrate and maintain these optical sensors. Instead, a profiling device with a CTD including chlorophyll-a sensor can be installed on large platforms. It also allows for the detection of sub-surface blooms that can be harmful.

Biological monitoring can be arranged using eDNA techniques with devices installed on smart buoys. Since such devices are not yet available for operational use, we suggest testing this approach in the framework of the “Merehunt” project (at only one platform) or initiating a separate project.

Underwater noise monitoring. Underwater noise monitoring is widely used for identification of natural and anthropogenic noise sources, including ship movements, development activities and

mining. We suggest including hydrophones at a few GORSMART platforms. Two issues must be tackled. First, it is too demanding to stream noise data from the platforms in near real-time. It is possible to post-process and analyze the recorded data when the device is recovered. To have real-time information on ship movements (including unmanned and automated vehicles) using hydrophones requires the development of algorithms that must be installed on the platform controllers. Thus, this application will depend on available resources.

The other issue is related to the delicate nature of noise data. It must be discussed and agreed with relevant authorities whether and how this data set is managed, especially in near-real-time mode.

Monitoring of other oceanographic and meteorological conditions. All proposed GORSMART buoys are equipped with meteorological stations registering wind speed and direction, air temperature, air pressure and humidity. Wind speed and directions were the most required data by the potential users.

Also, wave parameters (height, period and direction) are among the most wanted data from the smart buoys. These measurements can be arranged easily using a separate wave buoy (e.g., Lainepoiss, Sofar, Waverider). Since all proposed platforms should include many other sensors, adding them to the existing wave buoys is not a simple task. One solution could be to have a wave buoy as a separate unit close to the GORSMART buoy. There have been tests to calculate wave characteristics from the movements of navigational buoys. However, the data are not precise. Adding sensors to the smart buoys with different payloads requires additional calibration work for each deployment and is not feasible for operational use.

Water level measurements on smart buoys can be arranged by adding a pressure sensor at the seabed. It is feasible in navigationally difficult areas, such as the shipping lane in the Väinameri area.

Currents can be measured by a device attached to the surface buoy (either for point measurements or profiling) or at the seabed. The latter solution must be used if the aim is to monitor the water exchange (e.g. through a strait). However, it does not provide an accurate measure for surface currents in deeper locations. Thus, additionally, a point current meter should be installed on the buoy.

2.4. Concept and initial design of smart buoy network GORSMART

2.4.1. Location of platforms

A total of six GORSMART platforms are suggested and described. We took into account a “Merehunt” platform in the Ruhnu Deep (central Gulf of Riga). Another large (MIDI) platform is suggested for the Irbe Strait. All other platforms can be fitted on the MINI buoy. The locations of proposed platforms are shown in Fig. 6.

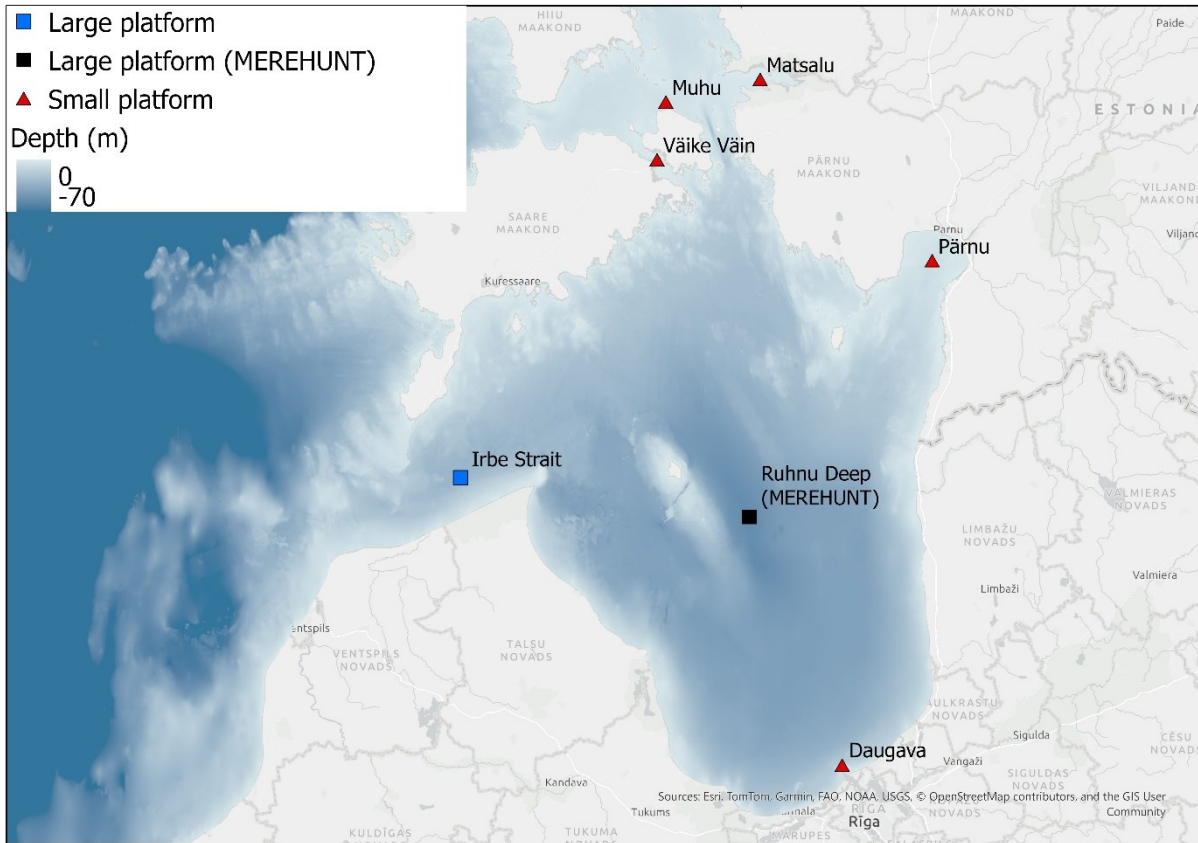


Figure 6. Suggested locations of six GORSMART platforms in the project area and a “Merehunt” platform in the central Gulf of Riga (black square). Large platforms are depicted as squares, while small platforms are represented as triangles.

Functionality, energy and communication solutions for proposed GORSMART platforms are described in filled platform templates. These mostly agree with the platforms in the “Merehunt” long-term vision. Exceptions are the platform in the sea area off Riga and the Väike Väin. An option was discussed to have the sixth prototype requested by the project description close to the Roomassaare harbor instead of the one in the Väike Väin. If so decided, it could be a small buoy with a configuration similar to the platform off Riga.

2.4.2. Functionality of proposed platforms

Large platform in the Irbe Strait

Main purpose	Detecting pollution near the main shipping lane to the Gulf of Riga. Characterizing water exchange between the Gulf of Riga and the open sea, continuous monitoring of the environmental status, including collection and real-time transmission of meteorological and oceanographic information
Suggested location	Irbe Strait
Depth	25 m
Type	MIDI
Anchoring solution	Two lines

Energy solution	Solar panels, batteries
Communication	Mobile network
Devices and sensor (air)	Wind direction and speed, air temperature, air pressure, humidity, (solar radiation intensity)
Devices and sensors (surface layer)	Water temperature, salinity, current speed and direction, waves (height, period, direction), chlorophyll and turbidity, oil pollution, video/image
Devices and sensors for profiling	Temperature, salinity, chlorophyll, oxygen, turbidity, current speed and direction
Devices and sensors in the bottom layer	Temperature, salinity, oxygen
Additional devices and capabilities	Underwater sound

MINI platform in the Pärnu Bay

Main purpose	Continuous monitoring of the environmental status and human impact in the Pärnu Bay area (load from Pärnu river, shipping lane, wastewater treatment plant outfall, recreational area), including collection and real-time transmission of meteorological and oceanographic information
Suggested location	Pärnu Bay
Depth	6 m
Type	MINI
Anchoring solution	One line
Energy solution	Solar panels, batteries
Communication	Mobile network
Devices and sensor (air)	Wind direction and speed, air temperature, air pressure, humidity, (solar radiation intensity)
Devices and sensors (surface layer)	Water temperature, salinity, current speed and direction, waves (height, period, direction)
Devices and sensors for profiling	
Devices and sensors in the bottom layer	
Additional devices and capabilities	Chlorophyll and turbidity, oil pollution, video/image

MINI platform in the Väinameri area

Main purpose	Continuous monitoring of the environmental status and navigation information in Väinameri near the shipping lane
Suggested location	Väinameri, NE direction from Muhu island. It will be negotiated with relevant authorities if a navigational buoy can be replaced by this GORSMART platform
Depth	5 m
Type	MINI
Anchoring solution	Two lines
Energy solution	Solar panels, batteries
Communication	Mobile network

Devices and sensor (air)	Wind direction and speed, air temperature, air pressure, humidity and if possible, also visibility
Devices and sensors (surface layer)	Water temperature, salinity, current speed and direction, waves (height, period, direction), oil pollution, video/image
Devices and sensors for profiling	Current speed and direction
Devices and sensors in the bottom layer	Pressure (for determining water level), temperature, salinity, oxygen
Additional devices and capabilities	Chlorophyll and turbidity

MINI platform in the Matsalu Bay

Main purpose	Continuous monitoring of the environmental status and estimating the loads from river Kasari and their impacts
Suggested location	Matsalu Bay
Depth	2 m
Type	MINI
Anchoring solution	One line
Energy solution	Solar panels, batteries
Communication	Mobile network
Devices and sensor (air)	Wind direction and speed, air temperature, air pressure and humidity
Devices and sensors (surface layer)	Water temperature, salinity, current speed and direction, chlorophyll, turbidity, nitrates
Devices and sensors for profiling	
Devices and sensors in the bottom layer	
Additional devices and capabilities	

MINI platform off Riga and Daugava mouth

Main purpose	Continuous monitoring of the environmental status and human impact in the area, close to Riga and major river mouths, including collection and real-time transmission of meteorological and oceanographic information
Suggested location	Off Riga
Depth	20 m
Type	MINI
Anchoring solution	One (two) line(s)
Energy solution	Solar panels, batteries
Communication	Mobile network
Devices and sensor (air)	Wind direction and speed, air temperature, air pressure, humidity
Devices and sensors (surface layer)	Water temperature, salinity, current speed and direction, waves (height, period, direction), oil pollution
Devices and sensors for profiling	

Devices and sensors in the bottom layer	
Additional devices and capabilities	Chlorophyll and turbidity, video/image

MINI platform in the Väike Väin

Main purpose	Continuous monitoring of the environmental status in Väike Väin and detecting potential changes after creating openings through the dam (building a bridge)
Suggested location	Väike Väin
Depth	2 m
Type	MINI
Anchoring solution	One line
Energy solution	Solar panels, batteries
Communication	Mobile network
Devices and sensor (air)	Wind direction and speed, air temperature, air pressure and humidity
Devices and sensors (surface layer)	Water temperature, salinity, chlorophyll, turbidity, and oxygen
Devices and sensors for profiling	
Devices and sensors in the bottom layer	
Additional devices and capabilities	

2.4.3. Data handling

It is proposed that the GORSMART project should use the same data handling platform that will be developed within the "Merehunt" project.

The smart buoy network, together with the data management platform, represents a complex set of integrated systems (Figure 7). The system design and operation ensure correct data measurement at sea and its transmission to users' computers, databases or smart devices in the form of real-time measurement data or a cleaned and/or aggregated form for the preparation of reports, analyses and forecasts.

For the development of the data management platform, a procurement process will be launched that outlines the specific conditions for data management. These include real-time data handling requirements, mobile user interface solution requirements, reporting requirements, data acquisition requirements, streaming data processing requirements, integration requirements, security and business continuity requirements, performance requirements, and usability requirements. These requirements are defined within the "Merehunt" project. No additional requirements are needed regarding the GORSMART project, except an access definition for the users outside Estonia. If the data are available freely, it has no implications. If the data are restricted for certain authorities, then it requires an agreement between the relevant Estonian and Latvian authorities.

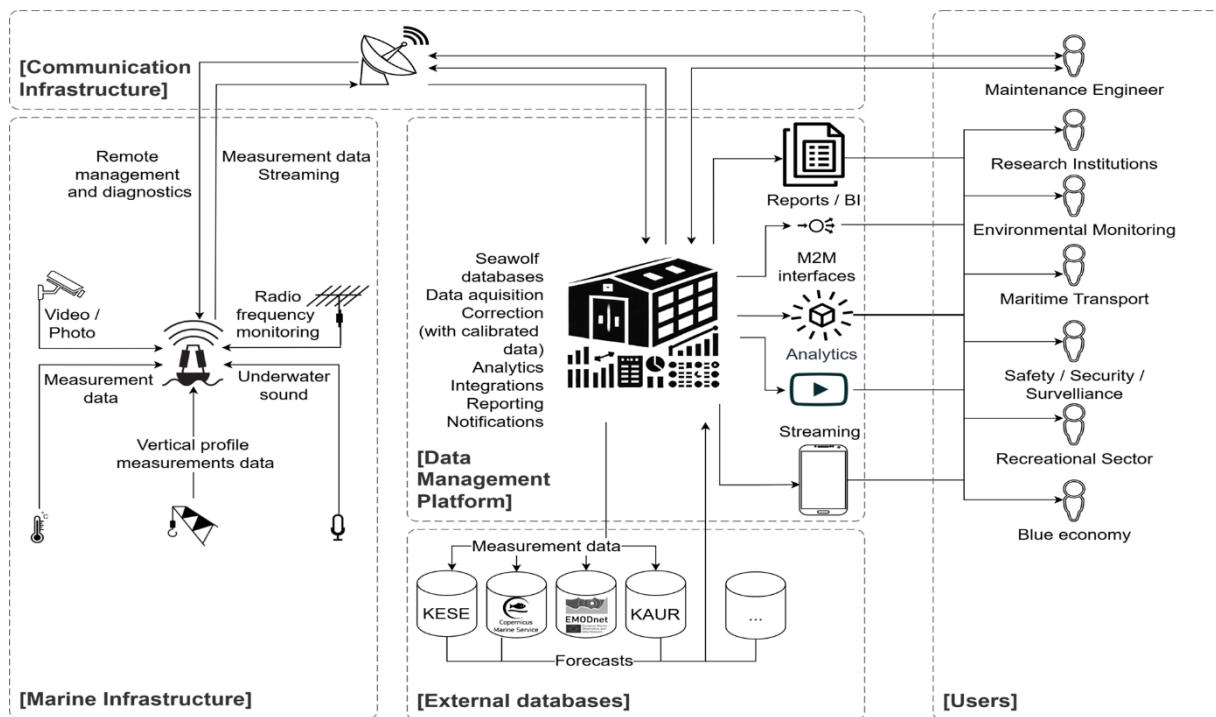


Figure 7. Sketch of the integrated system of smart buoys and data handling platform (source: “Merehunt” project).

It is planned that the data management platform of the smart buoy network “Merehunt” will gradually interface with the following databases and data sources of state and situation information for the Estonian maritime area and the Baltic Sea:

- Data from coastal stations of the Estonian Environment Agency;
- Sea level information system and wave information system Lainepoiss of the Department of Marine Systems (TalTech);
- Marine forecasts (model results) of the Estonian Environment Agency in the Estonian maritime area;
- Environmental monitoring information system KESE;
- Hydrographic information system;
- Official data sources (including ice data);
- EMODnet bathymetry and EMODnet geology;
- AIS.

For the GORSMART area, it should be discussed with data holders in Latvia, which databases and streams can be made available for the GORSMART network.

2.5. Next steps and the basic requirements for the development

The ability of smart buoys to respond and optimize their activities automatically according to the prevailing environmental conditions (weather, sea conditions, pollution) was considered in the analysis. Similar to the “Merehunt” platforms, all buoys include a controller and scripts for their automatic response to changing conditions and disruptions. All measurement data collected

from the sensors are stored in the internal memory of the controller and are deleted from there only after they have been sent to the server and the server has confirmed that the data has been received. In addition to the sensors, the control unit also logs important diagnostic parameters such as battery voltage, system power consumption, data communication quality indicators and GPS coordinates.

The software allows the operators to set limit values for various parameters and send notifications (SMS, email) from the buoy if any value goes outside the limits. For example, each buoy has a set installation location zone and if the GPS coordinates of the buoy fall outside the zone, the user will be notified.

The controller software monitors the energy balance of the buoy platform and, if necessary, reduces the measurement cycles of the sensors if the battery voltage drops below a predetermined limit. The controller automatically sends the data to the data management platform. This is done immediately after each measurement/profile or at a user-defined interval, depending on the requirements of the specific buoy platform. The data transmission intervals can be set remotely by the user.

All GORSMART platforms are designed to operate in ice-free conditions. Thus, the buoys will be deployed in early spring and recovered in late autumn. An exception could be applied if a platform is combined with a navigational buoy, which must be in place for the whole year. However, it will potentially increase the cost of such a buoy.

In the following sub-sections, the technical specifications of six potential GORSMART platforms will be described.

2.5.1. Large (MIDI) platform in the Irbe Strait

The aim is to collect environmental data from the Irbe Strait, which would reflect the environmental state (including meteorological and hydrographic conditions), enable the detection of pollution, characterize the water exchange between the Gulf of Riga and the open Baltic Sea, and provide input for the development of marine forecasts and digital twins. The proposed location is the central part of the Irbe Strait (deeper channel) with a depth of 25 m. The platform will be located near the shipping lane and the long-term monitoring station.

Platform capabilities, equipment and sensors

The parameters to be measured by the platform in the Irbe Strait will be the following:

- Meteorology: wind direction and speed, air temperature, air pressure, air humidity, irradiation;
- Parameters on the water surface: water temperature, salinity, current speed and direction, waves (height, period, direction), chlorophyll and turbidity, oil pollution, video/image;
- Profiles: temperature, salinity, chlorophyll, oxygen, turbidity, current speed and direction;
- Parameters in the bottom layer: temperature, salinity, oxygen;
- Possible additional sensors and/or devices: underwater sound.

Technical solutions: solar panels, which cover the need for 10 months of the year. In winter, the platform can be brought out or put into economy mode. The primary communication solution would be mobile communication, which works very well in the area. The buoy will be equipped with a GPS device for continuous monitoring of its location.

At least two anchor lines are required to enable the movement of the profiling device. The winch for winding the cable is located on the platform. The profiling device moves up and down with a

cable through the center of the buoy. A seabed-mounted current profiler (ADCP) is used to record currents. The bottom sensors can be integrated with the ADCP; however, if desired, a separate hydrophone can be placed on the seabed. A separate buoy measures wave parameters. The remaining airborne and surface layer sensors are connected to the buoy.

Table 1. Technical specifications of the sensors of the Irbe Strait platform

Parameter	Accuracy	Ranges	Resolution	Unit	Interval
Wind direction	3	0-359	1	°	1 s
Wind speed	2%	0-60	0.1	m/s	1 s
Air temperature	0.2	-20 - +30	0.01	°C	1 s
Air pressure	0.01%	800-1100	0.1	hPa	1 s
Humidity	3	0-100	0.4	%	1 s
Irradiance	1%	0-1600	0,4	W/m ²	1 s
Water temperature	<= 0.01	-2 ... +35	<= 0.002	°C	0.25 s / 10 min
Conductivity	<= 0.01	0...70	<=0.003	mS/cm	0.25 s / 10 min
Dissolved oxygen	<=5	0...120	<=1	%	10 s / 10 min
Chlorophyll a fluorescence	Sensitivity <=0.05	0.05-50		mg/m ³	10 s / 10 min
Turbidity	Sensitivity <=0.05	0...25		NTU/FTU	10 s / 10 min
Current speed	0.5 cm/s or 1 %	0-150	0.1	cm/s	10 min
Current direction	3	0-359	0.1	°	10 min
Wave height	0.1	0-10	0.01	m	30 min
Wave period	0.5	1.5-15	0.1	s	30 min
Wave direction	5	0-359	0.1	°	30 min
Oil pollution	Sensitivity 1 µm oil film	Range from the surface 2 m		µm (thickness)	10 s

The determination of oil spills on the water surface will be solved by a ready-to-use lidar device. If funding allows, an approach utilizing a thermal camera that requires developing the algorithms and testing the method can be planned. Underwater sound measurement and its methodologies will be agreed upon during the test period. When adding a camera, the initial methodology proposed is to transmit images at 15-second intervals.

2.5.2. MINI platform in the Pärnu Bay

The aim is to collect environmental data from the Pärnu Bay area. The collected data would reflect the environmental state of this area of the bay (including meteorological and hydrographic

conditions) and would provide input for the development of marine forecasts and digital twins. The Pärnu Bay area is important due to shipping traffic, land-based loads (and the resulting pressure) and a large number of users (including holidaymakers). Due to its location, buoy maintenance can be organized relatively easily and quickly. The Pärnu Bay buoy would be located in the area seasonally, i.e. would collect data from spring to autumn.

Platform capabilities, equipment and sensors

The parameters to be measured by the Pärnu Bay MINI platform would be the following:

- Meteorology: wind direction and speed, air temperature, air pressure, and humidity; additionally, irradiation could be measured;
- Parameters on the water surface: water temperature, salinity, current speed and direction, waves (height, period, direction), oil pollution, chlorophyll and turbidity, possibly also video/image;

Technical solutions: Solar panels and batteries, which ensure the need throughout the year, but the buoy operates only seasonally due to the winter conditions of the Pärnu Bay. Mobile communication is available in the area, it would be necessary to add a GPS device to track the platform's location.

One anchor line is sufficient for the installation of the platform. The wave buoy should be installed separately.

Table 2. Technical specifications of the sensors (Pärnu Bay)

Parameter	Accuracy	Ranges	Resolution	Unit	Interval
Wind direction	3	0-359	1	°	1 s
Wind speed	2%	0-60	0.1	m/s	1 s
Air temperature	0.2	-20 - +30	0.01	°C	1 s
Air pressure	0.01%	800-1100	0.1	hPa	1 s
Humidity	3	0-100	0.4	%	1 s
Water temperature	<= 0.01	-2 ... +35	<= 0.002	°C	10 min
Conductivity	<= 0.01	0...70	<=0.003	mS/cm	10 min
Current speed	0.5 cm/s or 1 %	0-150	0.1	cm/s	10 min
Current direction	3	0-359	0.1	°	10 min
Chlorophyll a fluorescence	Sensitivity <=0.05	0.05-50		mg/m ³	10 min
Turbidity	Sensitivity <=0.05	0...25		NTU/FTU	10 min
Wave height	0.1	0-10	0.01	m	30 min
Wave period	0.5	1.5-15	0.1	s	30 min
Wave direction	5	0-359	0.1	°	30 min

Oil pollution	Sensitivity 1 µm oil film	Range from the surface 2 m		µm (thickness)	10 s
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The determination of oil spills on the water surface will be solved by a ready-to-use lidar device. If funding allows, an approach utilizing a thermal camera that requires developing the algorithms and testing the method can be planned. When adding a camera, the initial methodology proposed is to transmit images at 15-second intervals.

2.5.3. MINI platform in the southern Gulf of Riga

The aim is to collect environmental data in the area under the impact of two major rivers (Daugava River and Lielupe River) and the city of Riga. The collected data would reflect the environmental state of this area. Since the Daugava River is the largest freshwater source to the Gulf of Riga, it would be essential for assessing its direct impact both locally and for the entire gulf. Data would provide input for the development of marine forecasts and digital twins. The platform will be situated in the Latvian coastal waters, and Latvian institutions could arrange its maintenance.

Platform capabilities, equipment and sensors

The parameters to be measured would be the following:

- Meteorology: wind direction and speed, air temperature, air pressure, and humidity;
- Parameters on the water surface: water temperature, salinity, current speed and direction, waves (height, period, direction), oil pollution, chlorophyll and turbidity, possibly also nitrates and video/image;

Technical solutions: Solar panels and batteries, which ensure the need throughout the year, but the buoy operates only seasonally due to the winter conditions. Mobile communication is available in the area. It would be necessary to add a GPS device to track the platform's location.

One anchor line is sufficient for the installation of the platform. The wave buoy should be deployed separately.

Table 3. Technical specifications of the sensors (Daugava)

Parameter	Accuracy	Ranges	Resolution	Unit	Interval
Wind direction	3	0-359	1	°	1 s
Wind speed	2%	0-60	0.1	m/s	1 s
Air temperature	0.2	-20 - +30	0.01	°C	1 s
Air pressure	0.01%	800-1100	0.1	hPa	1 s
Humidity	3	0-100	0.4	%	1 s
Water temperature	<= 0.01	-2 ... +35	<= 0.002	°C	10 min
Conductivity	<= 0.01	0...70	<=0.003	mS/cm	10 min
Current speed	0.5 cm/s or 1 %	0-150	0.1	cm/s	10 min

Current direction	3	0-359	0.1	°	10 min
Chlorophyll a fluorescence	Sensitivity ≤0.05	0.05-50		mg/m ³	10 min
Turbidity	Sensitivity ≤0.05	0...25		NTU/FTU	10 min
Wave height	0.1	0-10	0.01	m	30 min
Wave period	0.5	1.5-15	0.1	s	30 min
Wave direction	5	0-359	0.1	°	30 min
Nitrates	± (5 % + 0.1)	0-100	0.01	mg/l	12 hours
Oil pollution	Sensitivity 1 µm oil film	Range from the surface 2 m		µm (thickness)	10 s

The determination of oil spills on the water surface will be solved by a ready-to-use lidar device. If funding allows, an approach utilizing a thermal camera that requires developing the algorithms and testing the method can be planned. When adding a camera, the initial methodology proposed is to transmit images at 15-second intervals.

2.5.4. MINI platform in the Väinameri

The aim is to collect environmental data and navigation information in the vicinity of the Väinameri waterway. The collected data would reflect meteorological and hydrographic conditions in the area, provide input for the development of marine forecasts and digital twinning, and enable the development of remote pilotage services in the Väinameri waterway. The proposed location is the sea area northeast of Muhu Island, which is one of the most dangerous areas in the Väinameri waterway. Important information to be collected would be wind and current conditions, water level, and possible detection of pollution.

The platform is related to the objectives of remote pilotage development. There is a potential to combine this platform with a navigational mark in the area. This will be studied further on and agreed with the Transport Administration.

Platform capabilities, equipment, and sensors

The parameters to be measured by the Väinameri MINI platform would be the following:

- Meteorology: wind direction and speed, air temperature, air pressure, air humidity, and possibly visibility;
- Parameters on the water surface: water temperature, salinity, current speed and direction, waves (height, period, direction), pollution, video/image, chlorophyll and turbidity can also be added;
- Profiles: current speed and direction;
- Parameters in the bottom layer: pressure (to determine water level), temperature, salinity, and oxygen.

Technical solutions: Solar panels, which ensure the need throughout the year. In winter, the platform can be deployed when there is no navigation and/or ice. The communication solution

would be mobile communication, which works very well in the area. The buoy would be equipped with a GPS device to continuously monitor its location.

At least two anchor lines are required for the installation of the platform to fix the camera direction. Wave parameters are measured either by a separate buoy or by a pressure sensor on the bottom (which does not allow determining the direction of the wave). The airborne and surface layer sensors are connected to the buoy.

Table 4. Technical specifications of sensors

Parameter	Accuracy	Ranges	Resolution	Unit	Interval
Wind direction	3	0-359	1	°	1 s
Wind speed	2%	0-60	0.1	m/s	1 s
Air temperature	0.2	-20 - +30	0.01	°C	1 s
Air pressure	0.01%	800-1100	0.1	hPa	1 s
Humidity	3	0-100	0.4	%	1 s
Visibility	20%	0.01-10	0.01	km	30 min
Water temperature	<= 0.01	-2 ... +35	<= 0.002	°C	10 min
Conductivity	<= 0.01	0...70	<=0.003	mS/cm	10 min
Current speed	0.5 cm/s or 1 %	0-150	0.1	cm/s	10 min
Current direction	3	0-359	0.1	°	10 min
Dissolved oxygen	<=5	0...120	<=1	%	10 s / 10 min
Chlorophyll a fluorescence	Sensitivity <=0.05	0.05-50		mg/m ³	10 s / 10 min
Turbidity	Sensitivity <=0.05	0...25		NTU/FTU	10 s / 10 min
Wave height	0.1	0-10	0.01	m	30 min
Wave period	0.5	1.5-15	0.1	s	30 min
Wave direction	5	0-359	0.1	°	30 min
Pressure (detecting water level)	<= 0.1 % of the range	0...200	<= 0.01% of the range	dbar	10 min
Oil pollution	Sensitivity 1 µm oil film	Range from the surface 2 m		µm (thickness)	10 s

The determination of oil spills on the water surface will be solved by a ready-to-use lidar device. If funding allows, an approach utilizing a thermal camera that requires developing the algorithms and testing the method can be planned. When adding a camera, the initial methodology proposed is to transmit images at 15-second intervals.

2.5.5. MINI platform in the Matsalu Bay

The aim is to continuously monitor the environmental status of Matsalu Bay in a nature reserve area. It allows for the assessment of the impact of the load from the Kasari River on the marine environment. It could attract the public and serve as an environmental education platform.

Platform capabilities, equipment, and sensors

The parameters to be measured would be the following:

- Meteorology: wind direction and speed, air temperature, air pressure, and humidity;
- Parameters on the water surface: Water temperature, salinity, current speed and direction, chlorophyll, turbidity, nitrates.

Technical solutions: Energy is produced by solar panels. In winter, the platform will be taken out in emerging ice conditions. The communication solution would be mobile communication, which works very well in the area. The buoy would be equipped with a GPS device to continuously monitor its location. One anchor line is required to deploy the platform.

Table 5. Technical specifications of sensors

Parameter	Accuracy	Ranges	Resolution	Unit	Interval
Wind direction	3	0-359	1	°	1 s
Wind speed	2%	0-60	0.1	m/s	1 s
Air temperature	0.2	-20 - +30	0.01	°C	1 s
Air pressure	0.01%	800-1100	0.1	hPa	1 s
Humidity	3	0-100	0.4	%	1 s
Water temperature	<= 0.01	-2 ... +35	<= 0.002	°C	10 min
Conductivity	<= 0.01	0...70	<=0.003	mS/cm	10 min
Current speed	0.5 cm/s or 1 %	0-150	0.1	cm/s	10 min
Current direction	3	0-359	0.1	°	10 min
Chlorophyll a fluorescence	Sensitivity <=0.05	0.05-50		mg/m ³	10 s / 10 min
Turbidity	Sensitivity <=0.05	0...25		NTU/FTU	10 s / 10 min
Nitrates	± (5 % + 0.1)	0-100	0.01	mg/l	12 hours

2.5.6. MINI platform in the Väike Väin

The aim is to continuously monitor the environmental status in Väike Väin and detect potential changes after the opening of the waterway through the dam (building a bridge). It could attract the public and serve as an educational platform for environmental awareness.

Platform capabilities, equipment, and sensors

The parameters to be measured would be the following:

- Meteorology: wind direction and speed, air temperature, air pressure, and humidity;
- Parameters on the water surface: Water temperature, salinity, chlorophyll, turbidity, and oxygen.

Technical solutions: Energy is produced by solar panels. In winter, the platform will be taken out in emerging ice conditions. The communication solution would be mobile communication, which works very well in the area. The buoy would be equipped with a GPS device to continuously monitor its location. One anchor line is required to deploy the platform.

Table 6. Technical specifications of sensors

Parameter	Accuracy	Ranges	Resolution	Unit	Interval
Wind direction	3	0-359	1	°	1 s
Wind speed	2%	0-60	0.1	m/s	1 s
Air temperature	0.2	-20 - +30	0.01	°C	1 s
Air pressure	0.01%	800-1100	0.1	hPa	1 s
Humidity	3	0-100	0.4	%	1 s
Water temperature	<= 0.01	-2 ... +35	<= 0.002	°C	10 min
Conductivity	<= 0.01	0...70	<=0.003	mS/cm	10 min
Chlorophyll a fluorescence	Sensitivity <=0.05	0.05-50		mg/m ³	10 s / 10 min
Turbidity	Sensitivity <=0.05	0...25		NTU/FTU	10 s / 10 min
Dissolved oxygen	<=5	0...120	<=1	%	10 s / 10 min

2.6. Cost estimation

Cost estimates of three development stages of the GORSMART network are provided below, including a pilot solution, a medium-term solution and a complete solution. Also, an alternative solution is considered with lower costs for the pilot phase. In addition, we estimated the costs of ownership (maintenance, servicing, calibration, etc.) of the GORSMART buoy network. The cost assessments take into account long-term experience in conducting autonomous and operational marine observations and services by the Department of Marine Systems of TalTech. We have estimates of the investment needs and operating costs of similar systems.

2.6.1. Pilot solution

The pilot solution is described as a small-scale pilot project with the installation and testing of a limited number of smart buoys. This includes the installation and maintenance of 1-3 smart buoys, data transmission and basic monitoring systems. The solution is suitable for operational

piloting in the initial phase, where it is necessary to collect initial data and assess the performance of the system. Integration with the “Merehunt” smart buoy network is foreseen.

The suggested timeframe for this solution is 1-5 years from the start of the project. The Client indicated that its costs should fall into the range of 500,000 € to 900,000 €.

We suggest that a pilot solution would include three GORSMART platforms, one large platform in the Irbe Strait, one small platform in the Väinameri area and one small platform in the Pärnu Bay (or alternatively in the sea area off Riga). The latter alternative means higher maintenance costs if it is provided by an Estonian organization.

Estimates of investment costs are given in Table 7. In this estimate, an assumption is made that the development work for the data management platform is financed through the “Merehunt” project. Nevertheless, it could involve some specific software development for the GORSMART purposes to link the platforms to the central “Merehunt” system. An approximate estimate of this work is about 20,000 € per year that sums up to 60,000 € for 2026-2028.

Table 7. Estimates of investment costs in the case of a pilot solution with three GORSMART platforms.

Irbe Strait Platform	
Part/item/device/sensor	Cost estimate
Float with solar panels, batteries and data logger	50 000.00 €
Sensors on the platform (including meteo)	48 200.00 €
Camera	20 500.00 €
Wave buoy	7 600.00 €
Profiling module	30 200.00 €
Profiling probe and sensors	31 000.00 €
Bottom sensors (including ADCP)	65 600.00 €
Hydrophone	18 200.00 €
Anchoring	3 200.00 €
TOTAL - Irbe Strait platform	274 500.00 €
Väinameri Platform	
Part/item/device/sensor	Cost estimate
Float with solar panels, batteries and data logger	25 200.00 €
Sensors on the platform (including meteo)	45 700.00 €
Camera	20 500.00 €
Wave buoy	7 600.00 €
Bottom sensors (including ADCP)	64 700.00 €
Hydrophone	18 200.00 €
Anchoring	3 000.00 €
TOTAL - Väinameri platform	184 900.00 €
Pärnu Bay Platform	
Part/item/device/sensor	Cost estimate

Float with solar panels, batteries and data logger	25 200.00 €
Sensors on the platform (including meteo)	48 200.00 €
Camera	20 500.00 €
Wave buoy	7 600.00 €
Anchoring	3 000.00 €
TOTAL - Pärnu Bay platform	104 500.00 €
GRAND TOTAL of the solution	563 900.00 €

Additional costs are related to the deployment, recovery, maintenance, servicing and procedures to ensure data quality of platforms. The buoys are deployed in early spring and recovered in late autumn. If a two-day cruise is sufficient for that and applying an estimate of 10,000 EUR per day at sea for a working vessel, the amount for logistics is 40,000 €. We assume that these cruises are combined with regular cruises for deploying and recovering seasonal navigational buoys. Thus, half of the costs will be taken into account.

If accounting for a servicing interval of three months, two additional cruises during the summer to all platforms must be carried out. Since it is not needed to recover the buoys, it can be arranged using a smaller vessel. If assuming its daily costs at 3,000 €, the total costs of 12,000 € can be estimated.

Optical sensors working in the marine environment (especially in the turbid waters of the Baltic Sea) need to be calibrated by collecting water samples and analyzing them in the laboratory. Keeping the calibration interval as long as possible, at least six times a year, the sampling must be arranged. If this is done during the marine monitoring cruises, additional costs for logistics can be avoided. However, the costs of laboratory analyses have to be considered. An approximate estimate of these costs is 15,000 € per year.

We must also consider additional costs for engineers and experts, especially those engaged in initial deployments and testing of all systems. However, this must also be considered for the later operational period. Based on the experience of the Department of Marine Systems, yearly labor costs can be as high as 40,000 €.

Thus, the overall cost estimate for the pilot solution would be about 885,000 €. See the calculations in Table 8.

Table 8. Total cost estimate for the pilot solution of the GORSMART network.

Item		Cost estimate
Investment	3 platforms	563 900.00 €
IT-costs	3 years	60 000.00 €
Logistics	3 years	96 000.00 €
Laboratory analyses	3 years	45 000.00 €
Experts, additional workload	3 years	120 000.00 €
TOTAL		884 900.00 €

2.6.2. Medium solution

The medium solution contains, in addition to the pilot solution, additional data analysis tools, an expanded monitoring network (construction of additional buoys) and improved integration with existing systems. The solution is suitable for post-pilot activities and for building a larger network.

The suggested timeframe for this solution is 5-10 years from the start of the project. The Client indicated that its costs should fall into the range of 900,000 € to 1,800,000 €.

We propose that the medium solution includes all six suggested prototypes of smart buoys. Accordingly, the investment costs will increase by about 400,000 €. In the summary table below (Table 9), the costs for the software development (e.g., needed for the implementation of thermal cameras for the oil spill detection) are included. Also, all maintenance costs will increase by the number of additional years. We made calculations based on the costs for the operational use of the GORSMART network for 6 years. Replacement costs for the network sensors are estimated as 30% of the initial investment (during the pilot phase). It is based on the experience of the Department of Marine Systems.

Table 9. Total cost estimate for the medium solution of the GORSMART network.

Item		Cost estimate
Investment	6 platforms	965 000.00 €
Development of additional data analysis tools	1 set	80 000.00 €
Replacement of sensors/devices	6 years	170 000.00 €
IT-costs	6 years	120 000.00 €
Logistics	6 years	192 000.00 €
Laboratory analyses	6 years	90 000.00 €
Experts	6 years	240 000.00 €
TOTAL		1 857 000.00 €

2.6.3. Complete solution

The complete solution is the most comprehensive, incorporating advanced technology, real-time data transmission, an extensive monitoring network and advanced data analysis. The solution would be part of the long-term concept of the “Merehunt” project.

The suggested timeframe for this solution is 10-15 years from the start of the project. The Client indicated that its costs should fall into the range of 1,800,000 € to 2,700,000 €.

We propose that the complete solution includes two more smart buoys. Accordingly, the sum of investments is increased to 1,250,000 €. (Table 10). The costs for the software development (e.g., employing aerial drone systems) are estimated at 200,000 €. Also, all maintenance costs will increase by the number of additional years. We made calculations based on the costs for the operational use of the GORSMART network for 10 years. Replacement costs for the network

sensors are estimated as 30% of the initial investment (during the pilot phase). It is based on the experience of the Department of Marine Systems.

Table 10. Total cost estimate for the complete solution of the GORSMART network.

Item		Cost estimate
Investment	8 platforms	1 250 000.00 €
Development of additional data analysis tools	1 set	200 000.00 €
Replacement of sensors/devices	10 years	300 000.00 €
IT-costs	10 years	200 000.00 €
Logistics	10 years	320 000.00 €
Laboratory analyses	10 years	150 000.00 €
Experts	10 years	400 000.00 €
TOTAL		2 820 000.00 €

2.6.4. Alternative solution

An alternative solution is a modular system, a public-private partnership, allowing for the gradual addition of new components and expansion of the network according to the needs of universities, maritime companies and public authorities.

The suggested timeframe for this solution is 1-10 years from the start of the project. The Client indicated that its costs should be up to 500,000 €.

Depending on the focus of the alternative solution, some items and costs described in the pilot solution section can be skipped. If, for instance, other funding sources are secured by private or public partners, then the GORSMART share could be kept as low as 500,000 €. However, it must be negotiated and agreed (ideally via service level contracts) how to secure the data flow from those partners in the long run. We do not see it as feasible to propose such an alternative solution without further discussions and clarifications.

2.6.5. Total ownership costs

The cost of ownership, administration and maintenance of the smart buoys developed during the study for the State Fleet is estimated. The total cost estimate includes the following items: Initial costs for the installation of the smart buoys intended for piloting in 2025-2026; Costs for the post-installation period in 2026-2028; Ownership and maintenance costs in the post-project period 2028-2033, including recommendations and proposals for optimizing administrative and maintenance costs.

The costs for the ownership can be derived from the complete solution cost estimate table (Table 10). This is presented below in Table 11. The only addition or change is made for the replacement costs. It is estimated based on the total investment costs of 1,250,000 €. We assume that the lifetime of the systems in general is 20 years. Thus, a yearly investment cost

would be 62,500 €. Based on estimates in Table 11, ownership costs for different periods can be calculated.

Table 11. Estimates of yearly ownership costs of the GORSMART network.

Item		Cost estimate
Replacement of sensors/devices	1 year	62 500.00 €
IT-costs	1 year	20 000.00 €
Logistics	1 year	32 000.00 €
Laboratory analyses	1 year	15 000.00 €
Experts	1 year	40 000.00 €
TOTAL		169 500.00 €