RAMONES
Radioactivity Monitoring in Ocean Ecosystems

Deliverable

Document ID: D5.19 Vision and Blueprint for Environmental Intelligence in Europe no1

31/12/2021

RAMONES funded by European Union under Horizon 2020 FET Proactive programme via grant agreement No.101017808

Document Info

Project Information			
Acronym	RAMONES		
Name	Radioactivity Monitoring in Ocean Ecosystems		
Start Date	1 Jan 2021	End Date	31 Dec 2024
Program	H2020-EU.1.2.2. - FET Proactive		
Call ID	H2020-FETPROACT-2020-2	Topic	FETPROACT-EIC-08-2020 - Environmental Intelligence
Grant No	101017808	Instrument	RIA

Document Information			
Document Id	D5.19		
Document Title	Vision and Blueprint for Environmental Intelligence in Europe no1		
Due Date	31-Dec-2021	Delivery Date	15-12-2021
Lead Beneficiary	NKUA(1)		
Beneficiaries (part.)	NKUA(1), IST-ID(2), EVOL(3), ENS(4), NTUA(5), PLOA(6), UDUR(7), UCA(8)		
Editor(s)	Theodoros Mertzimekis (NKUA)		
Authors (s)	Mark Mulligan[a], Javier Senent-Aparicio[b], José M. Cecilia[c], Laura García-Carmona, Heiko Hamann, Theodoros J. Mertzimekis[e], Barbara Mazzolai[d] a. Department of Geography, King's College London, (North East Wing), 30 Aldwych London WC2B 4BG. PI of ReSET. b. Department of Civil Engineering, Catholic University of Murcia (UCAM), Campus de Los Jerónimos, Murcia (Spain). PI of SMARTLAGOON c. Department of Computer Engineering, Universitat Politècnica de València, Camino de vera s/n, Valencia (Spain). UPV-PI of SMARTLAGOON d. Bioinspired Soft Robotics Laboratory, Istituto Italiano di Tecnologia (IIT), via Morego 30, 16163, Genova (Italy). PI of I-Seed. e. Department of Physics, National and Kapodistrian University of Athens GR-15784, Athens, Greece		
Contributor (s)	Eleni Petra, Effie Zafeirakopoulou, Stavroula Kazana, Konstantina Bejelou (NKUA), Pedro Batista, Antonio Pascoal, Luis Sebastiao, David Cabecinhas (IST-ID), Konstantinos Nikolopoulos (UDUR), Konstantinos Karantzalos, Valsamis Ntouskos (NTUA), Lydia Maigne (UCA), Javier Escartin (ENS), Konstantin Kebkal (EVOL)		
Reviewer(s)	Angelos Mallios (PLOA)		
Workpackages	WP5 - Citizen Awareness, Dissemination and Communication Activities		
Version	V1.0	Stage	Submission
Distribution	Public		
Keywords	Environmental Intelligence, Underwater Research, Radioactivity	Type	DEC

Document Change Record

Version	Date	Change Description	Editor	Change Location (page/section)
1.0	31.12.2021	Document version submitted to EC	Theodoros Mertzimekis (NKUA)	

Disclaimer

RAMONES is a European Innovation Council (EIC) FET Proactive project in the Environmental Intelligence Scope B, related to radically novel approaches to resilient, reliable and environmentally responsible in-situ monitoring, funded by European Union under Horizon 2020 FET proactive programme, via grant agreement No. 101017808.

RAMONES project's main objective is to close the current marine radioactivity gap in sampling needs and foster new interdisciplinary research in ocean ecosystems. RAMONES will invest a significant effort to provide tools to enable long-term data acquisition missions, rapid deployments, low cost per information byte, and propose new AI and Robotics-driven and supported methodologies, being ambitious to eventually offer scaled-up solutions to researchers, policy makers and communities. These goals will be achieved by combining state-of-the-art (SoA) methodologies and equipment from various disciplines in a well-balanced synergy. It will also design new and effective methodologies targeting the marine environment, which will provide efficient response to existing natural and man-made hazards, and shape future policies for the global population. RAMONES will additionally contribute to shaping a blueprint on Environmental Intelligence in the EU and worldwide.

This document has been produced through funding from the European Commission. The content of this document is a product of the RAMONES project Consortium and it does not necessarily reflect the opinion of the European Commission. The editor, author, contributors and reviewers of this document have taken any available measure in order for its content to be accurate and lawful. However, neither the project consortium as a whole, nor the individual partners that have implicitly or explicitly participated in the creation and publication of this document may be held responsible for any damage, financial or other loss or any other issue that may arise as a result of using the content of this document or any of the project outputs that this document may refer to.

The European Union (EU) was established in accordance with the Treaty on the European Union (Maastricht). There are currently 27 member states of the European Union. It is based on the European Communities and the member states' cooperation in the fields of Common Foreign and Security Policy and Justice and Home Affairs. The five main institutions of the European Union are the European Parliament, the Council of Ministers, the European Commission, the Court of Justice, and the Court of Auditors (http://europa.eu.int/).

List of acronyms

Acronym	Description
AEMET	Agencia Estatal de Meteorología
AI	Artificial Intelligence
API	Application Programming Interface
CTD	Conductivity, Temperature, Depth
EI	Environmental Intelligence
EIS	Environmental Intelligence Systems
ESA	European Space Agency
EU	European Union
FAIR	Findability, Accessibility, Interoperability, and Reusability
FET	Future and Emerging Technologies
GPS	Global Positioning System
GSM	Global System for Mobile Communications
LiDAR	Light Detection and Ranging
LoRa	Long Range
IARPC	Interagency Arctic Research Policy Committee
ICT	Information and Communication Technologies
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
MCS	Mobile Crowdsourcing
OA	Open Access
OS	Open Source
PCB	Printed Circuit Board
SME	Small and Medium Enterprise
SSIV	Surface Structure Image Velocimetry
UN	United Nations
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
UNITAR	United Nations Institute for Training and Research
WLAN	Wireless Local Area Network

Table of Contents

Tables of Figures & Tables

Executive Summary

In this deliverable we define Environmental Intelligence, outline its key components, and why it is needed to better address environmental challenges in Europe and beyond. We also indicate the key challenges and the solutions adopted so far by the five projects in addressing these challenges. We classify the challenges under the headings: Hardware; Software; Networks; People, Training and Engagement, and Policy, all of which seem to be common across the five projects.

Environmental Intelligence (EI) brings together multiple data streams (facts) from ground, air, space and marine based sensors, living organisms, satellite and citizen sources with cutting-edge and efficient hardware, software and analytical technology employing human reasoning and machine learning to better understand and manage the environment. EI is not just about measurement, analysis and processing of data, but also about getting the right information to the right people at the right time in forms which support decision making and policy shaping. In this way, environmental intelligence systems (EIS) are not dissimilar from decision support systems or policy support systems. The difference seems to be the greater attention to integration of a wide range of data sources and technologies in EIS, but also the use of machine learning techniques to mine such information for intelligence.

Hardware challenges include energy autonomy, environmental tolerance, processing power and ability to sense various environmental variables in harsh environmental conditions. Software challenges include the need for intelligent, adaptable processing to cope with the huge array of different data available and the constantly changing data landscape. Network challenges include both bringing together the relevant networks of decision-makers involved in complex environmental decisions, but also the challenges of computing networks for distributed sensors that are resilient and low-power. People, training and engagement challenges include managing the contentious nature of many environmental issues and issues of trust and legitimacy around data. Policy challenges include navigating the complex policy landscapes associated with environmental policy and management and bridging the toolset available in academia with those tools and processes routinely used in regulation, policy development and investment decision-making. This first iteration of the *Environmental Intelligence* blueprint explores these challenges from the perspective of the five FET projects after almost one year of work.

1. Introduction

This document is the first iteration of a collaborative Blueprint for European Environmental Intelligence and is produced jointly by five projects of the Horizon2020 **Future and Emerging Technologies** (FET) Call in *Environmental Intelligence*: I-Seed, RAMONES, ReSET, SmartLagoon and Watchplant.

It aims to advance the understanding and use of environmental intelligence in addressing key challenges of European sustainability. This document was developed with support of the European Union's Horizon 2020 FET Proactive Programme (now part of the Pathfinder programme of the European Innovation Council).

There will be four iterations of this blueprint in total (one per year) as we advance Environmental Intelligence in Europe. In this first report we define Environmental Intelligence, outline its key components, why it is needed to better address environmental challenges in Europe and beyond. We also indicate the key challenges and the solutions adopted so far by the five projects in addressing these challenges. We classify the challenges under the headings: Hardware; Software; Networks; People, Training and Engagement, and Policy, all of which seem to be common across the five projects.

2. Defining Environmental Intelligence

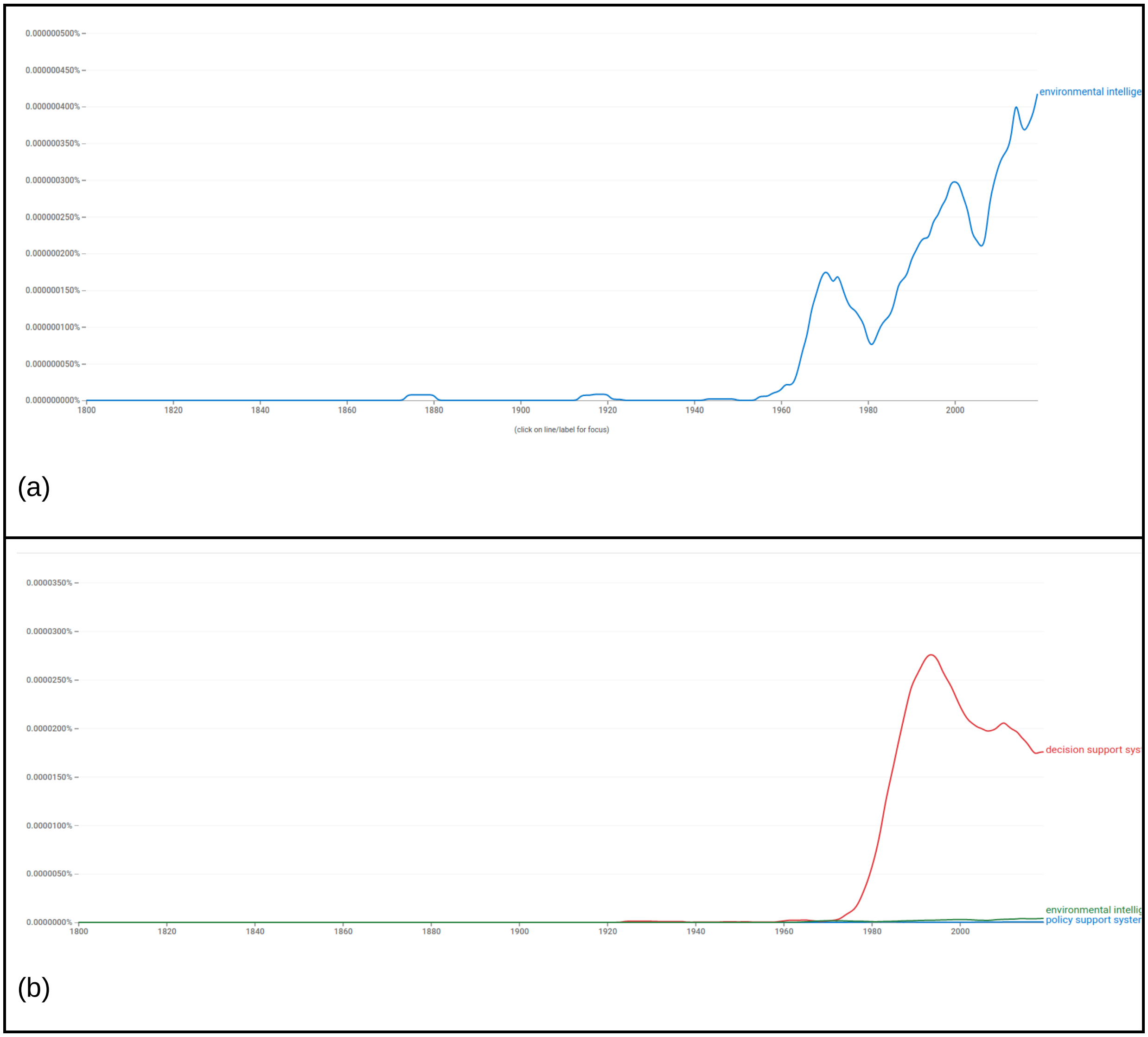
Intelligence is the ability to learn, understand and thus manage new or trying situations through reasoning (inferences based on facts or premises). In a broader sense, intelligence has been also defined as the ability to optimally respond to change through the interpretation of data to support adaptation or response. **Environmental Intelligence** (EI) has a variety of definitions depending on the discipline. Sometimes its use refers to the overall environment (for example the competitive, technological and regulatory environment of a business) rather than the *natural* environment. With reference to the natural environment, broadly it is defined as: *data and analysis of the earth's climate, geography and populations.* More specifically it is sometimes defined as: *a system through which information about a particular region or process is collected for the benefit of decision makers through the use of more than one inter-related source. (IARPC) or as actionable information created by collecting, compiling and analysing data to characterize the state of the environment.* Operationally, EI has been defined as *the use of tools and technologies to understand and coordinate a response to an environmental challenge (IGI GLOBAL).*

The UK Centre for Doctoral Training in Environmental Intelligence *defines EI as "the integration of environmental and sustainability research with data science, artificial intelligence and cutting-edge digital technologies to provide the meaningful insight to address these challenges and mitigate the effects of environmental change.” (https://www.eicdt.ac.uk/)*

For the EC (FET Proactive – Boosting emerging technologies (H2020-FETPROACT-2018-2020) Environmental Intelligence generates new synergies between the distant disciplines of environmental modelling, advanced sensor research, social sciences, and Artificial Intelligence that lead to radically new approaches for creating and using dynamic models of the environment, including predictive modelling, scenario testing and real-time tracking. The ultimate goal of EI is to build a systemic understanding of the socio-environmental inter-relationships, for instance to regulate or design policies and incentives for environmental sustainability and to track their effectiveness over time and to provide options for adjusting them.

For the purposes of this work, ***Environmental Intelligence*** brings together multiple data streams (facts) from ground, air, space and marine-based sensors, living organisms, satellite and citizen sources with cutting-edge and efficient hardware, software and analytical technology employing human reasoning and machine learning to better understand and manage the environment.

The term has shown a significant increase in use since the 1960s as shown in Figure 1(a). It may be being used in place of more established earlier terms such as "*decision support system*" which has decreased in use since the late 1990s (Figure 1b). The term *policy support system* has continued to grow (Figure 1c), as a broader term than "*decision support system*". Overall, the trend in terminology has been away from simple representations of environmental knowledge using terms such as *data* and *information* to more holistic representations that bring data closer to knowledge and intelligence (Figure 1d).


0.000000500%
0.000000450%
0.000000400%
0.000000350%
0.000000300%
0.000000250%
0.000000200%
0.000000150%
0.000000100%
0.000000050%
0.000000000%
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
(click on line/label for focus)
environmental intellige
(a)
0.0000350%
0.0000300%
0.0000250%
0.0000200%
0.0000150%
0.0000100%
0.0000050%
0.0000000%
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
decision support sys
environmental intellig
policy support syster
(b)

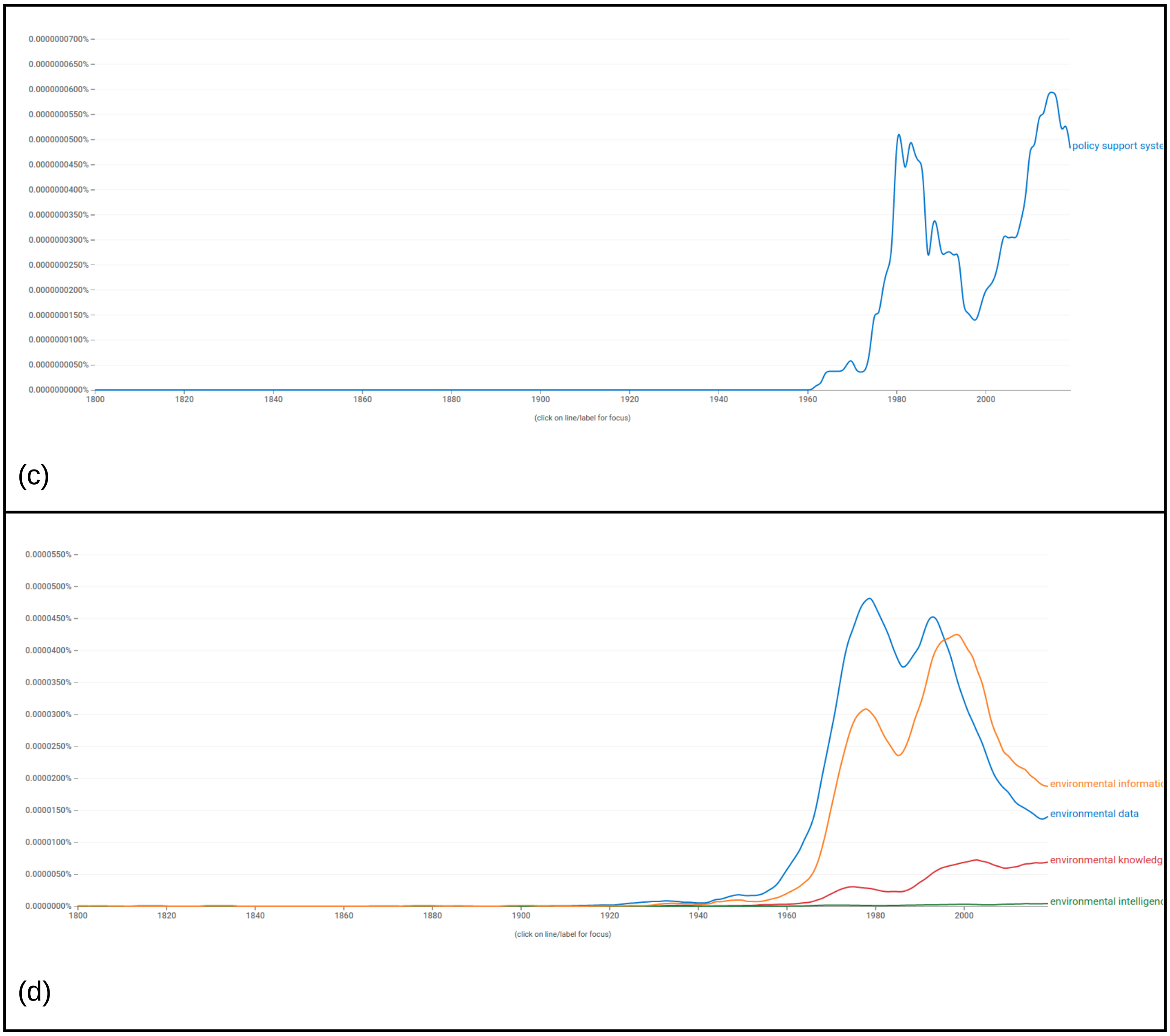


Figure 1. Increasing use of terms in the Google book archive 1800-2019. Source: Ngram viewer. (a) environmental intelligence (b) decision support system (c) policy support system (d) environmental information, data, knowledge, intelligence.

2.1 The key components of Environmental Intelligence

Figure 2 summarises the key components of EI. The environment is large and complex. Where an environmental problem is identified, we measure to produce a subset of environmental data that can then be processed to answer a question. The resulting answer provides relevant information that can be analysed towards a solution to the identified problem. Multiple streams of data and analytical tools convert information into intelligence which can advise an investment, policy or regulation to help solve the environmental problem, addressing wider sustainability concerns. Environmental intelligence produces actionable decision-quality information on an environment at a given location and time period. EI is not just about measurement, analysis and processing of data, but also about getting the right information to the right people at the right time in a form which supports decision making and policy shaping. In this way, environmental intelligence systems (EIS) are not dissimilar from decision support systems or policy support systems. The difference seems to be the greater attention to integration of a wide range of data sources and technologies in EIS, but also the use of machine learning techniques to mine such information for intelligence.

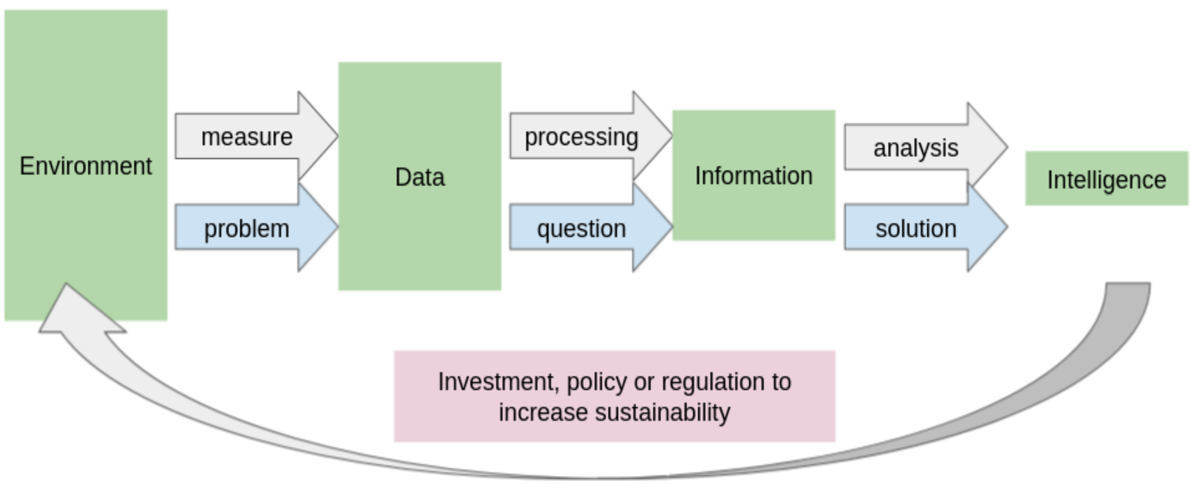


Figure 2. Summary of Environmental Intelligence.

Environmental intelligence connects data science with applications in the business, development, governmental, non-governmental, community and military sectors. It is as much about people and processes as it is about science and data. EI is highly question-focused and seeks the architecture, tools and data needed to answer these questions effectively and efficiently. EI is problem-centric rather than product-centric and requires flexible, interoperable tools capable of addressing the changing landscape of environmental problems.

The components of an environmentally intelligent system can be summarised as:

- **A goal to improve environmental sustainability through policy or management.** This may be communicated as a set of problems, questions or proposals for investment or management for which information is required.
- **Information.** This represents a new source of information obtained from currently undersampled parameters or a new combination or analysis of existing information.

Undersampling may have been due to difficulties with access, for example, in remote areas or because of the lack of appropriate measurement technology.

- **Hardware.** This represents the computing, the communication and the data collection hardware that provides, processes and communicates the derived intelligence. The EI challenge should always be addressed with green technologies to reduce the environmental footprint of the ICT itself.
- **Software.** This represents the code running on data collection, data processing and communication infrastructure that forms part of the environmentally intelligent system.
- **Networks.** This represents the soft networks of people, institutions and stakeholders, as well as the hard networks for data collection, data processing and communication of outcomes.
- **People, training and engagement.** This represents the people involved in the collection, processing and analysis of data (including model results), as well as those impacted by the environmental problem, asking the questions, assessing the proposed solutions and implementing investments, policies or regulations.
- **Policy.** This represents the policy context and policy levers available to facilitate change given intelligence on what needs to be done, but also the demand for evidence and effectiveness assessment that in-turn creates the need for environmental intelligence.

2.2 Why is Environmental Intelligence needed in Europe?

2.2.1 The need for Environmental Intelligence

Environmental intelligence is clearly integrative and moves environmental research in a more solution (rather than problem) focused direction. It is a logical extension of recent developments in data science, coupled with the increased need for high-quality, question-focused evidence to support sustainability interventions in unsustainable systems. Environmental intelligence addresses each of the following.

- **Data overload.** There is no shortage of environmental data, but it is collected in a variety of ways from a variety of platforms by a variety of organisations operating at the local, regional, national and international scale. Although data has some common features such as a timestamp and a location (latitude and longitude) all other elements of data are rather unique to the data type and data source. Data is thus highly heterogeneous and challenging to document, understand, share and bring together. One of the most significant challenges in environmental intelligence is using the data that already exists. The focus of Environmental Intelligence on integration and interoperability is a response to the need to make use of a wide range of existing, heterogeneous data sources, making them accessible and useful.

- **Complex human-environment landscapes.** Europe is characterised by a huge diversity of biophysical and socio-economic conditions both between countries and within countries. We have a complex policy landscape and a wide range of pressured environments in which centuries of unsustainable practice have created significant environmental challenges. This complexity, coupled with the need for science to provide evidence for better-informed policy, means that interdisciplinary, integrative approaches are the only way forward in providing decision and policy support.
- **The competing demands of multiple concurrent sustainability crises (eg the climate and biodiversity crises).** The answers to sustainability challenges are not simple and involve trade-offs between the environment, economy and other socio-economic factors. Moreover, the solution to a given problem may create problems elsewhere in the system. The main challenge for EI is that we face a climate crisis and a biodiversity crisis, amongst other challenges, but the adaptation or mitigation to any one of these in a given geographical area may deepen the other crisis. Environmental Intelligence provides opportunities to seek to achieve multiple goals and to use scenario analysis to examine trade-offs, opportunity costs, co-benefits and win-wins.
- **The need for sustainability across multiple sectors.** One of the greatest challenges for sustainability is the independent nature of developments whether they be technological, agricultural, urban or or industrial. New technologies may be tested for a range of potential impacts but never the full range of environmental impacts that are often only found out many decades later. Whilst each new development in a landscape will require permission and the need to meet particular regulations, there is often little oversight of the volume of these developments in a particular landscape and their cumulative impact. This is particularly true across sectors where the competing demands of agricultural, urban and infrastructural developments may conflict. Environmental Intelligence provides the means for a range of organisations to come together around a common system for understanding their individual and collective impacts on the environment.
- **The need for solution-focused science.** Environmental science is often focused on identifying problems and, whilst this has an important role in generating societal and political impetus to solve the problem, it does not tell us how to solve the problem. Environmental Intelligence can be solution-focused, so that identifying environmental problems is only the first stage in the collection and processing of data around a series

of policy options or scenarios that can advise on the most sustainable solution to the problem at hand.

- **The need for integration across institutions, disciplines, tools and datasets.** Governmental, non-governmental, commercial and academic institutions tend to work in silos, each with their own systems, data and technologies for understanding the environment and the impact on environmental sustainability of their or others' operations. Moreover, even within an institution, different departments or disciplines may see the world in different ways or experience challenges in communicating across to other disciplines. Each may have their own tool, tool-kit or dataset for managing their impacts on the environment but, if these tools are not understood across the institution and do not talk to other tools then their impact can, at best, be local and they may fail to identify the solution that is sustainable across sectors, but rather hone in on a solution that works only for the discipline at hand. A diversity of approaches and views is important, but connectivity and effective communication across these viewpoints is also.

2.3 Year 1 FET project developments in Environmental Intelligence

2.3.1 Project goals

I-Seed

I-Seed proposes to develop a new generation of self-deployable, biodegradable, soft miniaturised robots, which take inspiration from the morphology and dispersion abilities of plant seeds, for a low-cost, environmentally responsible, high spatial and temporal resolution, *in-situ* environmental monitoring. These seed-like robots contain sensor materials that react to relevant environmental parameters by a chemical transduction mechanism and a change in fluorescence that is accessible by optical readout. Measurements can be read via one or more drones equipped with fluorescent LiDAR technology and software able to perform a real-time georeferencing of data. By merging scientific research and technology design across the areas of bioinspired robotics, material science, artificial intelligence, mathematical modelling and hyperspectral imaging, I-Seed will build a radically new dynamic scenario for analysing and monitoring air and topsoil environments and their interface, extending environmental sensor networks and filling existing gaps of data analysis systems.

The first year of the project started with the definition of the I-Seed environmental scenario and field validation strategy, followed by a series of scientific and technical activities for the design and development of the I-Seed platform. Specifically, a focused study of plant seed materials and biomechanics have been carried out in order to define useful specifications for the modelling and the design of the artificial systems in terms of multi-functional materials, their structural properties, and morphological adaptation. Also, we have started parallel activities on mathematical modelling of movements of natural and artificial seeds, on the design and development of the artificial seeds and sensing, on the active laser-induced fluorescence system on the drone, as well as on their geo-referencing software and smart flight controller.

RAMONES

The EC H2020 RAMONES project offers a radical vision of science-enabled cutting-edge solutions in both instrumentation and robotic sensing platforms towards a step change in Radioactivity Monitoring in Ocean Ecosystems. The main objective in RAMONES is to **close the current marine radioactivity under-sampling gap** and **foster new interdisciplinary research** in ocean ecosystems. RAMONES will invest a significant effort to provide tools for long-term, rapid deployments, low cost per information byte, propose new AI-driven and supported methodologies, **being ambitious to eventually offer scaled-up solutions to researchers, policy makers and communities**. All these can be achieved by combining state-of-the-art equipment from various disciplines in well-balanced synergy, and designing new and effective methodologies targeting the marine environment, which will provide efficient response to existing natural and man-made hazards, and shape future policies for the global population.

In the first year, RAMONES partners (8 partners, 6 EU states, 2 SME) have invested significant time to develop the main framework of instrumentation development, perform extensive simulations of physical processes and instrumentation models, taking into account a wide range of environmental conditions and a variety of deployment scenarios. Optimization of the implementation of prototype sensors aboard state-of-the-art marine robotic vehicles has been a major engineering objective in the first year, as plans for field tests are finalized. The consortium is working towards developing new algorithmic approaches to meet the demanding conditions of the harsh marine environment where advanced prototype sensors will be deployed during the various phases of development, offering low-power operation, autonomous decision making and AI-driven exploration and monitoring capabilities. In addition, the foundation of a dedicated framework for risk analysis at various temporal scales towards data-driven policy making to be communicated to interested stakeholders has been under continuous development.

ReSET

The EC H2020 ReSET project (*Restarting Economy in Support of Environment through Technology*), brings together environmental scientists, social scientists, informatics specialists and stakeholders from five European countries to develop state-of-the-art green investment policy support systems. These combine the best available earth observation, crowdsourced and field-monitored data with sophisticated spatial policy support systems for biophysical and social processes. Harnessing combined machine and human intelligence, we seek to understand best-bet options for 'build back better' investments that maximise environmental, economic and employment benefits of green investments. We focus on both urban and rural green investments throughout Europe including those addressing air pollution, flood, drought, heatwave, noise and light pollution.

In the first year we have developed a range of new, low-cost IoT sensors, improved our FreeStation //Smart: system for gathering and processing data from these systems, deployed sensors at a series of demonstration sites where stakeholders are in need of environmental intelligence and begun the process of further developing and integrating our spatial policy support systems that will link with these data streams to provide actionable evidence to inform investment, policy and regulation.

SMARTLAGOON

The overall objective of SMARTLAGOON is to develop **cross-cutting and green technology for modelling and predicting** socio-environmental processes across different temporal and spatial scales. This will be achieved through a **digital twin strategy** that allows researchers, stakeholders and policy-makers to collect data in a more cost-effective way, and to create more precise models and predictions to support better decision making. As a case study, this project uses the **Mar Menor lagoon** (Murcia, Spain), an ecosystem that supports a great variety of human activities encompassing tourism, agriculture, fishing and mining, that have led to its deterioration.

An important novelty of the SMARTLAGOON approach relies on the holistic view of coastal lagoon ecosystems. Developing a data-centric technology solution will provide real-time monitoring and forecasting of socio-environmental tradeoffs in these ecosystems, aimed at helping policy-makers in their decision-making. It will also enable an increase in people’s awareness of these tradeoffs, which will benefit the understanding and enforcement of applicable legislation (e.g. EU Water Framework Directive (2000/60/EC), EU Floods Directive (2007/60/EC), RD 2/2019, December, 26th, Integral Protection of the Mar Menor).

Watchplant

In the case of WatchPlant, a novel approach consisting of developing a biohybrid system technology for *in-situ,* self-powered monitoring is proposed. It will allow plants to wear AI components and technological interfaces, which result in the creation of "smart biohybrid organisms" for environmental monitoring. The main goal is to develop, to deploy and to perform an experimental validation of this new biohybrid system technology to address the *in situ* monitoring of environmental context (such as pathogens, pollution and other impacting factors), together with living plants, primarily in urban scenarios using air quality as a study case, in order to establish a relation to human health.

In the first year we have addressed the challenging goal of using plant's health as indicators of the environment they inhabit by studying the experimental conditions, materials, and design specifications to develop the biohybrid system. Specifically, the definition of specifications and parameters for the design of the WatchPlant device and the new sensors, together with physical modelling, have been explored to address the challenge of accessing plant sap to look for new valuable information of plant status which can constitute a step ahead towards in situ monitoring. Additionally, new developments and experiments in distributed data gathering, processing, communication capabilities and AI have started to address the challenge of system-wide resilience, which will generate self-deployment, self-awareness, adaptation, and self-repair systems for the sensors. During the lifetime of the project this system is devoted to provide a remote sensing tool for decentralised analysis of environmental status which will provide different stakeholders with a powerful tool for decision making in real time based on the real status of the environment.

Key lessons learned

All projects have focused in the first year on clarifying the boundaries and parameters of the research, and developing the initial technologies that will be required for their Environmental Intelligence systems. This has included working with stakeholders to fully define needs and priorities, but also working on the basic research that underpins their applications. Lessons so far include the importance of capturing stakeholder views and the diversity of perspectives on an issue as well as the need for modularity in EI systems. Work to date has focused on planning and early implementation with key challenges including oversight of complex systems and incompatibility of technologies, approaches, data types and systems.

2.3.2 Key information

I-Seed

I-Seed technology would provide three key contributions to the current monitoring capabilities, specifically: (i) the possibility of filling geographical gaps to improve ongoing monitoring networks in areas where no monitoring infrastructures are available with low investment and management costs; (ii) increase the spatial resolution of monitoring points/sites with a technology that is cost-effective, robust over time, remotely controlled and which allows to monitor the selected parameters in the topsoil, and air above the topsoil (air-top soil interface). This represents crucial information for reducing the range of uncertainty in numerical atmospheric modelling evaluation aimed to assess spatial patterns of contaminant concentrations and exchange fluxes over terrestrial receptors with changing emission regimes and meteorological conditions; and (iii) the low cost of the I-Seed technology would allow execution of continuous field campaigns in contaminated sites/emission regions to cross-check the effectiveness of remediation measures adopted to restore ecosystems quality. This scenario would represent an advantage for the implementation of environmental policy at any geographical scale.

RAMONES

RAMONES technological advancements and targeted field deployments will offer key information for deep-sea ocean ecosystems that are largely unexplored, especially in terms of radioactivity levels. Radioactivity monitoring in marine environments lacks serious technological advancements, mainly due to the particularities of the underwater environment, despite its importance either as a direct observable quantity (e.g. in monitoring nuclear accidents or nuclear waste disposal in the marine environment), or as an important proxy for dynamic processes and phenomena occurring near the seabed (e.g. active underwater seismic faults and underwater hydrothermal vent fields in near-explosive conditions). Key information will include specifications of novel engineering solutions for marine robotics, AI algorithms, and new sensor prototypes for autonomous, long-term, in situ monitoring in the marine environment. The geological and geochemical processes hidden under the blanket of the vast ocean waters which have the potential to critically impact the ecosystem will be explored by means of radioactivity monitoring. This impact will be assessed in terms of various parameters, such as radiation dose delivered on marine life, and the key findings will be communicated to interested stakeholders aiming to strengthen the resilience of the socio-economic environment and provide sustainable solutions to natural and man-made hazards related to radioactivity monitoring.

ReSET

Key information for the ReSET project includes information on stakeholder priorities for investment and their information needs for better informed investment focused on all of: environment, economy and employment. We also need large volumes of high resolution and sophisticated spatial (earth observation) data that underpins our spatial policy support tools. To 'ground' these data we need to monitor the environment on the ground with low-cost, internet-connected sensors at fixed locations and in wearable form to better represent human exposure to the environment. In our first year, we have begun work in all of these areas. We have had a number of stakeholder workshops to better understand proposed green investments in our demo areas throughout Europe. These have enabled us to better understand types, scales, objectives of investments and stakeholder priorities and information needs. We have worked with a range of spatial data sources from ESA (Copernicus), NASA and elsewhere, to extend and update the data layers in our spatial policy support systems with the latest and highest resolution products. We have also developed a range of new sensors, circuit boards and software to improve our FreeStation IoT monitoring platform covering new variables such as noise, light and air pollution as well as new ways of measuring, including through wearables and intensive monitoring campaigns ("Golden days"). Moreover, we have developed deep learning approaches to identifying important infrastructural features in remote sensing imagery to better characterise the human and physical environment using high resolution freely available imagery and open-source software. COVID has created some challenges in access to stakeholders and field sites, but all work has gone ahead as planned, with mitigations in place. Key remaining data challenges are those concerned with quality control of large databases and maintenance of currency in data that is constantly evolving and improving.

SMARTLAGOON

Data collection is the first challenge SmartLagoon is facing in this first year of the project. The data must be of high quality and representative of all the points of interest in the study area. Moreover, the temporal scale at which key mechanisms operate in the Mar Menor is rapid. The lagoon may, for example, stratify for only a few days, resulting in formation of hypoxia and potentially fish kills. Such events are not captured by traditional monthly sampling campaigns. Rather, high-frequency sensor data is required. SmartLagoon takes an integrative approach, where data from new *in-situ* sensing is combined with data from other sources such as socio-environmental open-data and mobile crowdsourcing (MCS) data. Regarding *in-situ* sensing technologies, SMARTLAGOON will design two energy-efficient IoT infrastructures at the lagoon and the watershed with AI-powered sensing devices. A cost-effective monitoring buoy which is already designed based on experiences from Lake Erken (Uppsala, Sweden). AI powered sensing is based on a network of IP cameras deployed throughout the watershed to measure volumetric flows using the Surface Structure Image Velocimetry (SSIV) methodology. SSIV uses a method based on a cross correlation technique to measure the surface flow velocity. Water level is also optically measured using the images taken by the cameras. Using this information, the vertical velocity profile can be calculated, and if the stream channel bathymetry is known, the discharge can be obtained. Moreover, SSIV techniques can be applied to measure and predict conditions that can result in fish kill. In shallow eutrophic lagoons the presence of anoxic conditions is linked to three factors: 1) lack of water column circulation; 2) photosynthesis and respiration by phytoplankton; and 3) the decomposition of phytoplankton or organic material transported to the lagoon from the surrounding watershed. Using image sequences acquired by cameras, two parameters that influence the above process can be estimated: 1) wave height, and potentially direction, will provide information on the depth and magnitude of water column mixing water colour will provide information on the amount and source of organic matter suspended in the lagoon.

Another key source of data to be considered in SMARTLAGOON is data from Mobile Crowdsensing (MCS). MCS is a recent research trend that relies on data collection from a large number of mobile sensing devices. In comparison with traditional physical sensors (i.e. wireless sensor networks), MCS is inexpensive, since there is no need for network deployment, and its spatio-temporal coverage is outstanding. The generated data is complementary to or an alternative source to physical sensors. Moreover, it can be an effective way of increasing local and citizen awareness of socio-environmental impacts. Three data-generation modes in MCS can be distinguished:

- Mobile sensing, which leverages raw data generated from the hardware sensors that are embedded in mobile devices (e.g. accelerometer, GPS, camera or microphone, among others).
- Social sensing (or social networking), which leverages user-contributed data from social media. This mode of MCS considers participants as “social sensors”, i.e. agents that provide information about their environment through social-media services after the interaction with other agents.
- Crowdsensing, which empowers a large group of individuals equipped with mobile devices to collectively and voluntarily report and share data and content related to a specific issue.

Watchplant

In the case of WatchPlant, it is crucial to ensure that real data measured from new undersampled parameters and from new dynamics and combination of existing markers provide useful information. To ensure an impact in environmental intelligence, reliability of the data is essential. However, it is also crucial to ensure that the physiological interpretation of the data and the impact on the environment is well understood so it can influence policy and decision actions.

Key lessons learned

Key information lessons include the importance of careful documentation and data management as well as automated processing of data, given the large volumes and bewildering array of data available for the construction of Environmental Intelligence systems. Challenges associated with understanding data quality and uncertainty are also paramount.

2.3.3 Hardware challenges

I-Seed

The major hardware challenges in I-Seed are the following:

- **Challenge**: **Plant-seed inspired morphological computation**. To translate biological principles of seed dispersal strategies for designing and developing environmentally responsive seed-like soft robots made of multi-functional biodegradable materials. **Solution:** This challenge advances both biological knowledge on plant seeds and energy efficient robot design, thanks to a focused bioengineering investigation on the self-burial mechanism and the flying abilities of natural seeds in relation with environmental factors, to effectively exploit the passive abilities of these natural actuators in new engineering design principles.
- **Challenge**: **Biodegradable seed-like soft robots**. **Solution:** To build artificial seed-like robots with biodegradable/environmentally-friendly materials able to provide structural support and dynamically respond to several environmental stimuli. This challenge goes beyond the state of the art by using the natural combination of sensing and actuation through material computation to obtain a passive mobility (with no need of any internal energy source), exploiting their morphology, structure and biomechanics/aerodynamics.
- **Challenge**: **Transduction-based sensor materials**. **Solution:** To advance in-situ sensing technology based on chemical transduction mechanisms. This challenge will go beyond the current sensor network by using materials that react to environmental parameters, such as temperature or humidity, or to certain chemical analytes by changing optical properties.
- **Challenge**: **Optical signalling and fluorescence based on LiDAR (Light Detection and Ranging) technology**. **Solution:** To design and develop a multi-wavelength

fluorescence LiDAR system capable of detecting several excitations in one observation. This will extend the presented laser-induced fluorescence principle as evaluated for vegetation to other materials being part of the I-Seeds.

RAMONES

The major hardware challenges in RAMONES include:

- **Challenge: Efficient, low-power sensors** We need to develop various instruments to be deployed in large ocean depths and perform efficient, long-term measurements. The technology envisioned is high-risk and the ambition is to define the new state-of-the-art becoming a game changer in radioactivity monitoring in the marine environment.
- **Challenge: Advanced marine robotics and marine engineering** Sensors will be deployed aboard sea gliders which will offer great autonomy, guided by AI-driven decisions, and use optimized communication tools and software. The overall technology needs to be fully optimized to its full details to offer coordinated navigation of a scalable fleet of gliders and synergetic exploration by tracking and monitoring radiation in the water.
- **Challenge: Integration and marinization of sensors** State of the art sensors largely ignore applications targeting the marine environment. Radiation detectors used for detailed spectroscopy are typically made of scintillation or semiconductor materials, built to operate outside the ocean. The integration of radiation sensors in specialized housings to withstand high pressures presents a major challenge both for the mobile robotic platforms and the static benthic laboratory.
- **Challenge: Power supply optimization** The lack of continuous power supply (e.g. via tethering) is a major challenge to overcome. Minimization of power consumption is the first requirement for all sensor prototypes to be built, as well as communication instruments and onboard processing for real-time decision making. The solution of gliders offers an advantage as these robotics vehicles move following the ocean waves, but all other parameters are studied in exhaustive details to offer as long power autonomy as possible.

ReSET

To date ReSET has focused on the following hardware challenges:

- **Challenge: Power and communications. Solution: Multipower and multiport PCBs**. This addresses the challenge that many environmental sensors have different voltage and interface requirements. Adding support for three voltages and serial sensor communications to the FreeStation PCBs has opened up a much wider range of sensor possibilities.

- **Challenge: Human exposure. Solution: Smaller PCBs for wearable sensing.** In addition to logging sensors deployed at fixed locations and monitoring over time, EI demands spatial data collection at high spatio-temporal resolution that can validate remotely sensed or modelling proxies. This is particularly important when attempting to understand personal exposure to natural or environmental hazards. The development of smaller PCBs has enabled us to develop GPS-enabled wearable sensors for a wide range of variables.
- **Challenge: Intensive measurement. Solution: Multiplexer PCBs.** Sometimes very intensive monitoring is required at a single location in order to understand the processes or the detail of exposure to risk. Multiplexers allow many sensors to be added to a single data logger. These are usually power demanding and expensive. The development of FreeStation multiplexers brings many advantages to low-cost sensing, enabling the better parameterisation of models and the development of better models.
- **Challenge: Neglected risks. Solution: New sensors.** Many important environmental and natural hazards are not well monitored and thus are poorly understood. This is because suitable monitoring equipment is not available, very expensive, or not suited to integration with models. We have developed a range of new FreeStation sensors to better understand noise, light and air pollution as well as carbon-dioxide sequestration/emission and physiological responses to environmental stresses.
- **Challenge: Monitoring in tight spaces. Solution: Improved sensor housings.** In urban areas space for the installation of environmental monitoring is often restricted. We have thus miniaturised FreeStations to make them better suited for deployment on the person, on vehicles or on street furniture such as lamp posts.

SMARTLAGOON

To date SMARTLAGOON is addressing the following hardware challenges:

- **Challenge: Representative sensor deployment for the Mar Menor particular case. Solution: Comprehensive analysis of environmental needs and co-creation with stakeholders.** We have developed an oceanographic buoy for monitoring environmental variables that should be acquired to improve the management of Mar Menor. Mar Menor is a relatively shallow body of water (maximum depth 7 m) with a large surface area (135 km2). Consequently, it is not seasonally stratified, but is subject to ephemeral periods of stratification and mixing. It is the dynamics of this mixing regime that can be of great importance for determining the water quality of the lagoon, and it is these dynamics that the water quality forecasts will focus on being able to simulate. Of particular interest will be the effect of stratification on water column and near bottom oxygen concentrations, which can affect sediment nutrient release and fish kills. Further, monitoring of algal blooms and turbidity changes associated with storm event inputs is needed to both validate the camera-based sensing methods that will be developed and refined by SMARTLAGOON and will also be key outputs of the water quality forecasts.

With the above in mind, the following measurements will be collected by the monitoring buoy:

- Vertical temperature profiles at depths 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, and 6.5 meters.
- *In situ* dissolved oxygen concentrations at 1,3, and 6.5 (near bottom) depths.
- Chlorophyll fluorescence as an indicator of algal concentrations.
- Optical backscattering as an indicator of water turbidity.
- Meteorological data (wind speed, air temperature and relative humidity) that are inputs to the water quality models and can provide more representative model inputs when collected over water as opposed to land based measurements

The mounted electronic components consist of the data logger, the smart power charger and the communications system. We used a Campbell Scientific NL 240 WiFi Modem. The Campbell CR1000x data logger is the heart of the system. A variety of sensor signals are input to the data logger. Signals are measured at 30 sec to 1=-hour intervals and the data logger internally processes these to produce summary statistics at 5 min, 60 min and 24 hour intervals.

- **Challenge: Modular design for ease transport and manipulation. Solution: Modular design from the outset.** The oceanographic buoy developed by SMARTLAGOON has been initially tested, validated and calibrated with the monitoring program from Lake Erken, the Limnological Field Station of Uppsala University, Sweden. Lake Erken has one of the longest and most extensive lake monitoring programs in Europe and this long experience will provide feedback to maximise the success of in-situ IoT infrastructures in the Mar Menor lagoon. Thus, this set-up allows to make use of already tested approaches in Lake Erken, as well as providing insights of the functionality of the developed methods under different natural and social conditions, technological advancements and a climate gradient. Following development and testing at Lake Erken, the sensing system (electronics and sensors need to be easily transportable to Spain so that it can be installed in the monitoring buoy that will be deployed on Mar Menor. To make the system easily transportable to Spain, all the electronics and sensors were built in several components that can easily be transported as flight baggage, or by standard shipping methods. The system consists of:

  - A water-resistant suitcase that can be easily transported contains all the needed electronics.
  - A single sensor chain that contains all the under-water sensors.
  - The individual meteorological sensors that will be deployed above water.

- **Challenge: Energy harvesting. Solution: Energy assessment developed from design.** The power used by the system should be well documented so that the size of the solar panel and system battery can be optimised in the Mar Menor deployment. In order to assess energy requirements, the power supply sends data to the logger that specifies the voltage and current coming from the solar panels. The charge state (Active Charge, Floating Charge or None) and the voltage and current load on the battery from the sensor measurements and communication modem.
- **Challenge: Safety and vandalism. Solution: Safe and stakeholder-involved design.** The electronics are expected to be subjected to extreme conditions in the Mar Menor, i.e. high temperatures, humidity, high salinity. In addition, there is a risk of contamination of a natural environment that may affect the ecosystem and of vandalism due to the current political conflict situation in the area. These risks must be taken into account when designing the hardware to ensure that it can survive extreme climatic conditions, guarantee the environmental safety of the electronic components and prevent potential vandalism.

Watchplant

To date WatchPlant is addressing the following hardware challenges:

- **Challenge: Long-lasting phytosensing.** We attach sensor nodes and electronics (invasively) to living organisms (i.e., natural plants). These organisms eventually adapt to these objects in their environment, forming a dynamic environment for the sensor nodes in turn (e.g., leading to decreased phytosensing quality over time). The challenge here is to develop hardware methods that deal with ever adapting living organisms and still guarantee stable phytosensing quality over extended periods of time.

- **Challenge: Safety.** The electronics are subject to repeated extreme conditions because they operate indefinitely outdoors. Also, the safety of surrounding pedestrians in populated areas is at risk as sensor nodes attached to trees could cause injuries. Such risks should be taken into consideration while designing the hardware to ensure it can survive extreme weather conditions and to also ensure their proper attachment to plants.
- **Challenge: Energy harvesting.** Electronics attached to plants may have limited access to direct sunlight due to surrounding plant material or more ambitious sources of energy, such as sap flow. Therefore, we have to find methods that maximise chances to harvest energy and also investigate harvesting innovative renewable sources of energy.
- **Challenge: cellular biosensing**. Sensing biological processes on the level of cells (e.g. ionic processes on cell membranes) or even intracellular metabolic processes (e.g. ATP/ATF, proteins) with add-on sensors represent a serious challenge. Information about such processes is important to understand and monitor living organisms in real time, to validate biological models.

Key lessons learned

Common hardware challenges include the technical challenges of developing the hardware itself but also the challenges with installation, maintenance and operation with lessons learned, including the importance of local acceptance of monitoring both from a vandalism/security perspective and a health and safety perspective. Other lessons include the importance of attention to device power consumption and the challenge of sensor deployment in the natural environment, which can be subject to harsh environmental conditions (in the rural environment) and high electrical noise and pollution in the urban environment.

2.3.4 Software challenges

I-Seed

Concerning software challenges, I-Seed has been focusing on the following major topics:

- **Challenge**: **Modelling mechanical functions of biological and robotic seeds**. **Solution:** To formulate new reduced models of fluid-structure-interaction in order to assess and optimise the role of shape and elastic compliance in selecting the flying style and controlling trajectories and flight performance. Also, to develop models resolving the mechanics and energetics of interaction, study the motion of seeds in contact with the soil, and use the results to optimise the performance of the robotic seeds.

● **Challenge**: **LiDAR data post-processing and drone flight controller**. **Solution:** To design and implement a “smart” flight controller based on deep learning architecture, with a software able to read and process in real-time the data stream of the LiDAR data and a desktop software to do post-processing and data export.

RAMONES

RAMONES will collect several data streams from a variety of dissimilar sensors. As such

- **Challenge: Heterogeneous data streams** We will use a fleet of radiation sensors of different types, performing measurements in various modes. Additional sensors and instrumentation will operate simultaneously (such as CTD sensors or atomic clocks for timing synchronization). The data streams need to be combined to offer event-by-event data recording.
- **Challenge: Decision-making algorithms** AI-driven navigation and coordinated navigation are central requirements. In RAMONES, radioactivity levels will provide the signals to track and decide, but the strong attenuation of radiation in the water limits the efficiency of remote sensing. New approaches should be explored to overcome signal processing and decision-making at this level.
- **Challenge: Risk assessment** Risk due to radioactivity is important to be assessed by dedicated algorithms tracking continuous radioactivity monitoring, performing statistical tests, and performing machine-learning approaches to ultimately offer risk indices for various processes and natural/man-made hazards. The spatial and temporal granularity presents some limitations and an optimization of the dedicated algorithms is a necessary requirement for the successful implementation of a risk assessment and risk warning system.

ReSET

To date ReSET has focused on the following software challenges:

- **Challenge: Management of heterogeneous data. Solution: Online data management tools.** To address this challenge we have focused on improvements to the FreeStation //Smart: system for archiving, visualisation and analysis of data. These developments make the management, mapping, visualisation and processing of data seamless and hassle free as well as scaleable for new sensors and deployments.
- **Challenge: Siloed tools and models. Solution: Integration.** Environmental models and tools are necessarily specialised and focused rather than comprehensive and interdisciplinary. Our approach is to make the best use of existing tools rather than

build new ones, through techniques to bring existing tools together into more comprehensive policy support systems using (when needed bi-directional) data-trains (models running one after the other, APIs, emulation and technical integration).

SMARTLAGOON

SMARTLAGOON foresees the following software challenges in the design of the Mar Menor digital twin.

- **Challenge: Real time data crawling from open repositories. Solution: Test driven designs.** SMARTLAGOON needs to collect public environmental and socio-economic data from different sources, e.g. Copernicus, Twitter, AEMET, INE, etc. Therefore, there is a dependency on third party APIs that needs to be managed so that we are tolerant to possible external failures.
- **Challenge: Integration of heterogeneous data. Solution: Avoiding silos.** To meet this challenge, efforts have been made to unify all data collected by our data collection systems into a single database that centralises all information. This also allows for the cleaning and processing of data in a homogeneous way.
- **Challenge: Big data visualisation. Solution: Co-creation with stakeholders and high-performance processing power.** SMARTLAGOON will include a large amount of socio-environmental data that will also grow gradually over time. The digital twin that SMARTLAGOON intends to develop has to display this data in an interactive and effective way to users. However, depending on the data set being displayed, users often find it difficult to see objects that are related to each other. When visualised, it is difficult for users to separate these objects, which means that we have to make sure that we show only the necessary data without missing necessary information that may skew the conclusions. To avoid this flood of information, application views must necessarily be designed with experts who analyse the content to be visualised, i.e. potential users of the tool. This will facilitate the visualisation and organisation of data so that users can easily separate and relate certain objects in the visualisation. This will also ensure that the necessary data is displayed and that no information is lost in the visualisation. Finally, the amount of information to be processed/displayed is huge, so high performance processing power is required to make the system design scalable. Management based on microservices that can be optimised using HPC strategies is essential for a reactive application.

Watchplant

To date WatchPlant is addressing the following software challenge:

- **Challenge: understanding dynamics of biological systems** that require adaptive software, capable of learning specific biological processes. Especially important are explorative algorithms that can learn dependencies of metabolic processes.

Key lessons learned

Key lessons learned include the importance of adaptive software to manage changing data streams, APIs and siloed data as well as to facilitate integration and smarter analysis of heterogeneous data, making the best use of existing tools and data investments.

2.3.5 Network challenges

I-Seed

To date I-Seed has focused on the following major networking challenge:

- **Challenge**: **Environmental data collection Solution:** Filling geographical gaps to improve ongoing monitoring networks in areas where no monitoring infrastructures are available with low investment and management costs; increasing the spatial resolution of monitoring points/sites with a technology that is cost-effective, robust over time, remotely controlled; monitoring selected parameters in the topsoil, and air above the topsoil (air-top soil interface), which is a crucial information for reducing the range of uncertainty in numerical atmospheric modelling evaluation aimed to assess spatial patterns of contaminants' concentrations and exchange fluxes over terrestrial receptors with changing emission regimes and meteorological conditions; developing a low cost technology allowing to execute continuous field campaigns in contaminated sites/emission regions to cross-check the effectiveness of remediation measures adopted to restore ecosystems quality.

RAMONES

- **Challenge: Integration of various data streams and sources.** The integration of various data streams under a common scheme in an automatic way is highly desirable. Using various sensors operating on different OS, linking data streams of different formats, minimizing the online processing processes to keep power consumption down is a major challenge.

- **Challenge: Expand sampling resolution and granularity** Defining the new state-of-the-art requires to overcome the existing capabilities of radioactivity monitoring by other researchers. This part of the challenge is minor, as the envisioned scheme will offer a unique, multiple orders of magnitude, improvement along these lines. The major challenge is to translate the higher spatiotemporal resolution to meaningful Environmental Intelligence practices of directives, assisted by modeling and machine-learning.

ReSET

To date ReSET has focused on the following networking challenges:

- **Challenge: Integration of disparate data sources. Solution: Linkage through APIs.** Bringing data together in a manner that does not require much manual intervention is a challenge. Data are heterogeneous and complex. We have focused on linking field-deployed sensors, earth observation APIs and environmental policy support systems into seamless, communicating systems, and doing so in an expandable manner with a focus on simplicity and user-centrism, avoiding technological worm-holes where possible.
- **Challenge: Understanding information needs and institutional capacity to make use of new information sources. Solution: Ask.** To date we have focused on identifying and engaging key stakeholders in all case study areas and better understanding their environmental intelligence needs in terms of policy contexts, metrics and best means of communication.

SMARTLAGOON

SMARTLAGOON is addressing the following networking challenges

- **Challenge: Communication range and energy.** The oceanographic buoy will be deployed 14 km from the shore of the Mar Menor where there is no coverage of any kind. Communication protocols must be established to allow long distances to be reached without penalising the energy consumption of the device. We are designing an efficient LoRa-based communication protocol to reach a base station.

Watchplant

To date WatchPlant is addressing the following network challenges:

- **Challenge: Communication range and energy.** Ideally, sensor nodes on natural plants should be distributed over a whole city. Establishing a distributed network (e.g., multi-hop) requires communication ranges of about up to a kilometre. Depending on different optional radio communication protocols (e.g., GSM, LoRA, WLAN, Bluetooth), long communication ranges come at the cost of potentially high energy consumption. Due to physical constraints, communication range correlates with energy consumption. At the same time, environmental constraints require small, lightweight sensor nodes with minimal energy footprints confronted also with difficult energy harvesting situations. Hence, the challenge is to compromise between communication range and minimal energy consumption.

- **Challenge: Robust and efficient data routing.** Given we may aim for a high number of small, inexpensive sensor nodes, the system should be considered an open system with (unreliable) nodes coming and going. In addition, mobile sensor nodes may be used, too (e.g., smartphones). This requires a robust, decentralised, and possibly adaptive routing scheme that can deal with dynamic neighbourhoods on different timescales (from seconds to months). Similarly, routing needs to be efficient to minimise energy consumption. The close proximity to seasonal plants (e.g., trees losing leaves in winter) may also change link quality over periods of weeks and months.
- **Challenge: Duty cycling and task allocation.** In general, we try to bring energy consumption to a minimum. Here, the challenge would be to perform dynamic duty cycling that changes based on the measurement frequency necessity and to allocate specific tasks to nodes at relevant areas. For example, during the day, a higher measurement frequency might be necessary to obtain more precise predictions due to increased external noise and plant activity. Lower measurement frequency in calmer conditions (e.g., at night) would help reduce energy consumption. The network here should perform location-based duty cycle adjustment and task allocation based on surrounding environmental activity.
- **Challenge: Distributed connectivity control.** It is well-known that the rate of data propagation within the network correlates with its degree of connectivity. However, increasing the number of links between nodes can lead to deteriorated control and increased energy and computation costs. Similar to adaptive duty cycling, the challenge is to ensure desired communication performance while minimising energy consumption. Additionally, the effects that extrinsic and intrinsic disturbances have on the system performance must be considered when deploying a network in real-world scenarios. To address this challenge, we have developed a method for distributed topology control through algebraic connectivity measures. The algebraic connectivity is estimated locally with a trust-based consensus algorithm and links are dynamically added or removed to maintain desired connectivity.

Key lessons learned

Networking challenges have included stakeholder networking and technical networking of sensor devices. The high energy cost of networked devices is clear and a variety of adaptive approaches have been developed to reduce energy costs of network sensors. These include approaches based on hardware efficiency, different types of transmission technology, adaptive nodes and routing and adaptation of sensing and sending to the energy environment. These are designed to maximise the collection of important data whilst minimising energy costs and dropout rates.

2.3.6 People, training and engagement challenges

I-Seed

To date, the project has focused on the following challenges:

- **Challenge**: **Communication.** Raising awareness of the I-Seed project mission, challenges and results using social media (Twitter: https://twitter.com/iSeed_project), project website (https://iseedproject.eu/), press releases at national and international level, addressing popular newspapers, magazines, participation in radio and TV programs, in fairs, and organisation of "scientific café".
- **Challenge**: **Dissemination.** Dissemination of project results towards the scientific community and industrial representatives via scientific publication in peer-reviewed journals and international conferences; flyers, posters, presentations; organisation of special tracks, workshops, special sessions to present results and technologies in national and international conferences
- **Challenge**: **Environmental sustainability and community building**. Leverage the cross-disciplinary connection of the community of biorobotics and environmental science to support the evaluation of the effectiveness of measures undertaken in the implementation of environmental policies; and to promote eco-innovation initiatives through citizens involvement for raising awareness on critical environmental issues.
- **Challenge**: **Training**. Use of master classes, dedicated workshops, scientific tours, and summer schools, with the goal of educating a new generation of roboticists, material scientists, biologists and environmental scientists with the multi-disciplinary expertise for the creation of new environmentally-friendly technologies for the environment.
- **Challenge**: **Exploitation.** Use of presentations of I-Seeds prototypes, in their different phases, and meetings with potential customers and stakeholders.

RAMONES

Shaping data-driven policies, communicating near real-time information and informing public authorities, communities and various stakeholders is in the core of RAMONES

- **Challenge: Raising awareness of new developments** This challenge refers mostly to the academic and scientific communities, which are expected to significantly benefit from the novel technology that RAMONES is about to bring in the field. Following the EU directives on open science, but also respecting partners IP, may hinder the immediate availability of technological advancements and some fine balance needs be achieved to maximize our targeted impact
- **Challenge: Field tests in remote locations/harsh environments** RAMONES will face a major challenge in involving its partners during training on multi-disciplinary subjects, but more importantly engage them in activities aboard ships, away from shore for several days during field testing and final field deployment. Highly skilled personnel are required to provide coherence in the technical team during field missions.
- **Challenge: Disseminate efficiently to non-informed stakeholders** RAMONES expects to generate a wealth of day which will be able to be communicated to interested parties and stakeholders. As the level of complexity in the data and meta-data varies, downgrading disseminated information without losing its potential to inform, warn and mitigate risk is a major challenge in terms of efficient communication.

ReSET

To date ReSET has focused on the following *people* challenges:

- **Challenge: Raising awareness of new developments and engaging those that might benefit is challenging. Solution: Engage for co-design and co-creation.** We have begun awareness raising of the ReSET project using social media #H2020ReSET @H2020ReSET, web www.h2020reset.eu, participation at events, presentation at conferences and meetings with stakeholders. This in order to understand stakeholders needs, capacities and priorities and to make stakeholders aware of what we can provide.
- **Challenge: Testing of technologies in real cases. Solution: eEgage early and keep engagement regular and low time-cost for stakeholders.** In order to fully test our Environmental Intelligence Systems in active case studies we have focused on

relationship building and/or strengthening in case study locations and with European investors in order to ensure support for demonstration and application activities.

- **Challenge: Ensuring legacy. Solution: Teach and build capability.** Environmental Intelligence will only develop if there are skilled personnel who can design, develop and operate such systems. Thus we have also focused on training school and university students to build and use environmental monitoring equipment through the EduStation component of the project.

SMARTLAGOON

Watchplant

To date Watchplant has focused on the following *people* challenges:

- **Challenge: Raising awareness of new developments and engaging those that might benefit is challenging. Solution: engage.** We have begun awareness raising of the WatchPlant project using social media #WatchPlant, using twitter (@WatchplantP), LinkdIn (WatchPlant EU Project) and the web https://watchplantproject.eu. Additionally, participation at events, presentations at conferences.

Key lessons learned

Key lessons in people training and engagement have included careful communication of the complex topic that is Environmental Intelligence, and regular and diverse engagement activities with a range of stakeholder groups. Early publication of scoping papers in the IEEE GOOD-IT Special Track and other major conferences has been important in reaching out to the scientific community whilst smaller engagements with more local stakeholders have been important for building relationships, mutual understanding and access to data and knowledge. Going forward it will be important to communicate the key innovations of the projects with larger audiences towards impact and exploitation.

2.3.7 Policy challenges

I-Seed

To date I-Seed has focused on the following policy challenge:

- **Challenge**: **Policy makers and implementing agencies**. An important component of dissemination and outreach strategy of I-Seed is the involvement of international convention secretariat and expert groups supporting the policy implementation at UN level (i.e., UNEP, UNIDO, UNITAR) and EU and national levels. The evaluation of the effectiveness of measures undertaken by governments to achieve the objectives of an environmental policy depends primarily on the availability of monitoring data that may show the improvement of environmental quality over time. To leverage the ongoing monitoring programs with low-cost monitoring technologies would allow nations to promote nation-wide monitoring programs and be an active part of the policy implementation.

RAMONES

RAMONES has focused on the following challenges regarding policy

- **Challenge**: **Policy makers and implementing agencies**. **R**AMONES has already identified several key stakeholders interested in being informed on results and finding of the project. However, policy needs to be provided with the highest level of reliability and provided in a form/language comprehensible by various policy makers (scientific bodies, international agencies, governmental decision-taking bodies etc). Reliability is highly influenced by the overall efficiency of the technological part of RAMONES.
- **Challenge: Data and metadata FAIR and OA.** RAMONES fully aligns with the EU directives on data and metadata availability respecting the FAIR protocol and investing on open access publications and open science. The connection to policy making is strong, and as such, challenges exists as several layers of FAIR data are developed and become available to policy makers. Key policy makers need to be identified early in the project to allow for building strong and efficient communication channels once data from the field will be accumulated.

ReSET

To date ReSET has focused on the following *policy* challenges:

- **Challenge:** The toolkit for understanding flood mitigation through nature based solutions requires further work. By bringing together the best available remotely sensed data, existing models and connecting to new sensor networks, we are contributing to understanding the optimal solutions in this area, thus contributing to the water management and natural flood management agendas e.g. EU Water Framework Directive.
- **Challenge:** In transport infrastructure and urban contexts our focus is on using EI in contributions to improving air quality, climate net zero, climate resilience, investments for triple wins (environment, economy and jobs) i.e. European Green Deal, EU Adaptation Strategy. In addition to the overall impact of investments, we are also interested in exploring social justice aspects, thus understanding who is most affected by hazards and other environmental issues and who will benefit from investments.

Within the above two key challenge areas we are also examining **biodiversity net gain and no-net loss, net zero climate targets, and sustainable agriculture.** The toolkit for understanding biodiversity loss and managing for no net loss and net gain is poorly developed. We contribute to the solution by employing GIS, modelling, environmental monitoring and audio ecology to compare potential offset areas for new developments to better understand whether habitat quality is comparable to habitats being lost to development. This contributes to mitigating biodiversity loss through net gain and no net loss agendas i.e. EU Biodiversity Strategy. The toolkit for understanding the mitigation actions necessary to achieve net zero in the European urban and agricultural contexts are also poorly developed. Our carbon flex sensors, modelling of carbon storage and sequestration ecosystem services, and focus on new transport developments, contribute to climate change net-zero targets (in our agriculture, urban and transport related demos) through engagement in natural climate solutions and traffic management schemes. Sustainable agriculture could also be better supported by existing environmental intelligence systems. In the first year we have contributed to sustainable agriculture and the use of agricultural land management for ecosystem service provision agendas, e.g. the EU Farm to Fork Strategy. This is largely through the application of the consortium's existing toolkit: WaterWorld, Eco:actuary, Co$tingNature to case studies, ahead of integration.

2.4 Overall Conclusions

Environmental Intelligence requires expertise all the way from social science through environmental science to electronic engineering, computer science, data science and networking. Bringing such a diverse range of academic and technical know-how together to develop effective, efficient and seamless environmental intelligence focused on a range of different environmental contexts and issues is a challenge.

Nevertheless, little by little, even significant challenges like this can be overcome. This report documents what we understand Environmental Intelligence to be, why we think it is important and the progress each project is making to provide solutions to the key challenges faced. The next three iterations in this blueprint should take us closer and closer to producing the Information; Hardware; Software; Networks; People, Training and engagement, and Policy blueprints that are necessary for effective development and deployment of Environmental Intelligence in Europe and beyond.