D6.4 Strategic Roadmap (Release 2)

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Glossary

Word	Definition
AI	Artificial Intelligence
Argo	International programme on ocean observation using Argo floats
B-C	Blue-Cloud
CMCC	Euro-Mediterranean Centre on Climate Change
CMEMS	Copernicus Marine Environment Monitoring Service
CNR	Italian National Research Council
DG	Directorate-General (of the EC)
DG DEFIS	Directorate-General for Defence Industry and Space (formerly DG GROW)
DG RTD	Directorate-General for Research and Innovation
DG MARE	Directorate-General for Maritime Affairs and Fisheries
DG GROW	Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (succeeded by DG DEFIS)
DG ENV	Directorate-General for Environment
DG CONNECT	Directorate-General for Communications Networks, Content and Technology
DG DEVCO	Directorate-General for International Cooperation and Development
DIAS	Data and Information Access Service (funded by EC COPERNICUS programme)
DTO	Digital Twin of the Ocean
EASME	Executive Agency for Small and Medium-sized Enterprises
EC	European Commission
EcoTaxa	Web application dedicated to the visual exploration and the taxonomic annotation of images focused on planktonic biodiversity
EMBL	European Molecular Biology Laboratory
EMBL-EBI	European Bioinformatics Institute
EMBRC	European Marine Biological Resource Centre
EMODnet	European Marine Observation and Data Network
ENA	European Nucleotide Archive
EOSC	European Open Science Cloud
ESEB	External Stakeholder & Expert Board (of Blue-Cloud)
EU	European Union
EUDAT	Pan-European network and collaborative data infrastructure, consisting of a network of academic computing centres
EuroBioimaging	European Research Infrastructure for Imaging Technologies in Biological and Biomedical Sciences
EurOBIS	European Ocean Biodiversity Information System

FAIR	Findable, Accessible, Interoperable and Reusable
FAO	Fisheries and Agriculture Organisation of the United Nations
G7 FSOI	G7 Future of Seas and Oceans Initiative
GDDS	Green Deal Data Space
GPU	Graphics Processing Unit
H2020	Horizon 2020 EU Framework Programme
HE	Horizon Europe Framework Programme
HPC	High-Performance Computing
ICOS	Integrated Carbon Observation System
ICT	Information and communications technology
Ifremer	The French Research Institute for Exploitation of the Sea
ISC	International Science Council
IoT	Internet of Things
JRC	Joint Research Centre
KERs	Key Exploitable Results
KPIs	Key Performance Indicators
MARIS	SME expert in European marine data management infrastructures (Blue-Cloud technical coordinator)
ML	Machine Learning
MOi	Mercator Ocean International
MSFD	Marine Strategy Framework Directive
MSP	Marine Spatial Planning
MSPD	Marine Spatial Planning Directive
NOAA	National Oceanic and Atmosphere Administration (United States of America)
OGC	Open Geospatial Consortium
SDG	Sustainable Development Goals
SeaDataNet	A pan-European infrastructure to ease the access to marine data measured by the countries bordering the European seas (network of NODCs)
SME	Small-Medium Enterprises
SSBE	SME specialised in marine policy (Roadmap coordinator) - Seascape Belgium
Trust-IT	SME specialised in market and technical research analyses in the field of ICT (Blue-Cloud coordinator)
UN	United Nations
UN 2030	The 2030 Agenda for Sustainable Development
VLIZ	Flanders Marine Institute
VRE	Virtual Research Environment
Web-based Open Science	An approach to the scientific process that focuses on spreading knowledge as soon as it is available using web-based digital, collaborative technologies. In this document, “web-based Open Science” and “Open Science” are considered synonyms, but “web-based Open Science” is used to highlight the key role of web-based technologies in enabling Open Science.
WEkEO DIAS	WEkEO is one of the 5 Copernicus DIAS, bringing in the CMEMS, C3S and CAMS

Executive Summary

The Blue-Cloud project has piloted a digital platform and services showcasing how web-based Open Science can enhance the **marine knowledge value chain** in support of greater societal objectives, namely those seeking to address Ocean challenges and opportunities associated with the delivery of the **EU Green Deal** and **UN Agenda 2030**. It has proved how providing researchers with **cloud-based analytical tools** and **computing resources**, coupled with access to **marine data** openly available across different, **existing European data services** and **research infrastructures**, can shorten the research-to-innovation cycle, enabling them to harness artificial intelligence (AI) to improve the **transformation** of **marine data** to **products**, progress more efficient **modelling** of ocean variables, support **environmental analytical data services**, inspire and accelerate **community-driven innovation** and **collaborate** at a global scale. Blue-Cloud has further showcased the specific applications that these improved capabilities can deliver, advancing solutions towards e.g., monitoring biodiversity; predicting changes in ecosystems; producing marine environmental indicators; or managing fisheries and aquaculture.

Blue-Cloud Vision 2030

"To contribute to a European cloud-based knowledge system that provides access to a diverse and dynamic portfolio of analytical, prediction & visualisation capabilities underpinned by seamless access to a wealth of FAIR, transdisciplinary Ocean & freshwater observation data, enabling Open Science to deliver knowledge -including hindcast & forecast simulations-, and to drive innovation -notably through artificial intelligence-, science-based policies and public awareness for a safe, healthy and sustainably productive Ocean, in support of the EU Green Deal & UN Agenda 2030".

Building on its results and looking ahead (2026-2030), Blue-Cloud's distinctive and specific contribution to the marine knowledge value chain will be geared at accelerating **marine & freshwater data interoperability** and improving **data modelling** and **Big Data analytics** through collaborative, cloud-based Open Science (**Blue-Cloud's Mission 2030**). Blue-Cloud will evolve as a key component of Europe's **FAIR marine digital knowledge ecosystem**, providing a flagship **community of practice** and **incubator** for data analysis and modelling methods in support of applied research of the ocean, European seas, coastal and inland waters. It will contribute to the successful evolution of the **(digital) marine knowledge system** required to support the EU Green Deal and the UN Agenda 2030, namely becoming a key **link** in:

- **Making ocean & freshwater digital commons accessible to the wider scientific community via EOSC:** Blue-Cloud will offer its interoperable data framework to bridge the gap with EOSC, supporting the FAIRification of marine & freshwater data and facilitating multidisciplinary innovation at a wider scale.
- **Supporting the development of analytical services and/or Digital Twins that add value to the core European Digital Twin of the Ocean (EU DTO) to inform policy making in the delivery of societal objectives:** Blue-Cloud will leverage its digital ecosystem and community of practice to deliver both user-driven and/or community-driven value at the intersection of the communities enabling the development of environmental (marine & freshwater related) data analytical services and/or digital twins, namely: the "**Observation and Data Collection & Management**" communities, the "**Data Modelling**" communities and the "**e-infrastructures**" that provide cloud storage and computing capabilities.

To achieve its Mission, Blue-Cloud will strive to maximise value to **primary**, **secondary** & **tertiary** users:

- **Primary users** *(marine researchers, computer scientists & software developers)***:** It will improve its digital platform with user-driven upgrades (more functionalities, more computing power, more federated data); sustain a well-resourced customer support centre (including providing

expertise on the application of artificial intelligence); and nurture community-building by providing users with training opportunities and incentives, aiming at offering access to these resources free-of-charge to researchers.

- **Secondary users** *(EU and (inter)national environmental agencies; marine data & research infrastructures; EOSC; DestinE & EU DTO; Horizon Europe Mission Lighthouses & Blue Parks; Blue Economy SMEs & Industry)***:** It will continue to evolve its DD&AS with new data repositories from current contributing infrastructures and from new infrastructures to further bridge their gap with EOSC; set up a DTO Task Force to make Blue-Cloud resources easily portable and/or integrated into the future EU DTO; explore collaboration opportunities with other public and/or private initiatives seeking to develop digital twins to support the EU DTO and/or Blue-Economy undertakings, offering them a unique digital ecosystem to co-create, build and test the algorithms and models enabling the data streams and workflows required for their operation, together with an Open Science community of practice that can be leveraged for innovation; and engage with new marine and freshwater research projects and with Horizon Europe "Mission" platforms to identify needs and challenges of marine data users that could be addressed with new methods incubated in Blue-Cloud.
- **Tertiary users** (*policy makers, funders, civil society organisations, citizens*): Blue-Cloud will continue to steer innovation towards supporting strategic EU policy strategies and action (i.e., MSFD, WFD, Biodiversity and "Farm to Fork") and towards supporting international collaboration around global ocean observing and forecasting capabilities, with special attention to supporting the delivery of the UN Agenda 2030 SDGs 2, 13 and 14. It will closely monitor and engage with developments around the EU Green Deal Data Space (GDDS) to further identify challenges, opportunities and priority action areas where Blue-Cloud could contribute to accelerate progress. It will continue to support the development of user-friendly applications and interfaces that contribute to increasing the flow of citizen science data into the marine knowledge value chain and to bringing ocean science closer to citizens.

Strategic Goals 2026-2030 and a comprehensive **Action Plan** have been designed to drive future developments towards delivering Blue-Cloud's Mission 2030, working around **5 strategic paths of action**:

- **Strategic Action Path 1:** Sustain the flow of FAIR & open marine data into Blue-Cloud.
- **Strategic Action Path 2:** Trigger the development of innovative data analytics methods around priority environmental thematics to inspire and guide the Blue-Cloud community towards further evolving applications in support of key policy objectives.
- **Strategic Action Path 3:** (Further) Federate with key marine data, research and e-infrastructures and strategic initiatives (e.g., EOSC, EDITO-Infra) to enhance value to users.
- **Strategic Action Path 4:** (Further) Grow a thriving ocean open science community, leveraging skills, incentives and rewards and promoting wide dissemination of FAIR methods incubated in Blue-Cloud to boost innovation at a wider scale.
- **Strategic Action Path 5:** Connect and align with wider developments and other communities to contribute to a European and a global, international knowledge system in support of the EU Green Deal and the UN Agenda 2030.

Delivering Blue-Cloud's Mission 2030 will require support from **EU policy** and **funding frameworks**, which will be needed not only to continue to evolve Blue-Cloud's efforts, but also to create a thriving context for the successful delivery of its overarching **vision**, which spans well beyond the scope of action of Blue-Cloud. The following table sums up the **roadmap of actions** that Blue-Cloud has laid out to deliver its **Mission 2030**, coupled with **recommendations** for **policy actions** that are considered critical to realise the full potential of web-based Open Science in the marine domain, paving the way for the successful delivery of the knowledge system required to advance research of Ocean, seas, coastal and inland waters in Europe and beyond.

Table 1: Summary of Strategic Roadmap & Policy Recommendations

Strategic Action Path 1 & Policy Recommendations Towards Sustaining the Flow of FAIR and Open marine data in Blue-Cloud's (and other) Open Science environments	
Blue-Cloud Strategic Actions 2026-2030	**Policy Recommendations 2030**
1.1 Expand Data Discovery & Access Service (DD&AS) with priority EU marine data & research infrastructures. 1.2 Expand Data Discovery & Access Service with citizen science repositories. 1.3 Expand Data Discovery & Access Service with freshwater repositories. 1.4 Enhance DD&AS with additional functionality for sub-setting and extracting data sets, towards feeding and maintaining data lakes with EOVs. 1.5 Improve the FAIRness of the federation by optimising machine-to-machine interactions with connected RIs and data repositories.	1. Operationalise funding for trusted EU marine data infrastructures & services to maintain seamless operation and evolution of data services towards meeting future needs e.g., cloud-based data sharing & Open Science. 2. Take measures to strongly mandate improved flow of scientific data into EU marine data & research infrastructures and adopt mechanisms to help overcome barriers to data retention for publicly funded research.
Strategic Action Path 2 & Policy Recommendations Towards Triggering Innovative Data Analytics Methods Around Priority Thematics to inspire and guide the community	
Blue-Cloud Action 2026-2030	**Policy Recommendations 2030**
2.1 Test and develop new digital assets, including workbenches to improve quality control for EOVs. 2.2 Continue evolving existing Virtual Labs (e.g., Marine Environmental Indicators VLab) to upscale their current analytical products & services, enhancing their user value and user-friendliness with data inspection and/or visualisation capabilities to support policy objectives. 2.3 Develop new analytical services addressing priority policy areas of the EU Green Deal (e.g., biodiversity monitoring, Marine Spatial Planning). 2.4 Engage with the private sector to test and develop fit-for-purpose solutions in support of environmental analytical services and/or digital twins servicing Blue Economy applications.	3. Encourage EU initiatives to share outcomes of stakeholder consultation processes towards identifying user needs & requirements for new analytical, modelling and/or visualisation services that could be developed within Blue-Cloud, servicing different communities. 4. Capitalise on Blue-Cloud to service the needs of projects building analytical tools & services to support research (e.g., HE projects) and/or to inform policy (e.g., MSFD, WFD, etc). 5. Promote free access to data services with data formats and access protocols supporting interoperability worldwide (e.g., OGC, TDWG...), relaxing 3rd party barriers to Open data in the marine domain to enable user-driven innovation and Open Science at a wider scale, while fostering data licensing to support data usage tracking.
Strategic Action Path 3 & Policy Recommendations towards (further) federating marine data, research & e-infrastructures and strategic initiatives to enhance value to users	
Blue-Cloud Action 2026-2030	**Policy Recommendations 2030**
3.1 Advance further integration with key e-infrastructures (e.g., orchestrating analytical workflows, Single-Sign-On, upscaling computing power). 3.2 Further integrate with WEkEO to enable portability of Blue-Cloud assets to EU DTO, DestinE and other relevant environments.	6. Sustain progress towards federation of e-infrastructures to increase EU cloud storage, computing power and GPUs, enabling the research community to tap on EU digital capabilities, resources, and commons to engage in Open Science. 7. Encourage key players (EOSC, future EU DTO) to fix protocols and/or rules of compliance that enable

3.3 Setup DTO Task Force to align objectives and contribute digital assets to EU DTO & DestinE. 3.4 Connect with communities developing components of EU DTO to offer collaboration & synergies. 3.5 Ensure long-term EOSC alignment and integration.	users to easily port their digital assets across e-infrastructures, without being "tied" to them. 8. Promote cooperation between public marine data and research infrastructures, e-infrastructures and European, private cloud service providers to bring data and models to their platforms, making them also available in their computing facilities to support wider use, exploitation, dissemination and uptake.
Strategic Action Path 4 & Policy Recommendations towards (further) growing a thriving Ocean Open Science community leveraging skills, incentives & rewards and promoting FAIR methods to promote innovation at a wider scale	
Blue-Cloud Action 2026-2030	**Policy Recommendations 2030**
4.1 Continuously monitor & deliver the evolving needs of Blue-Cloud's primary users to offer an excellent service that contributes to consolidate and grow the community. 4.2 Set up a support service and a training academy to build FAIR data, AI & Big Data skills amongst researchers, attracting new users. 4.3 Set up competitions to invite users to address challenges set forth by secondary users, rewarding ideas with uptake potential. 4.4 Expand connections with (Horizon Europe) research project communities. 4.5 Set up MoU's with key EU initiatives to acknowledge methods developed in Blue-Cloud that could be taken-up with a special attribution of "excellence" and/or enticing Terms of Use. 4.6 Explore collaboration with commercial platforms offering analysis & visualisation of geospatial datasets (e.g., Google Earth) to promote dissemination of FAIR methods.	9. Include in curricula and support training efforts to build capacity amongst researchers in the use of artificial intelligence, machine learning (ML), and on the application of FAIR practices to analytical methods for wider exploitation, capitalising on Blue-Cloud's VRE to deliver data camps, courses and training. 10. Foster mechanisms that reward research teams that incubate methods and/or services that are taken-up by long term EU initiatives and/or services, including economic rewards linked to their exploitation (e.g., by sharing "exploitation fees" of "freemium" schemes offered to users). 11. Establish Terms of Reference for exploitation of digital commons across the EU Green Deal Data Space, promoting open access to such commons (e.g., data, data models, algorithms) and the adoption of an open-source approach to their exploitation if/when obtained and/or developed with public funding.
Strategic Action Path 5 & Policy Recommendations towards connecting and aligning with wider communities to contribute to a European and global knowledge system	
Blue-Cloud Action 2026-2030	**Policy Recommendations 2030**
5.1 Engage with GDDS Community of Practice. 5.2 Engage with HE Lighthouses, Blue-Parks and with EU4Ocean networks to identify community-driven challenges to "interrogating" the Ocean. 5.3 Continue collaboration with All-Atlantic Ocean Research Alliance. 5.4 Evolve methods into international Ocean Best Practices towards supporting international efforts (GOOS, GEOSS) and UN Decade programs.	12. Support uptake and capitalisation of the results of the community-driven, Open Science efforts delivered by Blue-Cloud into the EU Digital Twin Ocean and other EU and global environmental initiatives, such as the UN Convention on Biological Diversity and the UN Framework Convention on Climate Change.

1 About Blue-Cloud's Strategic Roadmap to 2030

The **Horizon 2020 pilot Blue-Cloud project**[1] is the component of "**The Future of Seas and Oceans Flagship Initiative"** aiming to demonstrate the potential of web-based **Open Science in the marine domain.** The project has **piloted** the development of a **web-based cyber platform** to provide marine researchers with enhanced **analytical capabilities**. It has provided them with powerful **computing facilities**, a range of **analytical tools**, and **simplified access to data** from *in situ* and satellite observations, data products and model outputs available across different marine data and research infrastructures, all integrated into one single environment that supports Open and FAIR (*F*indable, *A*ccessible, *I*nteroperable & *R*eproducible)[2] Science. Blue-Cloud has formed a **marine thematic community** integrating with developments of the **European Open Science Cloud** (EOSC).

The Blue-Cloud project has delivered **innovative, demonstrative assets**, which can be further taken up, sustained and evolved to capitalise on its results. The **Blue-Cloud Roadmap to 2030** seeks to provide strategic guidance for the future evolution of these efforts towards their further development beyond project-end and into the future (2026-2030). Developed over the course of the three-year pilot project as a co-designed, strategy and policy document, the Roadmap is the result of a **collective reflection of Blue-Cloud partners, experts** and **stakeholders** on how these results can be exploited and evolved into the future to maximise their impact, catering to a much larger user base, aligning with wider developments at European and global level and creating new opportunities for **Ocean**, **science-based innovation** in support of the **European Union (EU) Green Deal** and the **United Nations (UN) Agenda 2030**.

In 2020, building from an initial Concept Note[3], the project saw the start of an **initial phase** of **stakeholder dialogue** that extended into early 2021, including discussion amongst Project Partners[4], workshops with **Blue-Cloud External Stakeholder & Expert Board**[5] (ESEB), targeted conversations with representatives of the **European Commission** and consultation to key stakeholder communities (marine researchers, marine data infrastructures, research infrastructures, e-infrastructures, and international Ocean observing and data management initiatives)[6]. A first draft release of the roadmap was launched for wider stakeholder consultation in the summer of 2021, seeking to gather contributions from the wider marine and maritime community in Europe and internationally. This second phase of stakeholder dialogue also encompassed interviews with key stakeholders, as well as bringing feedback from participants engaged in the "**Blue-Cloud Hackathon**[7]".

Blue-Cloud's **Strategic Roadmap to 2030** is the result of this process, outlining a **vision**, a **mission statement** and a **strategic action plan** towards evolving Blue-Cloud's efforts into the decade, including a set of **policy recommendations** to create a thriving context in support of their successful delivery.

[1] https://www.blue-cloud.org/
[2] M. Wilkinson *et. al.* (2016). The FAIR Guiding Principles for scientific data management and stewardship
[3] Blue-Cloud strategic Roadmap Concept Note (Milestone MS41)
[4] https://www.blue-cloud.org/partners
[5] https://www.blue-cloud.org/eseb
[6] For a more detailed description of the stakeholders engaged in roadmap consultations see section "Acknowledgements"
[7] https://hackathon.blue-cloud.org/

2 Unlocking the potential of cloud-based Open Science in the marine domain: Opportunities & challenges

2.1 Opportunities for cloud-based Open Science in the marine domain

The motivations and goals behind **Blue-Cloud**'s efforts are shaped by the context of our times, driven by a confluence of **global change** - large scale, Planetary changes in the Earth system and in society - and the **digital revolution**. The Blue-Cloud project is part of EU action in response to this context, which on the one hand presents unprecedented challenges - connected to **climate change**, **pollution**, **waste** and the **loss of biodiversity** and **ecosystem integrity** at a planetary scale - while on the other is delivering new emerging opportunities enabled by the dawn of the **digital age**. Digital technologies are making it possible to accelerate the development of **science-based solutions** to global challenges and fostering **digital environmental cooperation** at an also unprecedented scale, making it more plausible to coordinate a more effective global response. This response, in return, has the potential to create **new jobs, wealth** and **wellbeing** by **advancing global sustainability** through environmental stewardship. Europe is embracing this context of challenges and opportunities through the **EU Green Deal**[8] and the **EU Strategy for Data**[9], further contributing to effective international action by aligning the objectives of these ambitious policy frameworks with those of the **UN Agenda 2030 for Sustainable Development**. From a marine perspective, the EU has launched **Mission "Restore our Ocean & Waters by 2030"** (here onwards "**Mission Ocean"**) [10], which sets clear goals to support the EU Green Deal through specific actions around **healthy Ocean**, **seas, coastal** and **inland waters** and is working through the **G7** to align action through the **G7 Future of Seas and Oceans Initiative**.

As by-products of the digital revolution, emerging **Artificial Intelligence** (AI) and **Big Data** systems are dramatically enhancing society's capacity to harness Ocean data. On the one hand, they enable methods that support easier **harmonisation** of **marine data**, one of the biggest "pain-points" for marine researchers[11], thereby driving progress towards underpinning Ocean research with an increasingly interoperable digital ecosystem. On the other hand, they are enabling the implementation of the "Digital Twin" paradigm. **Digital Twins of the Earth** are seen as an opportunity to generate the **actionable intelligence** that is needed to deliver on the EU Green Deal and the UN Agenda 2030[12]. Along these lines, the future **EU Digital Twin of the Ocean** (EU DTO) will open new opportunities to improve our **understanding, knowledge,** and **prediction** of the **Ocean**; inform better **science-based policies**; **trigger innovation** across the blue economy; and support the spread of **Ocean literacy** and thereby the development of an **Ocean citizenship**. Seizing these opportunities will require a sustained, long-term community effort. Not only to support the required shift of paradigm in the way that data is exchanged (towards automating interactions across multiple types of devices, repositories, domains, and related systems)[13], but also to orchestrate the **collective knowledge**,

[8] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

[9] https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/european-data-strategy_en

[10] https://ec.europa.eu/info/horizon-europe/missions-horizon-europe/healthy-oceans-seas-coastal-and-inland-waters_en

[11] Summary of Key Messages of 1st Phase of Consultations with the Blue-Cloud Community (SSBE, 2020)

[12] Nativi, S.; Mazzetti, P.; Craglia, M. Digital Ecosystems for Developing Digital Twins of the Earth: The Destination Earth Case. Remote Sens. 2021, 13, 2119. https://doi.org/10.3390/rs13112119

[13] Nativi, S. Geospatial Digital Ecosystems for developing Digital Twins of the Earth: Workshop on Data Science and Curation: Spatial Data Science. 2021. http://dx.doi.org/10.13140/RG.2.2.29293.51681

expertise, and **efforts** of the **diverse network** of actors that will be required to dynamically develop, support and maintain the underlying fabric of the EU DTO.

Cloud-based, **digital ecosystems** that enable **Open Science** can play a key role in supporting the EU and international Ocean community towards that end, allowing for the development, testing and validation of the AI analytics and Machine Learning (ML) tools that, in combination with thematic or sectorial models, and in addition to numerical models, are required to **transform data** into **knowledge**, facilitating harmonisation of databases, algorithms co-creation and interdisciplinary approaches[14]. This is key to advance digital solutions that can effectively represent reality and forecast future scenarios. Growing a thriving, **cloud-based Open Science digital ecosystem** in support of research of the Ocean, seas, coastal and inland waters, and furthering it for integration into the **European Open Science Cloud** (EOSC) and other key EU initiatives (i.e., EU DTO) is the overarching ambition of Blue-Cloud, as described in this **Strategic Roadmap to 2030**.

2.2 Blue-Cloud's added value to the EU marine knowledge value chain

Over the past decades, Europe has developed an impressive capability for marine observation. Europe's efforts to support increased knowledge of our seas[15], aligned with action at national level, has led to a remarkable increase of abundance of **marine data**, stemming from academia, major Research & Development projects and initiatives, Research Infrastructures (RIs), industry and civil society, which has contributed to the emergence of a well-developed, complex **European "marine knowledge value chain"** which brings together multiple European actors and assets. The emergence of citizen science and technological developments such as the "Internet of Things (IoT)" anticipates unprecedented potential to exponentially grow such abundance.

A resilient, existing European network of distributed **infrastructures** for Ocean observing and data gathering, handling and sharing is making it possible to **capture**, **manage**, **enhance** and **channel** this wealth of data into an additional layer of actors in the marine and maritime research and blue economy communities. Marine data infrastructures and services, such as the **European Marine Observation and Data Network** (**EMODnet**) and the **Copernicus Marine** and **Climate Change Services**, together with **Research Infrastructures** and **horizontal e-infrastructures**, play a key, strategic role in making data **findable**, **accessible**, **interoperable** and **reusable** (FAIR) to **marine data user communities**. Thanks to all these efforts, marine data is now recognised as a **public good** in Europe and multi-resolution maps of all Europe's seas and Ocean are available, together with large catalogues of **open** and **free data collections and data products** that span multiple disciplinary themes. Efforts along the marine knowledge value chain have also extended to applying technology towards enhancing the **analytical capabilities** of the marine community. The EU has supported the development of **e-infrastructures** as the pathway towards integrating **data services** with **analytical tools** in a seamless way.

In spite of its impressive capabilities, Europe's marine knowledge value chain still faces **challenges** towards further enhancing its performance and unlocking the full potential of Open Science, for the benefit of all engaged actors and ultimately, European citizens. On the one hand, it requires "lubrication" at different points of its underpinning gear, including better identifying and qualifying **user needs** for marine data to inform Ocean observations; **advancing** and **harmonising data**

[14] Nourishing Blue Economy & Sharing Ocean Knowledge. Tanhua T .et al (2021)

[15] COM(2014) 254 final/2 Innovation in the Blue Economy: Realising the potential of our seas and oceans for jobs and growth https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=COM:2014:254:REV1&from=EN

management practices towards FAIR principles across marine data infrastructures to support greater **interoperability**; making more of the currently available data **open** (to the extent possible); and **connecting to other data spaces** to support interdisciplinary research. But in addition to responding to those challenges, Europe's marine knowledge value chain can benefit from developing more **dynamic ecosystems** in support of **data analysis**. Harnessing the power of **web-based, "cloud" technologies** to unlock Open Science can boost the value chain's **productivity**, bringing a huge leap forward in the way that **marine data** - as well as the **methods** and **results** linked to **processing** and **analysing** such data - is **used**, **shared**, **enriched** and **applied**. The **Blue-Cloud project** is a step in that direction, showcasing how web-based collaboration can catalyse the development of **analytical tools** and **modelling methods** with great potential **impact** on the **productivity** of **research** across **priority policy areas**.

Blue-Cloud's **underpinning technology** and innovative concept builds on existing EU capability and has been designed to deliver **core services** that are deployed through smart federation of leading marine data and e-infrastructures, namely:

- A **Data Discovery & Access Service (DD&AS):** Offering **discovery** and **access** to a range of (open) **marine data** by federating and increasing interoperability between key European data infrastructures[16] to facilitate users in finding, retrieving and "pushing" multi-disciplinary datasets from existing repositories into an analytical environment.
- **A Virtual Research Environment (VRE):** Providing a **cloud-based**, **analytical** and **publishing framework** as a federation of computing platforms and analytical services for constructing, hosting and operating **virtual laboratories**. It also provides a Catalogue[17], connected to EOSC, ensuring that the digital assets produced within its ecosystem can be easily discovered and reused by the wider scientific community.
- **Blue-Cloud Virtual Labs (VLabs):** A VLab is a web-based, problem-solving environment that enables users across different physical locations and expertise to collaborate efficiently in an ongoing way, providing them with tools and services to develop analytical methods, mine data, test results and share scientific outputs towards solving complex problems. Blue-Cloud fit-for-purpose VLabs showcase (reproducible) **analytical methods** and **workflows** that have been developed to support marine researchers across different thematic areas[18] (i.e., advancing knowledge of Essential Ocean Variables, developing Environmental Marine Indicators, managing Fisheries & Aquaculture), and which in turn can trigger **new, community-driven applications** in support of wider policy and societal goals.

The Blue-Cloud project has demonstrated how the exploitation of these core services can enhance the **marine knowledge value chain**, overcoming existing barriers to Open Science, contributing to shorten the research-to-innovation cycle, and ultimately advancing the **application** of **research** to **policy objectives**, by:

- **Improving the transformation of marine data to specific products:** New algorithms have been developed to service and support marine data scientists by eliminating the hassle of harmonising the access from different data infrastructures to heterogeneous data sets. These

[16] EMODnet, CMEMs, SeaDataNet, EurOBIS, Euro-Argo, Argo GDAC, ELIXIR-ENA, EuroBioImaging, EcoTaxa, ICOS-Marine
[17] https://blue-cloud.d4science.org/catalogue-bluecloud
[18] https://blue-cloud.org/vlabs

algorithms use statistical and machine learning methodology enabling researchers to, for example, perform climatological studies on the environment that can reveal trends or anomalies leading to undesirable metocean conditions, providing early warning indicators. These algorithms can bring an important leap forward in enhancing scientific productivity and in shortening the time that researchers invest in transforming research outputs into actionable information.

- **Advancing more efficient data modelling:** New data models have been produced to better understand key EOVs, (i.e., plankton distribution and genomics) and make predictions, including their degree of uncertainty. Aside from their contribution to research, these models are a steppingstone towards the wealth of data workflows and digital components that will be required to fuel and maintain the EU DTO, as well as the increasing number of industry-led digital twins that will support and contribute to a more productive, sustainable Blue Economy.
- **Inspiring and accelerating community-driven innovation:** The use of Open data and tools that enable Open Science (e.g., Jupyter notebooks, Digital Object Identifiers, Creative Commons licences) has allowed other (non-project related) users to reproduce the methods and models developed by Blue-Cloud, evolving tools offering unexpected applications of these digital assets, within the lifetime of the project. For example, the phytoplankton concentration maps available in the "Zoo & Phytoplankton EOV" Virtual Lab were used during the Blue-Cloud Hackathon to underpin the development of a tool to monitor marine megafauna movements (Wildlife Tracker), which could be applied to e.g., reduce the risk of ship-strikes with protected species. Together with other innovative tools evolved by hackathon participants, it provides a tangible example of the potential of Blue-Cloud as an "incubator" of methods that can be potentially taken up by a much wider community of users to in turn service and **accelerate** the development of **innovative solutions** in support of Ocean sustainability.
- **Accelerating monitoring services to support policy:** New, advanced environmental analytical services have been piloted, offering promising potential across different environmental thematics, especially around **biodiversity**, which is central to the delivery of the EU Green Deal. Monitoring marine habitats, species and ecological processes is very challenging, but key to informing policy choices. By deploying AI, researchers can find new ways of bridging existing knowledge gaps. For example, Blue-Cloud has showcased how AI can be harnessed to classify coastal areas for aquaculture purposes, using satellite images. In the future, Blue-Cloud could evolve to support a suite of (environmental) services forming a single "digital dashboard" that would allow monitoring different, predefined biodiversity indicators to **measure progress** towards specific policy objectives. Likewise, as it has showcased, it can play a key role in supporting the generation of a broader range of **marine environmental indicators** and early warning solutions[19], which are key to **informing science-based policies** and **societal action**.

> *"Blue-Cloud, through the facilitated access to observation data and the application of innovative methods on big data, has the necessary elements to foster the production of marine biodiversity indicators, currently one key challenge towards delivering on the 2030 objectives of the EU Biodiversity Strategy and UN Convention on Biodiversity."*
>
> Jean-Nöel Druron (EC JRC)

[19] For more information, please see: https://doi.org/10.5281/zenodo.7292456

- **Enabling collaboration at a global scale:** The collaborative environment provided by Blue-Cloud - which not only offers easier access to data and computing power, but also common workspaces and key software tools mainly used by marine researchers to process and analyse data, such as R Studio or Jupyter Hub - coupled with a "community-of-practice" approach to define and/or apply common (meta)data standards and languages and to establishing (semantic) workflows - has enabled effective collaboration amongst remotely located researchers and developers, delivering outcomes with a potential global impact. For example, the UN Food and Agriculture Organisation (FAO) is using Blue-Cloud to evolve its Global Record of Stocks & Fisheries, leveraging Blue-Cloud capabilities to validate records, including their enrichment with other resources (e.g., oceanographic data), as well as to offer training on the implementation of the UN Sustainable Development Goal (SDG) 14 (Life Below Water) to relevant teams and communities across the world. In this regard, Blue-Cloud could evolve to become an international, **neutral hub** for **international**, **cross-institution**, **cross-domain collaboration** on the UN SDGs.

Blue-Cloud's Catalogue is connected to EOSC, ensuring that the digital assets produced within its ecosystem can be easily discovered and reused by a much wider scientific community. Considering that innovation follows non-linear patterns across the domain of science, technology and the economy[20], it is the potential applications of these digital assets what encapsules **Blue-Cloud**'s key **added value** to the **marine knowledge value chain:** namely, **catalysing innovation** by **enhancing marine data interoperability, modelling and Big Data analytics** through Artificial Intelligence, Machine Learning and cloud-based Open Science, in support of the **EU Green Deal & UN Agenda 2030**.

> *"Blue-Cloud addresses the bottlenecks that the European Marine Board Future Science Brief on Big Data in Marine Science highlighted in 2019. It has made amazing strides in overcoming some of the challenges that were identified in that document towards obtaining maximum value from marine big data. It goes a long way to enabling policy makers to make well-informed, data driven management decisions."*
>
> Sheyla Heymans (European Marine Board)

[20] Leydesdorff, Rotolo & de Nooy, 2013

What can Blue-Cloud contribute to the marine knowledge value chain?

Examples of applications developed as part of the Blue-Cloud project workplan by its demonstrators

Embedding Research into Operational Frameworks to Support Innovation

The **Zoo- and Phytoplankton Essential Ocean Variables (EOVs) VLab**[21] has developed a workflow to apply a **model** to analyse **phyto & zooplankton interactions**. This model contributes to a better mechanistic understanding of the spatio-temporal dynamic phytoplankton biomass - which for example can help predict whether an ecosystem might change under future climate scenarios and/or Blue Economy activities-, offering great added value to field observations in **environmental monitoring programs**. In parallel, the **Plankton Genomics VLab**[22] has evolved **data workflows** to extract new plankton data products from existing data, in particular from genomic samples collected by the "Tara Oceans" project[23]. These analytical tools are relevant to study plankton diversity at basin and global scales when observations are scarce, which is of particular interest for researchers in the fields of **plankton biogeography, marine biogeochemistry**, and **ecosystem health**. Users of this VLab can for example use these tools to produce **global maps** of potential **distribution** of selected **plankton taxa** and **genes**, through Machine Learning-based regression on environmental variables. Making these digital assets available to the wider community through Blue-Cloud's Open Science ecosystem caters to the objective of "pushing" scientific outputs from "research" into "operational" frameworks, supporting the reproducibility of science and enabling innovation across the marine knowledge value chain

From the Fishnet to the Internet

The "**Fish, A Matter of Scales**" demonstrator[24] has evolved innovative ways of delivering knowledge on **fisheries** to improve their **management** and **monitor trends** in **fisheries indicators**. Its **Global Tuna Fisheries Atlas VLab** provides an overview of FAO statistics, further allowing their visualisation in combination with other maps of environmental data, feeding from Copernicus Marine satellite data products and from EMODnet. It offers global thematic maps showing the **Earth's fisheries**, their **production** and **trade**, as well as **fish distribution maps** and **ecological zones**. Added maps, measurements and accurate analytical techniques allow users to place and analyse fisheries in a wider environmental context, potentially informing and supporting decision making across different **EU policies** -including the **Common Fisheries Policy**, the **EU "Farm-To-Fork" Strategy** and the **EU Biodiversity Strategy**- as well as at a regional level, further enabling **capacity building** to monitor progress towards the **UN SDGs**, more specifically **SDG 2** (Zero Hunger), **SDG 13** (Climate Action) and **SDG 14** (Life Under Water).

Using Artificial Intelligence to Classify Coastal Areas and Monitor Aquaculture

Blue-Cloud's "**Aquaculture**" demonstrator[25] has evolved a series of **algorithms** and a repeatable **data workflow** that enables the use of satellite images to support the **detection** and **tracking** of **aquaculture cages**, anytime, anywhere. This can evolve into a service that would enable the production of national aquaculture sector overviews, allowing countries to make use of OGC-compliant data services to monitor its aquaculture sector, built on interoperable services where teams can compute and publish reproducible experiments. This demonstrator provides a powerful example of how Artificial Intelligence could be harnessed to enhance monitoring capabilities and analytical services across different domains, in support of policy objectives.

Figure 1: Blue-Cloud's Added Value to the Marine Knowledge Value Chain: Examples of applications developed as part of the Blue-Cloud project workplan by its demonstrators

What can Blue-Cloud contribute to the marine knowledge value chain?

Examples of community-driven applications that have leveraged Blue-Cloud

Enabling resource-limited researchers to interact with state-of-the-art developments:

SeaClearly is a tool that uses advanced computer simulations and tracking methods to monitor the **impact** of **marine plastic** on **aquaculture farms**. It also tracks the impact of **plastic pollution** originating off aquaculture cages to the **environment**, including Marine Protected Areas (MPAs). The solution leverages an **open-access** particle-tracking framework (OceanParcels - https://oceanparcels.org/) to perform forward and backward tracking of virtual particles, including computer-modelled 2D surface flow data from Copernicus Marine Service and Mediterranean plastic concentrations. The tool can identify the likelihood and concentrations of plastic released from the Mediterranean coast reaching aquaculture farms, which can help to identify the impact of plastic pollution (for example by plastic ingestion) on farm produce. Likewise, pathways of micro-plastic particles originating from the cages of the aquaculture farms can be tracked to identify their most likely destination and prevent future contamination of the surrounding area. An interactive display enables anyone with an internet connection to access and use the tool, gaining insight into how plastic pollution might be affecting their local aquaculture farm or marine area. During the Blue-Cloud Hackathon, the Team behind this initiative **integrated** the tool into **Blue-Cloud's VRE**. Thanks to this integration, advanced users and/or developers who might otherwise not have access to computational resources or commercial software licences, can further use and co-develop the tool, improving it and/or interacting with it to evolve new, fit-for-purpose applications. A commercial version of the tool could, for example, be used to support safer and cleaner fish farming in offshore aquaculture farms, or to keep MPAs free from (wear-and-tear) plastic from cages.

Evolving an open digital ecosystem for aquaculture planning:

AqADAPT-PerfeCt was conceived as a geospatial web application that would enable forecasting the effects of **climate change** on **aquaculture**, looking into key performance factors: food conversion ratio, time-to-market, and risk of disease (vibriosis). The application relies on a range of open-source data. During the Blue-Cloud Hackathon, data available in Blue-Cloud (e.g., temperature, via Copernicus), was combined with new data sets on locations of fish farms and MPAs (previously only available via Croatian governmental repositories). The 'Add-my-pet database' was also integrated, containing parameters of Dynamic Energy Budget models for more than 900 fish and more than 3300 animal species. Following the hackathon, the application has been evolved into a tool with potential for large-scale and long-term aquaculture planning, targeted at users interested in **aquaculture farming**, distribution, or decision making (e.g., farmers, risk assessors, policymakers). The Team behind the effort has highlighted the **value** of **Blue-Cloud** to their work, namely: the possibility of developing and running test scripts without additional hardware or software investments; and enabling the use of a shared workspace with peers working on the same project, from multiple locations. The **code** of the application is available in Blue-Cloud, being **openly** accessible to anyone wishing to further **explore** it, **reuse** it, or **expand** it.

Evolving an open digital ecosystem for aquaculture planning:

The "**Wildlife Tracker for Oceans**" is a geo-framework geared at supporting real-time assessment of Marine Protected Areas (MPA). Leveraging geospatial technologies, it retrieves live feed data from Argos satellite for animal tracking, and Ocean bio-physic data from Copernicus Marine Service. The geo-framework is powered with a graphic interface that animates marine fauna movements until current time. Following the Blue-Cloud Hackathon, it has integrated other overlapping data products developed by the Blue-Cloud demonstrators, such as the 3D Chl-a concentration (i.e., Phytoplankton in mg/L at different levels of depth). The algorithms in the geo-framework can now add a yearly animation of Phytoplankton concentration and a monthly hotspot concentration (over 80% quantile). Thanks to these developments, Wildlife Tracker is evolving as a geospatial tool that marine scientists and/or marine spatial planners can use to support **MPA assessment & management**. The Team behind the initiative has highlighted Blue-Cloud as a key enabler of their work: *"Thanks to the open VLabs, we were able to understand how Chl-a datasets work. That is when the ideation of integration started. Currently, thanks to Blue Cloud, our product version v0.3 can offer Ocean datasets. Also, being trusted by Blue-Cloud makes our product reliable for future use in marine conservation*".

Figure 2: Blue-Cloud's Added Value to the Marine Knowledge Value Chain: Examples of community-driven applications that have leveraged Blue-Cloud

What can Blue-Cloud contribute to the marine knowledge value chain?

Examples of potential, future applications that could leverage Blue-Cloud in support of policy objectives

Supporting the implementation of the EU Marine Spatial Planning Directive

The MSP Directive reached an important critical point in 2021, as the deadline for the establishment of maritime spatial plans by EU Member States was met. To date, most maritime spatial planning efforts have taken place at local and national level[26]. With the new spatial plans laid out, Blue-Cloud could be used to set up a collaborative, EU-wide platform that would support their aggregation, providing the context and analytical tools to ensure spatial and ecological coherence across borders and sectors and suggesting eventual adaptations. This would considerably contribute to making progress towards the policy objectives of the directive, creating the conditions for a more sustainable use of our seas and Ocean.

Modelling & assessing the socioeconomic impact of MSP on coastal communities

In the last years, different initiatives have developed models to quantify the socio-economic effects of MSP on coastal communities[27]. Evolving and fine-tuning these models could further contribute to using existing data on human activities in coastal areas and at sea to develop different use scenarios of available marine space, providing policy makers with tools to test different planning options in real time. Besides gaining insight into uses that contribute higher social and economic value with a lower environmental footprint, collaborating in an EU platform would allow them to factor in how neighbouring countries are planning their Ocean space, enabling for example cost-efficient, collaborative investment decisions (e.g., on deployment of shared Ocean energy grid infrastructures).

Potential users:

- **Public authorities**: To ensure a transparent and sustainable use of marine space.
- **Blue economy entrepreneurs, SMEs & industry**: To identify & evolve business opportunities, benefitting from a level-playing field and sound economic planning in the marine space.
- **Civil society**: To monitor and influence the use of marine space according to societal needs.
- **Citizens**: To actively monitor and participate in policy decisions and Ocean governance.

Figure 3: Examples of potential, future applications in support of policy objectives

3 Blue-Cloud's Value Proposition, Mission & Vision 2030

3.1 Blue-Cloud's Vision & Mission 2030

Cloud and edge computing technologies are recognised as key enablers of the European Digital Transformation[21]. The Blue-Cloud project has demonstrated the powerful added value that a fit-for-purpose cloud environment can bring to accelerate solutions in support of specific policy objectives, namely those seeking to address Ocean challenges, and opportunities associated with the delivery of the **EU Green Deal** and **UN Agenda 2030**. Blue-Cloud's ambition is to contribute to the successful evolution of the complex knowledge system that will support the digital transformation required to achieve these ambitious policy frameworks, as reflected in **Blue-Cloud Vision 2030**.

Blue-Cloud Vision 2030

"To contribute to a European cloud-based knowledge system that provides access to a diverse and dynamic portfolio of analytical, prediction & visualisation capabilities underpinned by seamless access to a wealth of FAIR, transdisciplinary Ocean & freshwater observation data and services, enabling Open Science to deliver information and knowledge -including hindcast and forecast simulations-, and to drive innovation -notably through artificial intelligence-, science-based policies and public awareness for a safe, healthy, predicted and sustainably productive Ocean, in support of the EU Green Deal and the UN Agenda 2030".

Blue-Cloud's specific contribution to this vision is reflected in **Blue-Cloud Mission 2030**, which is articulated towards leveraging the key **added value** that Blue-Cloud can bring to the EU marine knowledge value chain, as described in section 2, towards delivering such vision. **Blue-Cloud Mission 2030** has been expanded to reflect EU Horizon Europe **Mission Ocean**'s approach to addressing **Ocean** and **freshwater challenges** under an **integrated framework**, which will require the marine community and those research communities focusing on inland waters to collaborate and work together, acknowledging the connectedness of water systems around the Planet, forming a single water cycle.

Blue-Cloud Mission 2030

"Accelerating marine and freshwater data interoperability, modelling and Big Data analytics through Artificial Intelligence, Machine Learning and cloud-based Open Science to catalyse innovation in support of the EU Green Deal & UN Agenda 2030".

3.2 Blue-Cloud's Value Proposition 2030

Contributing to the successful evolution of the complex knowledge system required to support the EU Green Deal and the UN Agenda 2030 signals the road ahead for Blue-Cloud. Improving marine and freshwater data interoperability, modelling and Big Data analytics through collaborative, cloud-based Open Science will be Blue-Cloud's distinctive and specific contribution to the marine knowledge value chain. But key questions remain: What form will the pilot Blue-Cloud project seek to adopt in the

[21] EU strategic dependencies and capacities: second stage of in-depth reviews (European Commission, DG GROW, 2022) - https://ec.europa.eu/docsroom/documents/48878

coming years to achieve that goal? To whom will it be catering, first and foremost? What will it deliver? Blue-Cloud's Value Proposition is articulated in response to these key, strategic questions.

> *"Blue-Cloud is Europe's leading cloud-based Open Science **community of practice** and **incubator** for data analysis and modelling methods in support of research of the Ocean, European seas, coastal and inland waters. As part of EOSC, Blue-Cloud helps researchers to improve marine and freshwater data interoperability, modelling, and Big Data analytics by providing them with a FAIR digital ecosystem offering **cloud capabilities**, **federated data**, **collaborative tools** and **Artificial Intelligence (AI) expertise, training & services** for Big Data analyses, as well as advanced **visualisation** tools for exploration of data and results".*

Blue-Cloud's Value Proposition identifies **researchers** - more specifically *marine scientists*, *data scientists & modellers, software developers* and *computer scientists* - as the **primary users** of Blue-Cloud. This is important to highlight, as Blue-Cloud's ability to satisfy the needs and expectations of these users will be the key factor determining its long-term success. However, there are other secondary and tertiary users in Blue-Cloud's landscape that can strongly influence future outcomes, as they shape the context in which Blue-Cloud must thrive. Understanding the needs and expectations of these latter, "indirect", users and rolling out effective strategies to develop win-win relationships with them will be key to effectively deliver Blue-Cloud's mission, as proposed in Section 4.

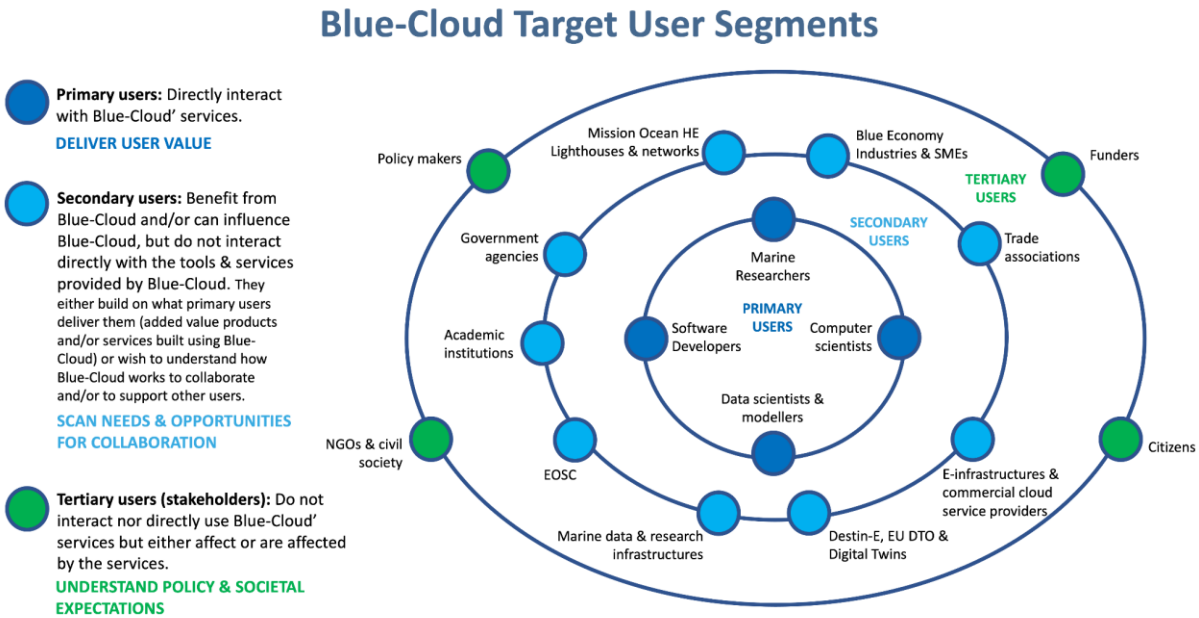

Figure 4: Blue-Cloud Target User Segments. Credit: Seascape Belgium

Blue-Cloud positions itself as a **community of practice** and as an **incubator** for FAIR data analysis and modelling methods in support of applied research of Oceans, European seas, coastal and inland waters. Within the EU Marine Knowledge Value Chain, Blue-Cloud will leverage its digital ecosystem to deliver value at the intersection of the communities enabling the development of digital twins, namely, the "**Observation and Data Collection & Management**" communities, the "**Data Modelling**" communities and the "**e-Infrastructures**" that provide cloud storage and computing capabilities.

A community of practice is a group of people who share a domain of interest, with a common concern, a set of problems, or interests in a topic and who come together to fulfil both individual and group

goals. Communities of practice often focus on developing, sharing, and disseminating best practices, as well as on creating new knowledge, breakthrough ideas and new practices to advance their domain. Blue-Cloud will capitalise on its underpinning technology and core services to empower "a community of communities'' of practice with a common interest in advancing **FAIR data** and **data modelling methods** across the marine and freshwater domains, through the use of **AI, Machine Learning (ML) and Big Data analytics**. Blue-Cloud will vertebrate a thriving Open Science community enabling new ideas to be discussed, challenged, tested, co-evolved and re-used, harnessing this collective intelligence to incubate and accelerate solutions that would require significantly longer periods to be spawned in other more rigid, formal settings and/or institutions. Blue-Cloud will **enhance** the **EU Marine Knowledge Value Chain** by evolving a fully-fledged digital ecosystem, including:

- A platform offering **cloud storage**, **computing power** and **analytical tools** enabling researchers to **develop** and **test** new **analytical methods** supporting **data interoperability** and **modelling** in the marine and freshwater domains.
- Resources for **training** and **capacity building** on application of FAIR principles, AI, ML and Big Data analytics to advance marine knowledge.
- Support in the application of AI to research of Ocean, seas, coastal & inland waters.
- Opportunities for **collective learning** via interactions, discussion, sharing of digital assets, problem-solving and relationship building.
- A wealth of **tested data workflows** that can be offered to other scientific communities via EOSC and/or evolved to be potentially exploited as services by third parties (e.g., EU data services, EU DTO, private companies developing Digital Twins of the Ocean, commercial cloud vendors, etc.).

The leading principle of Blue-Cloud is to federate services from RIs and e-infrastructures to provide researchers open access to data, algorithms, and computing resources. The federation of data will be made more FAIR by together deploying activities at RIs for improving and optimising their services for uptake of new data sets from a **multitude of data originators**, and for discovery and access of their structured data collections, by means of web services. This will allow RIs to reach out to more potential data originators, mobilising and channelling their data resources, while also operating more streamlined services for sharing their collated and structured data resources for wider use, underpinning EOSC principles, and strengthening the Blue-Cloud DD&AS.

3.3 Responding to user needs & expectations

3.1.1 Delivering value to Blue-Cloud's primary users: Servicing marine researchers, data scientists & modellers, software developers and computer scientists

The Blue-Cloud pilot project has already evolved a platform and services that have demonstrated potential in bringing added value to the wider Ocean research community. Efforts to build synergies with other ongoing initiatives and to promote the uptake of Blue-Cloud's services, including through the Blue-Cloud Hackathon, have contributed to bring over 1200 users to its digital environment within the lifetime of the project. Wide consultation and interaction with users have helped to identify the key features attracting primary users to Blue-Cloud, namely:

- The possibility of accessing a wealth of marine data, from across existing services, through a single-access point, without needing to download it to their own computer.

- Accessing and using widely adopted analytical software to process data.
- The possibility of running analyses using Blue-Cloud's computing power.

As these valued features indicate, "*no need to download data to your computer*; *no need to buy new software*; *no need to buy an expensive computer*" could be the bottom-line of what users are looking for in Blue-Cloud as a web-based Open Science service. When asked what else they would like Blue-Cloud to deliver, users' response could be summed up to be, "*more of the same, but in larger quantities*"[22]. Other noteworthy demands were voiced during the consultation, such as a user demand for **training opportunities** and **support** in the **application** of **AI**; as well as **supporting visualisation tools** enabling easier exploitation of analytical results. All these hint at potential ways in which Blue-Cloud could evolve to enhance its value to its **primary users**.

Further feedback gathered through targeted stakeholder consultation points to additional ways in which Blue-Cloud could contribute to deliver value to marine researchers, i.e., helping them to overcome current lack of data management skills by providing them with easy-to-use interfaces helping them to call for specific data sets without requiring IT knowledge; or supporting them not only in the preparation of data but also in its visualisation, tasks that are time consuming and require advanced skills (on data regression, data clustering, etc) that researchers often lack. Offering problem-solving resources will attract (new) researchers to Blue-Cloud. The more users using Blue-Cloud's services, the more these can be tailored to their needs.

The challenges

While pointing to emerging opportunities, interaction with current users has also highlighted needs and expectations that are not yet met, which would contribute to win user loyalty and to continue to widely expand Blue-Cloud's user base. Some key suggestions from users include:

- Upgrading the **"cloud" experience** offered by Blue-Cloud, both by allowing data discovered through its DD&AS to be more directly retrieved and by providing more computer resources than those currently offered (e.g., to allow access to Jupyter Hub for multiple users).
- Offering **training** to allow users to make the most of the tools that are available to them (e.g., analytics engine, software importer, etc).
- Co-designing, applying and reviewing community-driven best practice guidelines to the life-cycle access and management of the digital assets that are built in Blue-Cloud (from development, to production, to versioning), enhancing the user experience.
- Making digital assets produced in Blue-Cloud (e.g, notebooks) easily **portable** to other platforms, for further evolution and/or exploitation.
- Improving the user experience by **expanding** available **collaborative tools** (e.g., allowing co-working on notebooks or enabling collaboration on shared documents, as other services do).
- Adding more **tutorials** and tools to guide users (e.g., including tags to find inputs or resources for VLabs).
- Enhancing Blue-Cloud with improved **graphic functionalities** and/or with other services, e.g., access to sets of **pre-loaded, open Ocean models** that could be used to provide context to data analyses run in Blue-Cloud.

[22] Summary of Key Messages & Recommendations: 2nd Phase of Stakeholder Engagement & Consultation (SSBE, 2022)

Another important challenge ahead which falls outside of Blue-Cloud's current scope of action is the fact that access to marine open data is often still subject to **third party barriers**. While this might happen for good reasons (e.g., monitoring the use of data), it also creates hurdles towards reaching a wider user base. This might hinder the potential to grow Blue-Cloud's community of practice and its ambition to catalyse innovation at a larger scale, which is why Blue-Cloud will seek to promote relaxing such restrictions, when possible and needed.

Addressing challenges into 2026-2030

Responding to user needs, offering access to Blue-Cloud's computing resources at a competitive price, providing a well-resourced customer support centre, and building a sense of community by providing users with training opportunities are all acknowledged as key success factors needed to evolve and position Blue-Cloud as Europe's flagship cloud-based Open Science community of practice and incubator for marine and freshwater FAIR data analysis and modelling methods. As such, continuing to deliver on the **needs** and **expectations** of **primary users** will be at the heart of Blue-Cloud action into 2026-2030, towards expanding its user base.

Establishing synergies with other EU initiatives working to advance Ocean research has also proved to be an effective strategy to widen Blue-Cloud's primary user base. Collaborating with synergies has contributed to the development of new VLabs and increased the quantity and quality of data federated by Blue-Cloud, as well as to feeding user-driven suggestions for improvements in the services offered. It has further helped to increase the number of Blue-Cloud users and early adopters from specific domains, as they bring their communities to test available services and, through joint dissemination activities, contribute to reaching out to a wider community of potential adopters. This line of work will continue into 2026-2030, supporting collaborative science amongst an increasingly wider base of research initiatives towards growing Blue-Cloud's community of practice and delivering its Vision 2030. As synergies are established, a clear **governance scheme** for products and/or services built and/or further developed in Blue-Cloud, including policies for managing intellectual property rights, will have to be designed and set up, especially when considering the potential exploitation of such assets by secondary users.

3.1.2 Delivering value to Blue-Cloud's secondary users: Aligning objectives, requirements and practices with EOSC, EU Digital Twin of the Ocean and wider EU and international initiatives

The value of weaving a multi-stakeholder, Open Science community of practice around AI, ML and Big Data analytics in the marine domain has shown clear benefits to secondary users. Bringing the **multidisciplinary teams** engaged in **marine data and research infrastructures**, **e-infrastructures** and **scientific research together** has advanced a much-needed dialogue that has contributed to a better understanding of interoperability challenges, creating momentum for closer, mutually beneficial collaboration.

On the one hand, Blue-Cloud has shown the added value it can bring to marine data and research infrastructures by bridging the gap with **EOSC**, supporting them in their quest to expose their data catalogues to a much wider, interdisciplinary user base. By federating their data repositories into Blue-Cloud's Data Discovery & Access Service, blue data infrastructures can join efforts in providing EOSC users simplified access to a wealth of FAIR marine data through a single access point. This line of work

will continue to expand into 2026-2030, as Blue-Cloud will strive to evolve its DD&AS with new data repositories from current contributing infrastructures and from new infrastructures, offering an interoperable and standardised data framework. It will also cooperate with these infrastructures to increase the compatibility of their web services in order to improve the overall FAIRness of RIs and Blue-Cloud DD&AS.

Adding to this, other key developments in the marine knowledge landscape -namely progress towards establishing a **European Digital Twin of the Ocean**, as key objective of the EU, open new opportunities for Blue-Cloud. This objective is being pursued, among others, via the development of an **EU Public Infrastructure** for the DTO (**EDITO-Infra**) and **related projects** (e.g., ILIAD, BioDT, and other relevant EU funded projects), which are expected to contribute different components of the EU DTO. On one hand, subject to the technical roadmap followed by the EU EDITO-Infra developers, Blue-Cloud could potentially contribute to its data management component, as it is already federating discovery and access to many leading marine data and research infrastructures. Such federation will be further expanded and streamlined as part of the recently awarded "Blue-Cloud 2026" successor project by adding data lakes for selected essential data types that could potentially feed into the EU EDITO-Infra and ultimately the overall DTO. On the other hand, EDITO-Infra will provide Blue-Cloud's (primary) users with opportunities to test their (Blue-Cloud supported) data products and services for reproducibility in a public infrastructure. This opens opportunities to build connections and synergies with ongoing and future initiatives either supporting the deployment of new generation Ocean models and/or working to contribute to the building of key components of the EU DTO, which are identified as potential secondary users of Blue-Cloud, making its digital ecosystem fit-for-purpose to cater to their efforts. Along the same lines, Blue-Cloud will seek to position itself as a key partner for other **public** and/or **private** initiatives seeking to develop **digital twins** to support **Blue-Economy** undertakings, offering them a unique digital ecosystem to co-create, build and test the algorithms and models enabling the data streams and workflows required for their operation, as well as an Open Science community of practice that can be leveraged for innovation. Blue-Cloud will also continue to actively scan new collaboration opportunities, identifying needs from user communities by engaging with **Horizon Europe Mission Lighthouses** and **Blue Parks** initiatives.

Last but not least, building on initial conversations with EU and international initiatives (e.g., EuroGOOS, GOOS, GEOSS) and communities (e.g., AANCHOR), Blue-Cloud will step up its commitment to international Ocean observing efforts and to the UN Decade of Ocean Science for Sustainable Development by teaming up with the **Ocean Best Practice System** (OBPS) of UNESCO. This collaboration will deliver new training opportunities to researchers to boost their capabilities in the deployment of AI, ML and Big Data analytical methods and in the adoption of FAIR and Open Science practices, further growing Blue-Cloud's Community of Practice and enriching its digital ecosystem in support of these international initiatives.

The challenges

As emerging from user and stakeholder consultations, issues connected to **interoperability** between **computing infrastructures** for the execution of processes are still limiting the possibilities of Open Science practitioners and the potential for wider exploitation of their research outputs. For example, one important technical consideration is the need to achieve less dependency between **computing infrastructures** and **algorithms/analytical methods**. Ideally, a FAIR catalogue of algorithms should make it possible to **deploy any desired, available algorithm on any computing infrastructure**, **on-**

demand, **closer to** the required "input" **data**. Making this possible requires the use of **open-source libraries** and the definition of **protocols** for **interoperability** of the **digital assets** supporting such **methods** across **computing infrastructures**.

At the moment, methods developed in Blue-Cloud may not be directly portable into other environments. Solving this shortcoming by further aligning technical requirements with other, key infrastructures will open new opportunities, enabling wider uptake of innovative methods by existing or future, operational services (e.g., Copernicus Marine, EMODnet, EU DTO, digital twins developed by other research communities and/or industry, etc). Reassuring primary users that the products they develop in Blue-Cloud (e.g., Jupyter Notebooks) can be ported and run in other infrastructures, will also enhance their trust and willingness to use and/or continue using Blue-Cloud's services, while enhancing value to secondary users.

Addressing challenges into 2026-2030

Blue-Cloud plans to set up a **DTO Task Force** that will guide the work towards ensuring compatibility between Blue-Cloud infrastructure and EDITO-Infra, e.g., ensuring the proper bridging between Blue-Cloud's planned data lakes and the **EU DTO**, or making user resources easily exportable to the EU DTO and **DestinE**. It will also explore further opportunities for contribution to the biodiversity and to the coastal Ocean component of the EU DTO, e.g., collaborating with the HORIZON-MISS-2022- OCEAN-01-07 project and JERICO-RI, respectively.

From a data federation perspective, Blue-Cloud will continue to **grow** its portfolio of connected marine data and research infrastructures to expand its coverage and offer. This will include seeking new cooperation with **freshwater data repositories**, in support of Mission Ocean. It will also further strive to identify opportunities to accelerate progress in data harmonisation and interoperability through the application of AI, seeking to maximise value to the EU Green Deal Data Space (e.g., by monitoring and engaging with the "EU **Gr**een D**ea**l Da**t**a Space Foundation and its Community of Practice (GREAT)" - DIGITAL-2021-CLOUD-AI-01- PREP-DS- GREEN-DEAL).

3.1.3 Delivering value to Blue-Cloud's tertiary users: Understanding and responding to societal needs & expectations

The Blue-Cloud pilot project has showcased how delivering value to its primary and secondary users impacts the **marine knowledge value chain**, supporting greater **societal objectives**. Blue-Cloud VLabs offer many practical examples of how providing researchers with **web-based**, **analytical tools** and **greater cloud computing power** - allowing them to perform heavy computational analyses otherwise not possible or too timely to perform on local computers - underpinned by **open access to data** available across different European marine data and research infrastructures, leads to a more effective and efficient development of **innovative data products** that contribute to support progress towards **improving knowledge** and **understanding** of the Ocean. As demonstrated during the Blue-Cloud Hackathon, thanks to the implementation of Open Science principles, such products also potentially pave the way to new, innovative applications, thus enhancing the overall performance of Europe's **marine knowledge system**.

Blue-Cloud's Mission 2030 is geared at supporting the achievement of the **EU Green Deal** (including **Mission Ocean**'s goals and objectives) and **UN Agenda 2030**, representing one of the many

contributions of the EU to the **UN Decade of Ocean Science for Sustainable Development** and the **G7 Future of Seas and Oceans Initiative**. The overarching societal objectives of these policy frameworks will continue to inform the future evolution of Blue-Cloud, contributing to generating actionable knowledge and innovation across relevant policy areas (see Table 2). By continuing to work around international standards (such as EOVs or Essential Biodiversity Variables), Blue-Cloud will seek to maximise value to initiatives geared at developing the underlying fabric of digital twins (as discussed in the previous section), while also supporting global Ocean observation and forecasting capabilities.

Table 2: How Blue-Cloud can contribute to relevant EU and global policy objectives

Policy Priorities and/or Challenges Identified Across Key Policy Frameworks **EU Green Deal & Mission Ocean (2025-2030)** **UN Agenda 2030 & Decade of Ocean Science for Sustainable Development**						
	Cross-cutting Themes				**Blue Economy**	**Ocean Observation**	**Ocean Modelling & Forecasting**	**Data & Knowledge Access**	**Ocean Citizenship**
Policy priority:	**Pollution**	**Biodiversity**	**Food**	**Climate Change**	**Ocean Hazards**				
EU Green Deal (policy priorities 2030) **& Mission Ocean** (selected policy targets 2025-2030)	• A zero-pollution ambition for a toxic-free environment (zero spill and plastic litter generation; underwater acoustic emissions are reduced by at least 50% by 2030). • Preserving and restoring ecosystems and biodiversity (active regeneration of 20% of degraded habitats; 30% of EU waters are highly to fully protected; 50% of DNA of life in Ocean & waters is fully sequenced and publicly available by 2030). • From 'Farm to Fork': designing a fair, healthy and environmentally friendly food system (end overfishing; zero carbon aquaculture by 2030). • Increasing the EU's climate ambition for 2030 and 2050.				Mobilising industry for a clean, circular economy. Supplying clean, affordable & secure energy. Building and renovating in an energy & resource efficient way.	20% of data collections from citizen science. North Atlantic seabed fully mapped by 2025. European seabed fully & coherently mapped in high-resolution by 2030.	European digital twin pilot of European Ocean and waters (DTO) is operational by 2025. Global digital twin of all oceans and waters operational by 2030.	All (marine & freshwater) data collected by EU Member States pooled centrally & accessible to all by 2025. Global marine & freshwater observation streamlined: All global data pooled centrally & accessible to all.	Activating education and training. Each European is a citizen of our Ocean and waters.
UN Decade of Ocean Science (challenges 2030)	• Understand and beat marine pollution. • Protect & restore ecosystems & biodiversity. • Sustainably feed the global population. • Unlock Ocean solutions to climate change. • Increase community resilience to Ocean hazards.				Develop a sustainable and equitable Ocean economy.	Expand the Global Ocean Observing System.	Create a digital representation of the Ocean.	Deliver data, knowledge and technology to all.	Change humanity's relationship with the Ocean.
How Blue-Cloud can support these policy objectives	Blue-Cloud will contribute to: • Improve knowledge and understanding of marine ecosystems, including their status. underlying processes and interconnections. • Monitor trends and evolution around cross-cutting themes, predicting future developments around different, simulated scenarios. • Evaluate and guide policies, strategies and plans, providing scientific evidence to support and/or improve and/or update them.				Trigger innovative, science-based applications that inform management of Ocean & freshwater resources and contribute solutions to challenges. Shortening the time span between research and innovation.	Support harmonisation and federation of catalogues of EU marine data and RIs and align FAIR standards towards EU Green Deal Data Space and global capability. Develop new observation technologies and capabilities through science-based innovation.	Develop algorithms and models enabling interoperable data streams and workflows to build underpinning fabric of "digital twins". Train future scientists, researchers in data modelling. Train future users of DTOs. Develop scenarios & policy options.	Support FAIR digital assets and make them available to wider communities via EOSC. Train future scientists & researchers in FAIR data management, AI and Big Data analytics.	Develop user-friendly applications and interfaces to bring Ocean science closer to citizens.
Bottom line	**Scientific**				**Economic**	**Technological Economic**	**Scientific Economic**	**Technical Cultural**	**Cultural**

As also previously mentioned, Blue-Cloud will closely monitor and engage with developments emerging from the "GREAT" Community of Practice and initiative to further identify **data challenges**, **opportunities** and priority action areas where it could contribute to progress the **EU Green Deal Data Space**, guiding its own community of practice towards delivering innovative solutions in support of identified action areas.

Blue-Cloud will also seek to support progress towards delivery of **EU international environmental commitments** and **agreements**. Adapting to EU environmental standards and/or regulations often requires resources that many communities lack, requiring sustained (international) governmental support towards alignment or compliance. Domain specific services - such as those offered by Demonstrators 4 and 5 - are proving valuable towards bridging the gap between the "last sea-mile" of cloud services and ground-based communities, opening a window of opportunity to serve resource-poor communities with **FAIR marine data services**. Blue-Cloud VLabs can contribute to service community needs in a cost-effective manner, which will continue to be explored and pursued.

Finally, Blue-Cloud will continue to scan opportunities to support the development of virtual environments that contribute to bringing Ocean science closer to citizens, by visually replicating real-life marine habitats and ecosystems and thereby contributing to developing closer, emotional connections between people and the marine realm. Another way in which Blue-Cloud will contribute to Ocean citizenship is by further promoting and empowering **citizen science**, which in turn can enhance the marine knowledge value chain by encouraging and enabling the generation of "non-scientific" data streams that complement and refine "traditional" methods of observation. As part of its strategy 2026-2030, Blue-Cloud will continue to support the development of user-friendly applications and interfaces that contribute to increasing the flow of citizen science data into the marine knowledge value chain.

4 Strategic Goals 2030: From piloting an Open Science platform to growing a thriving digital ecosystem for FAIR data analysis and modelling in support of research of the Ocean, seas, coastal & inland waters

Blue-Cloud will capitalise on the Open Science platform and services emerged as Key Exploitable Results of the Blue-Cloud project (2019-2023) to build momentum and progress towards its Mission 2030. Setting **Strategic Goals 2026-2030** will help to pace and guide this process, providing the framework for a clear **action plan** geared at responding to **user needs** and expectations, addressing Blue-Cloud's current **weaknesses** and anticipating **risks**, while leveraging **strengths** to tap on emerging **opportunities** and **maximise** its **impact** on the **EU marine knowledge value chain**.

4.1 Blue-Cloud's Strategic Goals 2026 & 2030

Strategic Goals 2026
SG2026.1. Blue-Cloud grows its Data Discovery & Access Service with most relevant, priority EU marine data & research infrastructures and with citizen science repositories, while deploying data lakes to showcase potential added value to wider EU services and initiatives (e.g., EU DTO).
SG2026.2. Blue-Cloud further demonstrates value of Open Science across current and new research topics, also testing and developing new, Big Data analytical workflows that could potentially support or be exploited by other infrastructures and/or EU services and initiatives, such as the EU Digital Twin Ocean and/or DestinE, demonstrating its added value to the marine knowledge value chain and inspiring and guiding its community towards EU priority (policy) areas of action.
SG2026.3. Blue-Cloud creates an enticing framework of incentives that inspires target users to test and develop their (AI) experiments and/or environmental analytical services in Blue-Cloud, leveraging existing resources and methods to catalyse innovation at a larger scale.
SG2026.4. Blue-Cloud further attracts new Open Science practitioners and users to its community by developing a training academy & catalogue of virtual courses that contributes to build skills & capacity on applying FAIR data principles, best practices and common methods to analyse data, including through the use of AI and collaborative tools for Open Science in the marine domain.
SG2026.5. Blue-Cloud establishes a long-term community dialogue with key stakeholders to enable seamless discovery and exploitation of Blue-Cloud's digital commons, assets and services by users via wider EU (i.e., EOSC, EU DTO & DestinE, Green Deal Data Space, EOOS) and international (e.g., GEOSS, GOOS) initiatives, as well as broadening interaction with RTD projects to establish connections with researchers in the freshwater domain.
Strategic Goals 2030
SG2030.1. Blue-Cloud consolidates as Europe's flagship cloud-based Open Science **community of practice** and **incubator** for innovative marine and freshwater data analysis & modelling methods, contributing to accelerate data interoperability, modelling and Big Data analytics in the marine & freshwater domains.

SG2030.2. All relevant EU marine & freshwater data services, Research Infrastructures and initiatives contribute to continuously feed a wealth of FAIR marine & freshwater data into Blue-Cloud, supporting its dynamic user environment and the flow of data into EOSC.

SG2030.3. Blue-Cloud leverages the collective intelligence of its Open Science community to deliver a constant flow of **digital assets** (methods) that enhance the **EU Green Deal Data Space** and **EU DTO** and can be discovered by other research communities via **EOSC**. Blue-Cloud's federated approach enables these assets to be portable to other environments for further exploitation, also potentially as services, supporting a wide range of users in transforming data into information, knowledge & innovation.

SG2030.4 Blue-Cloud consolidates its position as a key link of the EU marine knowledge value chain, securing a **sustainable financial framework** for its operation and further development.

The **key assets** that are expected to emerge from the delivery of these objectives include:

- An **interoperable, marine & freshwater data space federated into EOSC** that supports Open Science and connects to wider EU initiatives (i.e., EU DTO, but also thematic digital twins currently under development e.g., ILIAD, BioDTO Biodiversity Digital Twin, etc).
- An **incubator** of "blue" data analytical methods and services in support of research of Oceans, seas, coastal and inland waters.
- A trusted **community of practice** for evolving data analytical methods and modelling, leveraging AI and cloud technologies.
- A **sustainable business model** for Blue-Cloud's efforts.

4.2 Blue-Cloud's Action Plan 2026-2030

Delivering **Blue-Cloud's Mission 2030** will require action at different fronts, directing and coordinating efforts towards achieving the **strategic goals** set out for **2026-2030**. A strategy has been designed towards that end, structuring the roll-out of an effective action plan around **5 strategic paths of action**, namely:

- **Strategic Action Path 1:** Sustain the flow of FAIR and open Ocean data into Blue-Cloud.
- **Strategic Action Path 2:** Trigger the development of innovative data analytics methods around priority thematics to inspire and guide the Blue-Cloud community.
- **Strategic Action Path 3:** (Further) Federate with key marine data, research and e-infrastructures and with strategic initiatives (EOSC, EDITO-Infra & DestinE) to enhance value to users.
- **Strategic Action Path 4:** (Further) Grow a thriving Ocean Open Science community, leveraging skills, incentives and rewards and promoting wide dissemination of FAIR methods incubated in Blue-Cloud to boost innovation at a wider scale.
- **Strategic Action Path 5:** Connect and align with wider developments and other communities to contribute to a European and global knowledge system in support of the EU Green Deal and the UN Agenda 2030.

These paths of action touch on all the key pillars or elements required to successfully unlock the full potential of Open Science in the marine domain: Open & FAIR data; analytical resources;

infrastructures; people and policies[23]. By working around these strategic pillars, Blue-Cloud will benefit from generating and exploiting **positive feedback** across all actions: Sustaining the flow of FAIR, open data into Blue-Cloud and guiding the community with practical, inspiring demonstrators that show how methods developed deliver value to (primary, secondary & tertiary) users, will invite a wider community of Open Science practitioners to test and use Blue-Cloud. Offering opportunities to build the skills of primary users engaged will enhance their ability to apply FAIR, Open Science practices and to contribute innovative methods, raising the bar for the community. Federating with key initiatives and identifying user-driven needs with secondary and tertiary users can lead the way to new incentives for an expanding community of users to rely on Blue-Cloud to develop, test and potentially offer fit-for-purpose digital solutions for wider exploitation. Connecting with wider developments will ensure keeping the community aligned with policy and societal developments, needs and expectations, while opening new opportunities to continue to grow Blue-Cloud's community of practice and the underpinning services offered.

An **Action Plan 2026-2030** has been outlined identifying specific actions around these 5 strategic paths towards meeting Blue-Cloud's Strategic Goals 2026-2030. Each of the actions identified relates to one or more of the aforementioned Blue-Cloud Strategic Goals. An indicator and target value has been further assigned to each action, to indicate ambition and as a guiding reference to measure progress against overarching goal(s).

[23] Blue-Cloud Draft Strategic Roadmap - Release 1 (2021)

Table 3: Blue-Cloud Action Plan 2026-2030

Action	Strategic Goal	KPI	Target 2026	Target 2030
Strategic Action Path 1: Sustain flow of FAIR and open marine data in Blue-Cloud				
1.1. Expand Data Discovery & Access Service with priority EU marine data & research infrastructures	SG2026.1 SG2030.2	• Number of MoUs signed with relevant data and/or research infrastructures • Technology Readiness Level (TRL) of service • Number of citizen science initiatives feeding data into Blue-Cloud DD&AS via partner marine data infrastructures • Number of MoUs signed with relevant data and/or research infrastructures • Service cost (€) per user	+4 new data infrastructures added to Blue-Cloud DD&AS from 2022 baseline (EMSO, EMODnet Physics, EMO-BON (EMBRC) and SIOS) TRL of service from TRL7 to TRL8 New dataflows established to automate ingestion of citizen science initiatives into Blue-Cloud DD&AS Mapping exercise completed for priority freshwater repositories to be targeted for connection to Blue-Cloud DD&AS	New data infrastructures added to Blue-Cloud DD&AS from 2026 baseline TRL of service from TRL8 to TRL9 Prioritised freshwater data repositories added/connected to Blue-Cloud DD&AS
1.2. Expand Data Discovery & Access Service with citizen science repositories	SG2026.1			
1.3 Expand Data Discovery & Access Service with freshwater repositories, e.g., by exploring opportunities for collaboration with WMO Hydrological Observing System (WHOS)	SG2026.1 SG2030.2			
1.4 Enhance DD&AS with additional functionality for sub-setting and extracting data sets or for feeding and maintaining data lakes for Essential Ocean Variables (EOVs)	SG2026.1 SG2030.2			
1.5 Improve the FAIRness of the federation by optimising the machine-to-machine interactions with connected research infrastructures and data repositories	SG2026.1 SG2030.2			
Strategic Action Path 2: Trigger development of innovative methods around priority thematics to inspire & guide the community				
2.1 Test and develop new digital assets, including workbenches to improve quality control for EOVs large datasets	SG2026.2 SG2030.3	• Number of workbenches tested and/or established	• Dedicated EOV analytical workbenches tested between EMODnet, CMEMS and RIs	• Analytical workbenches implemented between EMODnet, CMEMS and/or relevant RIs to support the EU DTO

2.2 Continue evolving existing Virtual Labs to upscale current analytical products & services, enhancing their user value and user friendliness (e.g., with data inspection and/or visualisation capabilities) to support policy objectives	SG2026.2 SG2030.3	• Number of workflows developed and implemented in existing VLabs • Number of new VLabs implemented • Number of meetings held to present Blue-Cloud to Blue Economy clusters • Number of VLabs set up as public-private partnership	• New Carbon Plankton Dynamics workflows • New Marine Environmental Indicators workflows • New Global Fisheries Atlas workflows • +1 VLab "Coastal Ocean observations" • +1 VLab "Coastal currents from observations" • N.A	• Harmonisation across different data types and data portals (e.g. ICOS-LifeWatch). • Inclusion of freshwater data in the VLabs • +5 VLabs set up as public-private partnership
2.3 Test and develop new analytical services addressing priority policy areas of EU Green Deal (e.g, for coastal information, building on synergies established with JERICO-RI; for biodiversity monitoring and/or MSP)	SG2026.2 SG2030.3			
2.4 Engage with the private sector to test and develop fit-for-purpose solutions in support of environmental analytical services and/or digital twins servicing Blue Economy applications	SG2026.2 SG2026.3 SG2030.3 SG2030.4			
Strategic Action Path 3: (Further) Federate with key marine data, research and e-infrastructures and with strategic initiatives to enhance value to users				
3.1 Advance further integration with key e-infrastructures (orchestrating analytical workflows, Single-Sign-On, monitoring & accounting services, upscaling computing power)	SG2026.5 SG2030.3	TRL progress Number of methods designed for and executed in the WEkEO infrastructure by Blue-Cloud users Number of FAIR digital objects of Blue-Cloud Catalogue integrated into EDITO Nº of MoUs signed with	Further integration with EUDAT, EGI and WEkEO achieved (the latter towards integration with EDITO) TRL of service from TRL7 to TRL8 Shaping a collaborative community of practice exploiting Blue-Cloud and EU DTO assets 10 FAIR digital objects of Blue-Cloud Catalogue integrated into	TRL of service from TRL8 to TRL9 Incubate operational services for the EU DTO EOSC Blue Task Force sustains alignment with EOSC developments
3.2 Further integrate with WEkEO to enable portability of Blue-Cloud assets to EU DTO, DestinE and other relevant environments	SG2026.4 SG2030.3			
3.3 Setup DTO Task Force to align objectives and contribute digital assets to EU DTO & DestinE	SG2026.5 SG2030.3			

3.4 Connect with communities developing components of EU DTO to offer collaboration & synergies	SG2026.5 SG2030.3	relevant initiatives Number of EOSC users querying Blue-Cloud Catalogue	EU DTO MoUs signed with key initiatives: ILIAD, HORIZON-MISS-2022-OCEAN-01-07 project EOSC Blue Task Force formed, ensuring full compliance with EOSC principles for service management	
3.5 Ensure long-term EOSC alignment and integration	SG2026.5 SG2030.3			
Strategic Action Path 4: (Further) Grow a thriving community of Ocean Open Science practitioners, leveraging skills, incentives & rewards and promoting dissemination of FAIR methods incubated in Blue-Cloud to boost innovation at a wider scale				
4.1 Continuously monitor & deliver the evolving needs of Blue-Cloud's primary users to offer an excellent service that contributes to consolidate and grow the community	SG2026.1 SG2030.1	Number of users registered in Blue-Cloud Number of trained users Number of users participating in Blue-Cloud Hackathons Nº of MoUs signed with relevant initiatives	• Blue-Cloud's user base grows by 100% from 2022 baseline 3 training courses launched on Best Practices for FAIR data +450 participants take part in Blue-Cloud related hackathons Connectivity open to iMAGINE & EGI-ACE +10 MoUs signed with key initiatives and/or new project communities +3,000 stakeholders engaged 1 hackathon	Blue-Cloud's user base grows by 200% from 2026 baseline +1000 participants take part in Blue-Cloud related hackathons +50 MoUs signed with new project communities
4.2 Set up a support service and a training academy to build FAIR data, AI & Big Data skills amongst researchers to attract and service new users in Blue-Cloud	SG2026.4 SG2030.1			
4.3 Set up competitions to invite users to innovate solutions to challenges put forward by secondary users of Blue-Cloud, with prizes for ideas with uptake potential	SG2026.3 SG2026.4 SG2030.1			
4.4 Expand connections with (Horizon Europe) research project communities to attract new users to Blue-Cloud	SG2026.4 SG2030.1 SG2030.4			
4.5 Set up MoU's with key EU initiatives (e.g., EU DTO, DestinE) to acknowledge methods	SG2026.3 SG2026.4			

developed by users in Blue-Cloud that are taken up by such services with a special attribution of "excellence"; and/or enticing Terms of Use, when possible	SG2026.5 SG2030.1 SG2030.3 SG2030.4			
4.6 Explore opportunities for collaboration with commercial platforms offering scientific analysis and visualisation of geospatial datasets (e.g., Google Earth) to promote dissemination of FAIR methods "incubated" in Blue-Cloud	SG2026.3 SG2026.4 SG2030.1 SG2030.4			
Strategic Action Path 5: Connect and align with wider developments and other communities				
5.1 Connect with Green Deal Data Space Community of Practice	SG2026.3 SG2026.5 SG2030.3	New areas identified requiring methods for user-driven, interoperability purposes Nº of MoUs signed with relevant initiatives Contribution to the "Draft Zero version of the Roadmap for the Implementation of the All-Atlantic Ocean Data Space" Number of methods that are published and/or validated as Ocean Best Practices by IOC-IODE Ocean Best Practices initiative New collaborations established with key UN Ocean Decade Programs (e.g., Jerico CORE, CoastPredict)	• At least 3 MoUs signed with related Horizon Europe Mission Lighthouses and/or Blue Parks initiatives. • At least 3 new methods submitted to the Ocean Best Practice System to advance international Ocean observing, research and monitoring efforts in support of the UN Agenda 2030. • At least 1 collaboration established with a UN Ocean Decade Program.	• At least +5 MoUs signed with related Horizon Europe Mission Lighthouses and/or Blue Parks initiatives. • At least +10 new methods submitted to the Ocean Best Practice System to advance international Ocean observing, research and monitoring efforts in support of the UN Agenda 2030. • At least +3 new collaborations established with a UN Ocean Decade Program.
5.2 Engage with Mission Lighthouses and EU4Ocean networks to identify community-driven priorities when "interrogating" the Ocean	SG2026.3 SG2026.4 SG2030.1 SG2030.3			
5.3 Continue collaboration with All-Atlantic Ocean Research Alliance	SG2026.3 SG2026.4 SG2030.1 SG2030.3			
5.4 Evolve methods into international Ocean Best Practices towards supporting international efforts (GOOS, GEOSS) and UN "Ocean Decade" Programs	SG2026.3 SG2026.4 SG2030.1 SG2030.3			

4.3 Enabling the sustainability of Blue-Cloud's efforts

The Blue-Cloud pilot project has demonstrated the potential of supporting and enabling Open Science in the marine domain. As explained in Section 2.2, Blue-Cloud has showcased how gearing up the EU marine knowledge value chain with "Blue-Cloud-type" resources and services can contribute to shorten the research-to-knowledge-to-innovation cycle, by improving the **interoperability** of marine data, progressing more efficient data **modelling**, supporting **analytical environmental data services**, inspiring and accelerating **community-driven innovation** and strengthening **collaboration** at a global scale.

As outlined in Blue-Cloud's Service Exploitation & Sustainability Plan (SE&SP)[24], the project key exploitable results will be openly available to the wider European marine research community (via EOSC) and beyond, for further exploitation and capitalisation. However, in order to realise the full potential that has been showcased through this pilot project, Blue-Cloud's efforts will need to be sustained into the decade. There are important reasons informing the need for supported sustainability:

- On the one hand, stakeholder consultations carried during the pilot project have shown that **service quality**, **confidence** and **long-term commitment** are key success factors determining users' choice when selecting an Open Science infrastructure to service their needs. The fact that Blue-Cloud facilitates access to a wealth of INSPIRE[25] compliant, open, marine data, gives Blue-Cloud a competitive edge against other available (market) alternatives, providing a head start towards building a thriving Open Science community in the marine domain that is built on European capabilities. However, to create further user traction and to widen its user base, Blue-Cloud needs to provide assurance that the services built today, will continue operating and supporting the marine community in the longer term, sustainably. This confidence is key to enable Blue-Cloud to continue building a thriving marine thematic community into EOSC. The Blue-Cloud consortium is working towards finding a sustainable framework for the long-term exploitation and evolution of its efforts, but until that framework is secured, it will have to rely on public (opportunistic) funding to further build and retain user confidence.

- On the other hand, the services that have been tested in Blue-Cloud can be evolved to deliver **value** to key **EU, strategic, public initiatives** (i.e., future EU DTO & DestinE) that are currently being evolved. Sustaining Blue-Cloud's efforts into 2030 could not only contribute to step up the production of their underlying fabric, -complementing their top-down development with a bottom-up, community-driven approach-, but it could also ensure the future integration of Blue-Cloud's efforts into these initiatives, which could in turn provide the long-term sustainability framework that would ensure the further exploitation and capitalisation of Blue-Cloud's results, beyond 2030.

- Finally, the Blue-Cloud pilot project has proven its value as a "neutral" platform that can support international collaboration to advance and deliver the UN Agenda 2030 SDGs, aligning with the objectives of the UN Decade of Ocean Science for Sustainable Development. As the Ocean Decade programs unfold, new opportunities for synergies and collaboration will open, paving the way to expand Blue-Cloud's reach and value to the global Ocean and freshwater

[24] D6.5 Blue-Cloud Service Exploitation & Sustainability Plan (Trust-IT, MARIS 2022)
[25] https://inspire.ec.europa.eu

communities. Blue-Cloud is an important component of the EU's contribution to the Ocean Decade: It offers a collaborative platform and tools that can support the international community in monitoring progress towards the UN Agenda 2030 SDGs, while contributing to win buy-in from the public and private sectors on FAIR data sharing towards global Ocean data coverage, by showcasing practical win-win applications emerging from these efforts. While it is difficult to estimate the return on investment of such a contribution, some important benefits can be anticipated. For example, the potential savings that could be derived from evolving innovative ways of monitoring compliance with international environmental agreements (often funded via external aid mechanisms) could already, on their own, provide a strong case for further supporting the sustainability of Blue-Cloud's efforts.

Blue-Cloud's SE&SP has estimated that additional funding of €10 million is needed to support the evolution of the underlying infrastructure and services required to meet the Blue-Cloud 2026 objectives and action plan. To approach this next phase (2023-2026) of developments, the original Blue-Cloud consortium has been expanded from 18 partners to 40 partners, taking onboard new research infrastructures (e.g., EMSO, EMBRIC, SIOS, JERICO-CORE) and a wider catalogue of marine data products and services (e.g., from EMODnet), as well as expanding the scientific reach of the thematics covered. Funding for this next phase has been secured, through the Horizon Europe program "Call: HORIZON-INFRA-2022-EOSC-01-03". During this next phase, key actions will be undertaken towards stepping up a sound sustainability framework Blue-Cloud's ecosystem of services, community and digital assets throughout 2026-2030 and beyond.

5 Policy recommendations

As explained in the previous section, implementing Blue-Cloud Action Plan 2026-2030 will require wider support from **EU action** and **funding frameworks**. This support will be needed not only to continue to evolve Blue-Cloud's efforts, but also to create a thriving context for the successful delivery of its overarching **vision**, which spans well beyond the scope of action of Blue-Cloud. This section outlines specific **policy recommendations** that could contribute significantly towards that end, hoping to offer guidance to relevant units of the **European Commission** (i.e., DG RTD, DG MARE, DG DEFIS, DG ENV, DG Connect, DG DEVCO) and other relevant (national and/or regional) authorities of **EU Member States** on key actions needed to realise the full potential of web-based Open Science in the marine domain, paving the way for the successful delivery of the (digital) knowledge system required to advance research of Ocean, seas, coastal and inland waters in Europe and beyond. These recommendations stem from the extensive stakeholder consultation exercise carried out during the implementation of the Blue-Cloud project, as described in section 1.

Table 4: Policy Recommendations

Policy recommendations:

Towards sustaining the flow of FAIR and open Ocean data in Blue-Cloud's (and other) Open Science environments:

1. **EC**: Operationalise funding for trusted EU marine data infrastructures and services to maintain seamless operation and evolution of data services towards meeting future needs e.g., cloud-based data sharing and Open Science.
2. **EC & National Research bodies of EU Member States**: Take measures to strongly mandate improved flow of scientific data into EU marine data & research infrastructures and adopt mechanisms to help overcome barriers to data retention for publicly funded research.

Towards triggering the development of innovative data analytics methods around user-driven needs and policy priorities to guide the community:

3. **EC Horizon Europe Program:** Encourage EU initiatives to share outcomes of stakeholder consultation processes towards identifying user needs & requirements for new analytical, modelling and/or visualisation services that could be developed within Blue-Cloud, servicing different communities.
4. **EC DGs & Horizon Europe Program:** Capitalise on Blue-Cloud to service the needs of projects building analytical tools & services to support research (e.g., HE projects) and/or to inform policy making (e.g., MSFD, WFD, etc).
5. **EC:** Promote free access to data services with data formats and access protocols supporting interoperability worldwide (e.g., OGC, TDWG...), relaxing 3rd party barriers to Open data in the marine domain to enable user-driven innovation and Open Science at a wider scale, while fostering data licensing to support data usage tracking.

Towards (further) federating key marine data, research & e-infrastructures and strategic initiatives (EOSC, EDITO & DestinE) to enhance user value:

6. **EC:** Sustain progress towards federation of e-infrastructures to increase EU cloud storage, computing power and GPUs, enabling the research community to tap on EU digital capabilities, resources and commons to engage in cloud-based Open Science.
7. **EC:** Encourage key players (EOSC, future EU DTO) to fix protocols and/or rules of compliance that enable users to easily port their digital assets across e-infrastructures, without being "tied" to them.

8. **EC:** Promote cooperation between public marine data and research infrastructures, e-infrastructures and European, private cloud service providers to bring data and models to their platforms, making them also available in their computing facilities to support wider use, exploitation, dissemination and uptake.

Towards (further) growing a thriving community of Ocean Open Science practitioners, leveraging skills, incentives & rewards and promoting wide dissemination of FAIR methods to boost innovation at a wider scale:

9. **EC & EU Member States:** Include in curricula and support training efforts to build capacity amongst researchers in the use of AI, ML, and on the application of FAIR practices to analytical methods for wider exploitation, capitalising on Blue-Cloud's VRE to deliver data camps, courses, and training.
10. **EC:** Foster mechanisms that reward research teams that incubate methods and/or services that are taken-up by long term EU initiatives and/or services, including economic rewards linked to their exploitation (e.g., by sharing "exploitation fees" of "fremium" schemes offered to users).
11. **EC:** Establish Terms of Reference for exploitation of digital commons across the EU Green Deal Data Space, promoting open access to such commons (e.g., data, data models, algorithms) and the adoption of an open-source approach to their exploitation if/when obtained and/or developed with public funding.

Towards connecting and align with wider developments and communities to contribute to a European and global knowledge system in support of the EU Green Deal and the UN Agenda 2030:

12. **EC:** Support uptake and capitalisation of the results of the community-driven, Open Science efforts delivered by Blue-Cloud, into the EU Digital Twin Ocean and other EU and global environmental initiatives, such as the UN Convention on Biological Diversity and the UN Framework Convention on Climate Change.

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