SYSTEMS AND ARCHITECTURAL SUPPORT FOR OPEN DATA PRINCIPLES: A MARINE EARTH OBSERVATION PERSPECTIVE

Bolelang Sibolla [1,2,*], Raymond Molapo[1], Lufuno Vhengani[1], Lizwe Mdakane[1]

[1] Next Generation Enterprises and Institutions,
Council for Scientific and Industrial Research, Meiring Naude Road, Pretoria, South Africa - bsibolla@csir.co.za
[2]Department of Geography, Geoinformatics and Meteorology, University of Pretoria, Pretoria, South Africa

KEY WORDS: Blue economy, Open data, System of systems, Geospatial data sharing, Interoperability, Open source software.

ABSTRACT:

The GMES and Africa, MarCOSIO project, promotes the sustainable management of marine resources, improves marine governance, and stimulates the growth of the blue economy in the Southern African and Indian ocean region. Because of its mandate, a wide range of applications, and regional view that incorporates eight countries, the MarCOSIO Information Management System adopts and continues to strive towards implementation of open data principles. This paper presents considerations of the MarCOSIO information management systems towards the adoption and implementation of open data, FAIR and TRUST principles, to ensure the sustainability of its services and offerings. The implementation of the system is evaluated against criteria that assess the alignment to FAIR, TRUST, and Open Data principles. An assessment of the results shows that the system aligns closely, though not fully, with the FAIR and TRUST principles. This is mainly due to the use of reputable open-source tools that implement well-known and accepted standards. On the basis of the services provided, the system cannot be fully open, as in some cases the need for security outweighs the openness. This is specifically true for cases where there is a need to protect personal information, and public disclosures are prohibited by law. The use of open data from the European Commission has allowed the rapid development of regionally relevant solutions that, in turn, have remarkably improved decision making in promoting the protection and growth of the ocean economy. It is one of the goals of the open data directive to increase public participation in the achievement of economic growth.

1. INTRODUCTION

1.1 Towards a sustainable blue economy

The United Nations defines the blue economy as an ocean economy that aims to improve “human well-being and social equity, while significantly reducing environmental risks and ecological scarcities”. The World Bank further defines the blue economy as “the sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of ocean ecosystem” (Lee et al., 2020). This aligns directly with Sustainable Development Goal 14: “conserve and sustainably use the oceans, seas and marine resources for sustainable development” (United Nations, 2022).

The global ocean economy is estimated at 1.5 trillion US dollars (United Nations ECA, 2023). The African Union Commission reported that the blue economy sector in Africa generated 296 billion US dollars in 2018. However, significant losses in the economy and misuse of natural resources are still hampering the realisation of the full potential that this sector could contribute. The African Union, through various programs, strategies, and implementation plans, is spearheading the support and growth of the blue economy in several African regions. (Sacko, 2020). One such program is the Global Monitoring for Environment and Security (GMES) and Africa, Marine and Coastal Operations for Southern Africa and the Indian Ocean regions (MarCOSIO) project.

The GMES and Africa, MarCOSIO project promotes the sustainable management of marine resources, improves marine governance, and stimulates the growth of the blue economy in the region. The project aims to maintain, further develop and provide a sustainable platform for local, institutional, human, and technical capabilities in the region. The MarCOSIO project is strongly focused on providing decision makers with services and tools in a clearly directed response to the sustainable development goals; directly linked to national, regional, and continental mechanisms. The project strengthens regional and national capacities to generate and apply Earth Observation (EO) technology, as demonstrated by the user-focused Earth Observation service development methods, substantially proposed user engagement, and training mechanisms. Furthermore, a wide application range, multi-sensor and regionally optimised algorithms and products are used, and sophisticated Information Technology (IT) and processing/serving capability of the MarCOSIO Information Management System (IMS). The MarCOSIO project, through the support of the European Commission that is facilitated by the GMES and Africa program (African Union, 2022), uses the data and services of the Copernicus program within the African context.

Lee et al. (2020) indicated that due to the multidisciplinary nature of the blue economy, the successful realization and implementation of programs require partnerships and collaborative efforts from various stakeholders (Lee et al., 2020). This is evident in the nature of the MarCOSIO project. Collaboration and partnership require a mechanism for effective sharing of data, communication of products and services, and policy agreements. As a result of its mandate, a wide range of applications, and regional view that incorporates several countries, the MarCOSIO Information Management System adopts and continues to strive towards implementation of open data principles. This contribution presents the considerations of the MarCOSIO

* Corresponding author

information management systems towards adoption and implementation of open data, FAIR and TRUST principles to ensure sustainability of its services and offerings.

1.2 Open data for sustainable development

By definition open data describes the ability to access, use, modify, and share data freely by anyone and everyone. Open data guidelines and principles have been widely applied to government- or public-funded data holdings such as the MarCOSIO project. According to the international open data charter, (Open Data Charter, 2015), open data must comply with technical and legal requirements that will enable it to support the above definition. Above all this, the principles that govern openness in this respect prescribe that data must be open unless there are security reasons that prohibit its use in an open nature; drive innovation and inspire public participation towards inclusive economic growth (Borgesius et al., 2015). Open data is focused on the democratisation of data and the use of data for the public good. Open data is often complemented by the FAIR data guidelines in practice as guidelines for data management. However, it should be noted that, although they overlap, these principles are not similar but have been applied complementary to each other towards the common goal of data management in the public service domain as discussed by Jati et al. (Jati et al., 2022).

FAIR focuses on the reusability of data and states that data must be ”findable, accessible, interoperable, and reusable”. The four elements that define the principles of FAIR as described by Wilkinsonet et al. (2016) are briefly described below (Wilkinson et al., 2016). Findability means that both humans and machines should be able to find data with ease through the use of common metadata protocols. Accessibility requires that authorization mechanisms for accessing data be made easy for both humans and machines. Interoperability states that it should be possible to merge two or more data resources for storage, analysis, and processing purposes. Reusability means that humans and machines should be able to replicate and reuse data in different environments (Jacobsen et al., 2020). Although FAIR only provides guiding principles and does not prescribe specific protocols and standards to be used, several works have shown the value of well-described metadata and the use of open standards to achieve FAIR (Hasnain and Rebholz-Schuhmann, 2018).

As indicated by both the Open Data and FAIR principles, findability, accessibility, and reuse of data are central themes toward making data and information available to a community of users. Therefore, online data repositories have become popular for data sharing and information communication. TRUST principles have emerged over the years as guiding principles for the effective management of data holdings and repositories and have been adopted by many. The MarCOSIO project in its implementation aims to provide TRUST-worthy data holdings for its user community and stakeholders. The elements of TRUST with a specific focus on data repositories are transparency, responsibility, user focus, sustainability, and technology. According to TRUST principles, data repositories require maintenance, certification, and auditing and should therefore be set up to support certain measurable criteria. Lin et al. (Lin et al., 2020) provide a detailed description of the criteria to which a TRUST-worthy data repository should adhere. The criteria are summarized below and their implementation, compliance and relevance to the GMES-MarCOSIO project will be demonstrated in Section 3. Transparency allows users to learn about the repository and how they can use it. It is important that the owners of the repository communicate their terms of use, the data preservation period, and data governance policies to manage user expectations. Responsibility refers to the verification and integrity of the data provided. It is demonstrated by adherence to and communication of metadata standards to the user community, provision of technical services that can be used to interface with the data, and protection of data providers through intellectual property rights and system security, where necessary. The needs of the user committee are central to a TRUST-worthy data repository; therefore, repository managers are required to be aware of the user needs and make considerations to address them as much as possible, whilst providing metrics about the available data and contributing to community catalogs. Sustainability measures the continued uninterrupted access to the data, making it important for data repositories to design and provide a governance framework for long-term preservation of the data so that the data resources remain discoverable, accessible, and usable in the future. Technology considers the software, hardware, and processes required to facilitate the operation and maintenance of the data repository. The technology requirements of a data repository should ensure the implementation of appropriate standards, tools, and technologies, along with appropriate cyber security measures in this regard (Lin et al., 2020).

Having looked at the theoretical requirements for open data, FAIR, and TRUST, the rest of the paper is organized as follows. Section 2 explores existing related work and provides a review of systems and projects within the Earth observation domain that have implemented these policies and principles, as well as the standards tools and technologies used. Section 3 describes the implementation of these principles in the MarCOSIO Information Management System, toward the realization of the objectives of the MarCOSIO project. Section 4 demonstrates the functionality of the information management system. Section 5 presents the successes and challenges that the MarCOSIO information management system has had in the implementation of the principles and in relation to the various criteria discussed in the literature above. Section 6 presents the conclusions and the way forward.

2. RELATED WORK

2.1 Open Data in Earth Observation

Several key producers of earth observation (EO) data have made their data freely and openly accessible. This has enabled further uptake, usage, and generation of derived products that are used in various sectors at varying scales throughout the world. Leading examples of open data platforms include the European Space Agency (ESA), Copernicus Open Access Hub, and NASA Earth data portal (Zhu et al., 2019, Prakash et al., 2020, Wulder and Coops, 2014). In addition, these key producers have led the way in the development of legal policies, technology frameworks, and implementation considerations that are used for data governance in the field of earth observation. These key data producers are thus leading the curve in making the FAIR, TRUST principles operational and understandable (Harris and Baumann, 2015, Miura, 2016).

2.2 Standards, tools and technologies

In the domain of earth observation applications, spatial data infrastructures are widely used and adopted as a means to facilitate the use and sharing of data and information. According to the literature, a spatial data infrastructure (SDI) is a platform that serves as an interface between humans and systems in the exchange and sharing of spatial data, including EO information, by providing the required technologies, policies, and standards (Gomes et al., 2020). SDIs are thus adopted as building blocks towards the implementation of FAIR, TRUST and the Open Data policy.

The Open Geospatial Consortium Web standards have been used extensively within spatial data infrastructures for the purpose of making data findable, accessible, and interoperable. Notable standards include the Web Map Service (WMS), Web Feature Service (WFS), and the Catalog Service for the Web (CSW) (Kotsev et al., 2020, Mhangara et al., 2019).

2.3 Implementations of FAIR and TRUST in geoportals and EO applications

Stewards of earth observation data repositories have in recent years aligned their repositories to the FAIR principles (Voidrot et al., 2023). Examples of these and highlights of their implementations are summarised in the next section. In response to the need for a system to make big Earth observation data available in their region, SwissEnvEO was developed. The system consists of an SDI that is complemented with digital repository capabilities with the objective of facilitating the publication of Ready-to-Use information products that are derived from satellite EO data (Giuliani et al., 2021). DeLima et al. (2022) discuss the advantages and challenges of generating forest data in Brazil (de Lima et al., 2022). There are several other examples (Huntington et al., 2021, Cudennec et al., 2020).

3. METHOD

3.1 Description of the MarCOSIO Information Services

The MarCOSIO Information Management System consists of six applications, on the themes of fisheries and aquaculture, marine and maritime services and coastal monitoring services. The applications are illustrated in figure 1.

Figure 1. Overview of MarCOSIO information services

The applications are loosely coupled, but central to these applications is a data portal that provides access to information products that are generated within the various applications of the system. The system primarily makes use of the European Union Space Program's Copernicus data products to generate derived products that are then made accessible to the stakeholder community within the region.

The system is developed with input from the stakeholder community through a co-design and co-development methodology to ensure that the applications are fit for purpose and to encourage high usability and uptake from the marine and coastal communities in the region. Therefore, consideration is given to all countries and stakeholders in the eight African countries.

3.2 Data

Free and open data are preferred and used as much as possible within the system, and the identification of suitable data sets is determined to match the information output products that are developed. Along with Sentinel 1, 2 and 3 data, the open Copernicus products used in the system include the OLCI, SLSTR, SST data.

Whilst these datasets are used regularly by the system, they are not stored but rather the derived products are stored to form part of the data repository.

3.3 Overall System Architecture

A general conceptual pipeline is followed when designing and implementing geospatial information systems, often referred to as the spatial data infrastructure. At its core, the pipeline works to facilitate the flow of data and information in a manner that can be easily consumed and visually represented. The flow of data is essentially a process that manages the execution of a wide range of data processing patterns. Consequently, careful consideration is given to the general flow of information, end-to-end, through each stage of the pipeline. These stages include data acquisition and collection, preparation, processing, visualisation, reporting, and sharing. These factors contribute to the key objective of the MarCOSIO project which is to ensure that data and services are available to all stakeholders and partners and to foster intergovernmental cooperation. The objective requires that services and data products be of a certain quality and level of trustworthiness. For this reason, services are built according to leading international standards and guidelines. MarCOSIO's general process flow is illustrated in figure 2.

Data that are ingested and processed through the pipeline generate new products and data sets that must be managed internally and externally to the pipeline as distributed across the MarCOSIO data nodes as shown in figure 3. As a result, data are guaranteed to be organised, protected, and stored securely so that they can be easily used and exploited. It is essential to ensure that this process is automated due to the high rates at which data are retrieved and analysed. Each stage of the pipeline exists as an independent microservice and is decoupled from the others. A microservice is triggered from start-to-end by the preceding stage via an API through a fully automated process. Automation is essential for repeatability and to ensure that data are reliably processed and captured systematically for every iteration. Once the processed data are stored and described, it becomes the responsibility of the MarCOSIO consortium to supervise and ensure that it is updated and accessed by authorised users where necessary. Additionally, open standards are followed to ensure that data are adequately curated to facilitate discovery.

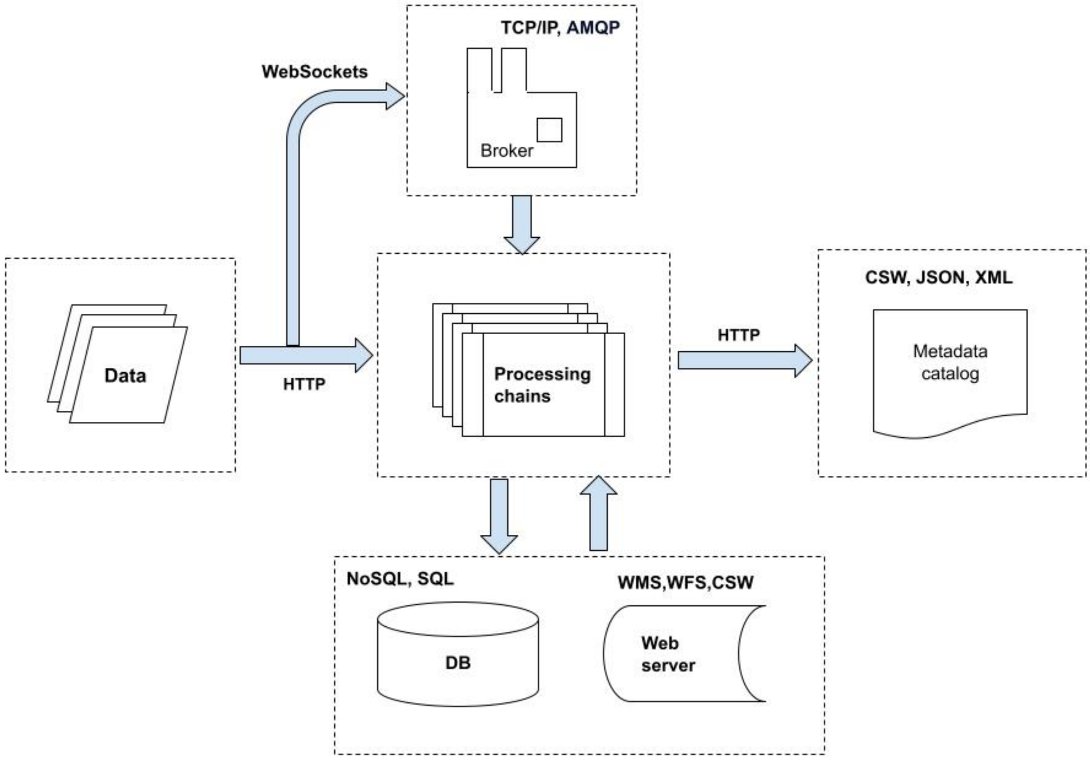

Figure 2. Overall MarCOSIO end-to-end dataflow

3.4 Implementation of TRUST in the MarCOSIO information management system

Based on the large number of datasets anticipated, the Comprehensive Knowledge Archive Network (CKAN) was the selected option for implementation of the data management layer (geoportal) because it is open source, widely used, and powers many ”big data” hubs and data portals globally. CKAN is a data management technology used across different sectors globally. It is an open-source project developed with the aim of facilitating data sharing and reuse, especially amongst governmental and non-governmental organisations looking to collaborate, which is the same purpose for the MarCOSIO system. It allows for easy data publication, discovery, sharing, and accessibility. Therefore, all partners within the project can share and discover data and information. One major requirement, which is essential for the MarCOSIO data hub, is its interoperability. The data hub has the ability to facilitate unrestricted interfacing, communication, and sharing of data resources between systems, devices, applications, and products. CKAN, as the underlying technology, provides tools and interfaces to facilitate this functionality.

The alignment of the project’s technical specifications with the TRUST criteria specified by Lin et al. (2020) are as follows.

Transparency: Currently, the MarCOSIO geoportal and information management system does not provide the terms of use, both for the repository and for the data holdings. The minimum digital preservation timeframe for the data holdings is also not communicated in the geoportal, but is communicated in the MarCOSIO applications. Any sensitive data are not provided or referenced in the geoportal; however, applications that produce data that are not public have sufficient authentication to safeguard the sensitivities.

Responsibility: The MarCOSIO geoportal makes use of well-known metadata standards, namely ISO19115 and the South African SANS 1878. The geoportal does not provide data processing capabilities, but allows for data download. Sensitive data that require a level of security clearance are not available on the geoportal. The intellectual property rights of the data producers are protected by not making copies of data but by encouraging the data producers to host their own discoverable data portals that are interoperable with MarCOSIO.

User Focused: Constant regional stakeholder and user engagement sessions ensure that the project development team continuously receives feedback from the user community, allowing the team to be aware of community expectations and changing needs.

Sustanability: MarCOSIO services currently provide at least 90 percent uptime for all its services. The imminent migration to cloud-centric environments will guarantee up to 99.9 percent uptime with increased throughput and scalability.

Technology: The MarCOSIO geoportal implementation is comprised of state-of-the-art open-source software. As a result, the software is long-term supported by a large community of users. The technology stack is absolutely transparent, flexible, scalable, and cost-effective. Most importantly, open-source techno-

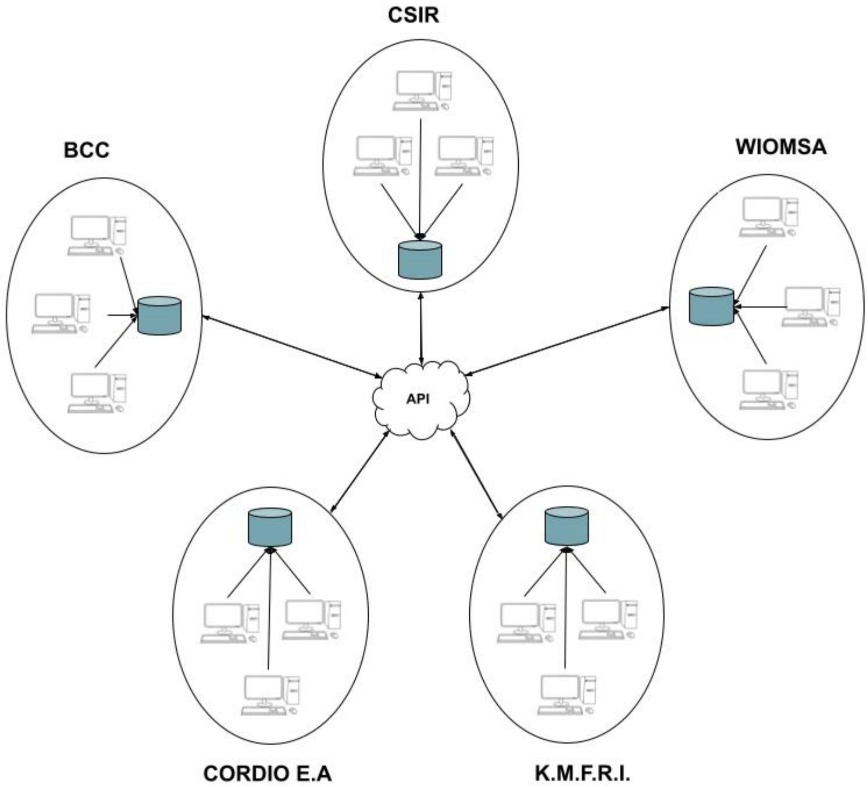

Figure 3. MarCOSIO data node network

logy provides enhanced security support through regular software patches and updates.

3.5 Implementation of FAIR in MarCOSIO geoportal

Revisiting the FAIR principles introduced in Section 1.2 and extended to the purpose of the MarCOSIO information management system as presented in Section 3.1; thus, this section explores how the MarCOSIO data portal currently adheres to the principles. This is done by discussing the solutions implemented in the MarCOSIO project in alignment with FAIR principles and criteria described by Jacobsen et al (2020).

Implementation of findability requires the following:

- *(Meta)data are assigned a globally unique and persistent identifier*: CKAN generates a unique URL that is used as a unique identifier for each dataset.
- *Data are described with rich metadata*: Data described manually, adhere to the ISO19115-2, and regional SANS geospatial standards. Catalogue Service for the Web (CSW) harvested metadata must conform to ISO19139, which is an XML schema implementation from ISO19115.
- *Metadata clearly and explicitly include the identifier of the data they describe*: This functionality is provided by CKAN.
- *(Meta)data are registered or indexed in a searchable resource*: CKAN provides data search functionality by name, tags, and spatial regions. All metadata records that are described with bounding boxes are auto-indexed during manual and harvested addition.

Implementation of Accessibility:

- *(Meta)data are retrievable by their identifier using a standardised communications protocol*: the following standards protocols are used. Metadata are retrieved using OGC CSW. Data by OGC WMS, WCS.
- *The protocol is open, free, and universally implementable*: Yes, protocols are based on OGC standards
- *The protocol allows for an authentication and authorisation procedure, where necessary*: CKAN provides user management capabilities that allow authorised users with tokens to access and manipulate the records. Furthermore, metadata records can be accessed privately or by a specific group or organization.
- *Metadata are accessible, even when the data are no longer available*: Metadata acquired through harvesting would still be accessible, since only the reference to the data is provided in the description.

Implementation of Interoperability:

- *(Meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation.*: The OGC standards used make use of XML and JSON encodings, which are both well understood and used in the geospatial computing domain.
- *Meta)data use vocabularies that follow the FAIR principles*: CSW used in conjunction with CKAN ensures that only data exposed through CSW can be harvested through

CSW. Thus, the metadata custodian, responsible for governance, would determine the suitability of the vocabulary and a list of codes and new definitions to comply with the ISO standard.

- *(Meta)data include qualified references to other (meta)data*: Yes, CKAN provides functionality for harvesting from other metadata catalogs.

Implementation of Reusability:

- *Meta(data) are richly described with a plurality of accurate and relevant attributes*: Yes, this is achieved for both the ISO and SANS standards
- *(Meta)data are released with a clear and accessible data usage license*: Yes, this is achieved for both the ISO and SANS standards
- *(Meta)data are associated with detailed provenance*: Not tested
- *(Meta)data meet domain-relevant community standards*: Yes, ISO and OGC standards are well understood worldwide, while the SANS standards are mandatory for the Southern African context.

4. RESULTS

4.1 System demonstration

This section provides a demonstration of the services and applications of the MarCOSIO system, with a specific focus on the applications that provide fully open services.

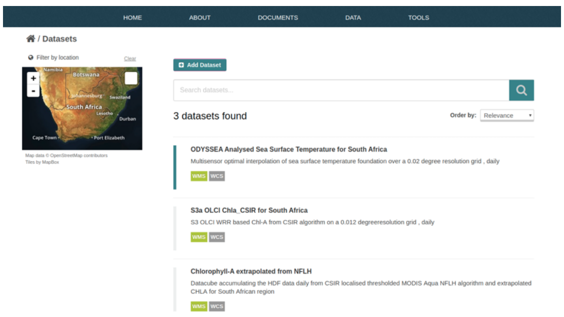

Figure 4. MarCOSIO geoportal

The MarCOSIO geoportal, shown in Figure 4, serves as the interoperable system of systems for data discovery, accessibility, and sharing.

Harmful Algal Bloom service, in figure 5, provides users with the ability to monitor historical and current harmful algal bloom events along the coast of Angola, Namibia, South Africa, Mozambique, Tanzania, Kenya, and Reunion Islands. Decision makers can now be notified of red-tide events and develop the ability to predict rock lobster walkouts.

The Coral Bleaching Service, shown in Figure 6, provides users with the ability to monitor the occurrences of coral reef bleaching by building new services based on Copernicus products to detect thermal stress. The service provides users with the ability to assess historical and real-time bleaching alerts. Additionally, it provides the ability to assess other sources of coral stress, such as sand mining.

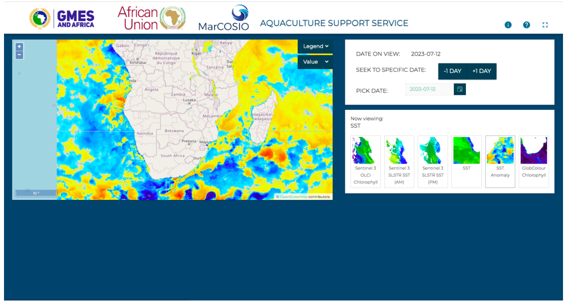

Figure 5. MarCOSIO harmful algal bloom service

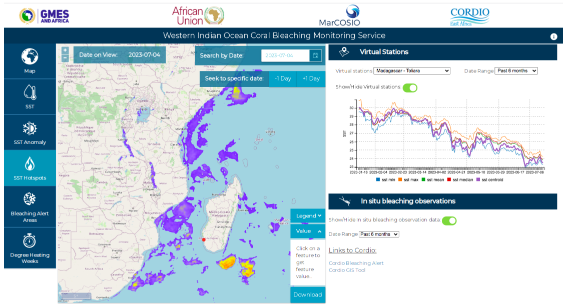

Figure 6. MarCOSIO coral bleaching service

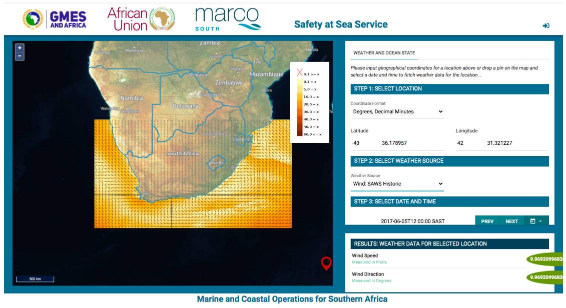

Figure 7. MarCOSIO safety at sea service

Safety At Sea service, shown in figure 7, gives users the ability to monitor and predict ocean and sea state variables such as wind, currents, and waves. Sea search and rescue organisations make use of this service to assist with the planning of sea search and rescue operations across the MarCOSIO region.

5. DISCUSSION AND CHALLENGES

An assessment of the alignment of MarCOSIO's geoportal and information services to the FAIR, TRUST, and Open Data principles shows that the system aligns very closely , though not fully, to the FAIR and TRUST principles, as a result of its use of reputable open source tools that implement well-known and accepted standards.

Based on the services provided, the system can not be fully open, as in some cases the need for security outweighs the openness. This is specifically true for cases where there is a need to protect personal information, as there are laws and policies in the region that prohibit certain disclosures publicly.

The use of open data from the European Commission has enabled the rapid development of regionally relevant solutions, which in turn have remarkably improved decision-making toward the protection and growth of the oceans economy. This is in line with the open data goal of increasing public participation toward economic growth.

The main challenge that the system encounters towards becoming further FAIR and TRUST aligned is that due to the regional mandate, the system implementation must consider policies from all 8 countries. While mainly regional mandates apply, there may also be local considerations that are important for each of the countries, therefore equal representation must be maintained.

6. CONCLUSIONS AND RECOMMENDATIONS

MarCOSIO project, through its funded model, has adopted the philosophy of openness of technology to enhance the accessibility of knowledge. Furthermore, this is underlined by the use of reputable, free, and open-access data services through the European Union Space Program's Copernicus data products.

The success of MarCOSIO can be attributed to the co-development and co-design processes where different project partners collaborate to conceptualise and design services and products suitable for the Southern Africa and Indian Ocean regions.

Well-managed and efficiently distributed data allow for increased productivity and better decision making in organisations. Not all data must be stored and reused once processed. However, data that are processed must conform to identified principles that govern and provide a common framework that helps facilitate the implementation of these best practices.

When TRUST and FAIR principles form the basis and foundation for proper data governance, it is possible to embrace good practices to ensure that data are reusable by humans and machines.

Future work within this scope will be towards improving MarCOSIO's alignment with FAIR and TRUST by ensuring that all regional data considerations are met. Furthermore, as technology continues to innovate, new standards, protocols, and tools are emerging for efficient management of big EO data. The system needs to remain relevant and sustainable by adopting these improvements.

REFERENCES

African Union, 2022. GMES and Africa. http://gmes.africa-union.org/.

Borgesius, F. Z., Gray, J., Van Eechoud, M., 2015. Open data, privacy, and fair information principles: Towards a balancing framework. *Berkeley Technology Law Journal*, 30(3), 2073–2131.

Cudennec, C., Lins, H., Uhlenbrook, S., Arheimer, B., 2020. Editorial–towards fair and square hydrological data.

de Lima, R. A., Phillips, O. L., Duque, A., Tello, J. S., Davies, S. J., de Oliveira, A. A., Muller, S., Honorio Coronado, E. N., Vilanova, E., Cuni-Sanchez, A. et al., 2022. Making forest data fair and open. *Nature Ecology & Evolution*, 6(6), 656–658.

Giuliani, G., Cazeaux, H., Burgi, P.-Y., Poussin, C., Richard, J.-P., Chatenoux, B., 2021. SwissEnveo: A FAIR national environmental data repository for earth observation open science. *Data Science Journal*, 20, 22–22.

Gomes, V. C., Queiroz, G. R., Ferreira, K. R., 2020. An overview of platforms for big earth observation data management and analysis. *Remote Sensing*, 12(8), 1253.

Harris, R., Baumann, I., 2015. Open data policies and satellite Earth observation. *Space Policy*, 32, 44–53.

Hasnain, A., Rebholz-Schuhmann, D., 2018. Assessing fair data principles against the 5-star open data principles. *The Semantic Web: ESWC 2018 Satellite Events: ESWC 2018 Satellite Events, Heraklion, Crete, Greece, June 3-7, 2018, Revised Selected Papers 15*, Springer, 469–477.

Huntington, J., Erickson, T., Harring, J., Melton, F., 2021. Multi-source earth observation data and fair data principles for improved natural resource management and decision making. *AGU Fall Meeting Abstracts*, 2021, SY22A–02.

Jacobsen, A., de Miranda Azevedo, R., Juty, N., Batista, D., Coles, S., Cornet, R., Courtot, M., Crosas, M., Dumontier, M., Evelo, C. et al., 2020. Fair principles: Interpretations and implementation considerations. data intelligence 2: 10-29.

Jati, P. H. P., Lin, Y., Nodehi, S., Cahyono, D. B., van Reisen, M., 2022. FAIR versus open data: A comparison of objectives and principles. *Data Intelligence*, 4(4), 867–881.

Kotsev, A., Minghini, M., Tomas, R., Cetl, V., Lutz, M., 2020. From spatial data infrastructures to data spaces—A technological perspective on the evolution of European SDIs. *ISPRS International Journal of Geo-Information*, 9(3), 176.

Lee, K.-H., Noh, J., Khim, J. S., 2020. The Blue Economy and the United Nations' sustainable development goals: Challenges and opportunities. *Environment international*, 137, 105528.

Lin, D., Crabtree, J., Dillo, I., Downs, R. R., Edmunds, R., Giaretta, D., De Giusti, M., L'Hours, H., Hugo, W., Jenkyns, R. et al., 2020. The TRUST Principles for digital repositories. *Scientific Data*, 7(1), 144.

Mhangara, P., Lamba, A., Mapurisa, W., Mudau, N., 2019. Towards the development of agenda 2063 geo-portal to support sustainable development in Africa. *ISPRS International Journal of Geo-Information*, 8(9), 399.

Miura, S. H., 2016. Earth observation data access interoperability implementation among space agencies. *2016 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, IEEE, 3621–3623.

Open Data Charter, 2015. International Open Data Charter. https://opendatacharter.net/principles/.

Prakash, M., Ramage, S., Kavvada, A., Goodman, S., 2020. Open Earth observations for sustainable urban development. *Remote sensing*, 12(10), 1646.

Sacko, J. L. C., 2020. Africa moves towards the blue economy through ecosystem-based assessment and management practices in African Large Marine Ecosystems. *Environmental Development*, 36, 100575.

United Nations, 2022. Sustaianble Development Goals. https://sdgs.un.org/goals/goal14.

United Nations ECA, 2023. Blue Economy. https://www.uneca.org/eastern-africa/blue-economy.

Voidrot, M.-F., Bye, B. L., de Salvo, P., Franziskakis, F., Benedict, K., Maso, J., Schubert, C., Rubio, J. M., Downs, R. R., 2023. New resources promoting the geo data sharing and management, fair, and care principles. Technical report, Copernicus Meetings.

Wilkinson, M. D., Dumontier, M., Aalbersberg, I. J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.-W., da Silva Santos, L. B., Bourne, P. E. et al., 2016. The FAIR Guiding Principles for scientific data management and stewardship. *Scientific data*, 3(1), 1–9.

Wulder, M. A., Coops, N. C., 2014. Satellites: Make Earth observations open access. *Nature*, 513(7516), 30–31.

Zhu, Z., Wulder, M. A., Roy, D. P., Woodcock, C. E., Hansen, M. C., Radeloff, V. C., Healey, S. P., Schaaf, C., Hostert, P., Strobl, P. et al., 2019. Benefits of the free and open Landsat data policy. *Remote Sensing of Environment*, 224, 382–385.