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Towards a Marine Spatial Data Infrastructure for Oman: A Foundational Framework Based on FAIR Principles

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ABSTRACT

The maritime industry of the Sultanate of Oman is one of the key drivers of its Blue Economy, but the potential of the industry is limited by the lack of marine spatial information and its distribution across various organisations. This fragmentation brings about inefficiencies, poor decision-making, and integrated ocean management. In order to overcome this problem, the paper suggests the creation of a national Marine Spatial Data Infrastructure (MSDI), which is built on the principles of FAIR, i.e., Findable, Accessible, Interoperable and Reusable. A systematic review of the international MSDI practices and an examination of the Oman market data landscape and the ecosystem around the stakeholders allow us to develop a framework specific to the national perspective. The framework clearly relates every FAIR principle to key pillars of governance, technology, data standards and capacity building and offers a specific blueprint on how to implement them. Moreover, we introduce a roadmap of a gradual shift of the decentralised data store to a coordinated, resilient national infrastructure. The work can assist policymakers, scientists, and industry leaders in developing a strategic roadmap to base a data-driven ecosystem on in order to improve maritime spatial planning and sustainable economic development and ensure the long-term sustainability of the blue economy in Oman.

1. Introduction.

The maritime industry in Oman is a strategic foundation of the national Blue Economy and diversification goals of Oman Vision 2040. Taking advantage of a strategic place in geography, the industry combines ports and logistics, fisheries and aquaculture, and coast protection into inseparable pillars contributing to economic development, food security, and environmental sustainability (Kadhafi, 2024; R. Ahmed, 2024). High-quality and integrated marine spatial data are the basis of successful governance and development of this important sphere to inform the planning, regulation, and investment.

The present situation of marine spatial information in Oman is, however, defined by fragmentation. Although useful datasets are available, such as species databases in international archives, real-time oceanographic sensors, and fisheries databases managed by GIS, they are scattered across lots of organisations, including the Hydrographic Department, the Environment Authority, port authorities, and research organisations (GbifOrg, 2021; Du Vall, 2007; Alakhzami, 2000). Such siloed management generates high levels of operational inefficiency by creating duplication in the data collection process, a weak ability to conduct a holistic environmental assessment and conservation planning, and barriers to the development of consistent maritime safety and investment analysis (Tzouramanis, 2021; Gorringe et al., 2018). By extension, this fragmentation of data poses a formidable impediment towards the actualisation of an actually integrated, sustainable, and data-driven blue economy.

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The mechanism that has been formed to deal with these challenges internationally is the Marine Spatial Data Infrastructure (MSDI). MSDI is an institutional system of national coordination, which standardises, centralises and shares marine geospatial information, contributing to transparent and evidence-based decision-making (Contarinis et al., 2020; Guay et al., 2023). Compliance with the FAIR principles to ensure such infrastructure is Findable, Accessible, Interoperable, and Reusable is the current paradigm of providing maximum value to the infrastructure. These principles help to establish a solid base to increase the data finding, technical integration, and usefulness in the long term (Gomez et al., 2025; Tanhua et al., 2019).

Although there is an exact congruency between MSDIs and FAIR principles globally, there is a wide gap between the two as applied to the context of Oman. The country does not have a custom-made, supporting, and practical framework in which these global best practices can be adjusted to the local institutional setting, priorities in the policies, and available data resources. The only difference between the strategies of adopting generic models and failure to implement them is the absence of this essential grounding, and its resulting implementation failure and low adoption rates by stakeholders.

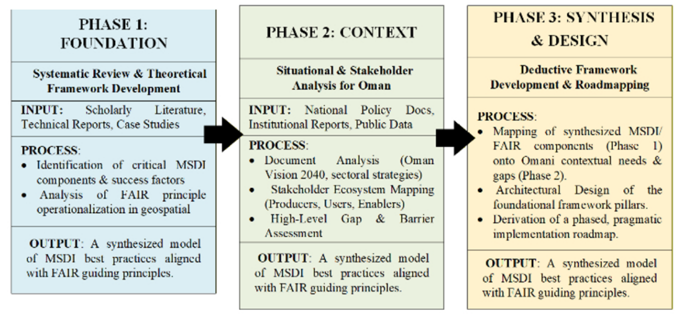
To fill this gap, the given paper will work on the creation of the first dedicated, FAIR-based, and governance-oriented architecture of a national Marine Spatial Data Infrastructure in Oman that will be specifically designed based on the FAIR principles and will be developed through the evolution of the international experience and the specifics of the institutional reality of Oman. This is because the given approach makes the proposed infrastructure sound in theory and practical in reality. It is hoped that the following objectives will be achieved: (1) synthesise the main lessons of international MSDI practices and FAIR implementations; (2) analyse the current marine data ecosystem and stakeholder conditions in Oman; (3) suggest a tailored FAIR-based MSDI framework; and (4) provide a practical step-by-step plan of its implementation. The framework aims at offering policymakers, researchers and industry leaders a practical roadmap towards migrating through the divide between disjointed data repositories to an integrated, resilient and value-creating national infrastructure.

The rest of this paper will be structured in the following way: Section 2 will describe the research methodology. Section 3 is devoted to the results with the analysis of the Omani environment and the offered framework of FAIR-based MSDI. Section 4 talks about implications of the framework, a roadmap of implementation and research requirements in the future. Section 5 concludes the paper.

2. Methodology.

In its search to construct a contextually related and principled framework, this research utilised a design science research methodology with a multi-method qualitative analysis. It was not only to present the current state of affairs, but to shape and offer an innovative artefact, a basic FAIR-based MSDI framework, adapted to the requirements of Oman (Hevner et al., 2004). The execution of the methodology followed three integrated and repetitive steps as summarised visually in Figure 1.

Figure 1: Research Methodology and Design Process.



Source: Authors.

2.1. *Systematic Literature Review and Theoretical Synthesis.*

This step laid the groundwork for the theory and practice of the framework. The systematic review was systematic, structured and narrative, and performed in two parallel streams to cover both infrastructural and data philosophy aspects. The former stream was about MSDI designs and global deployments. The search of the academic databases (Scopus, Web of Science) and technical repositories (e.g., International Hydrographic Organisation, Open Geospatial Consortium) related to the literature published between 2010 and 2024 was conducted. The search query used was targeted to keyword strings:

(”Marine Spatial Data Infrastructure” OR ”marine SDI”) AND (”governance” OR ”case study” OR ”framework”)

First stream, and (FAIR principles and (geospatial or marine or ocean data)) Second stream. Inclusion criteria were:(i) English-language, peer-reviewed articles and significant technical reports (e.g. of IHO, OGC);(ii) must be majorly on MSDI architecture and implementation, or FAIR data management;(iii) must be on a national or regional case study. The inclusion criteria eliminated only the articles that covered terrestrial SDIs or data science in general without a geospatial/marine connection. The duplicates were eliminated, and the rest of the documents were filtered on the basis of relevance based on the title of the article, abstract, and the entire text.

Implementations of landmark schemes like the INSPIRE Directive, IHO S-100 framework and national MSDIs in Canada, Norway and Mauritius were critically assessed. The analysis was intended to identify and classify the success-critical elements in four emergent themes, which included: (a) Governance & Policy models, (b) Technology and Standards, (c) Data Management protocols, and (d) Stakeholder Engagement strategies.

Stream two (operationalisation of FAIR principles in geospatial and marine science settings) was concerned with the operationalisation of the principles of FAIR. The literature on the topic of data science and geoinformatics was reviewed to deconstruct each principle of FAIR (Findable, Accessible, Interoperable, Reusable) into tangible requirements, e.g. the use of persistent identifiers to be findable or the use of open standards like OGC Web Services to be interoperable. The results of the two streams were then combined to form a synthesised representation that directly connected high-level MSDI elements to individual FAIR-directed data practices.

2.2. *Situational and Stakeholder Analysis of the Omani Context.*

A qualitative situational analysis was carried out in order to base the framework on the realities on the ground. The stage was based on the analysis of documents and mapping the ecosystem of stakeholders in the use of publicly available data to create a comprehensive profile of marine data in Oman.

- Document Analysis: They were analysed using a thematic analysis of key national strategic documents, such as Oman Vision 2040, the National Logistics Strategy 2040, the Fisheries Strategy and annual reports of the concerned ministries. The aim was to institutionalise clear and unclear national priorities and policy guidelines, and articulate data requirements regarding maritime development and environmental management.

- Stakeholder Identification and Mapping: The key institutions that participate in the marine data value chain were discovered and put into a preliminary matrix (see Table 1). The basis of this mapping was through review of institutional mandates, published project outputs and organisational responsibilities to deduce their role as Data Producers (e.g. Hydrographic Office), Primary Users (e.g. Ministry of Transport, Communications and Information Technology) or Policy/Technical Enablers (e.g. Information Technology Authority).

- Gap and Barrier Assessment: A high-level Assessment of the institutional barriers was developed by combining the results of the document analysis with the stakeholder analysis. It is necessary to mention that the presented stakeholder mapping and the given analysis rely upon the publicly available information; their validation and clarification by direct consultation with stakeholders is deemed an important step.

2.3. *Synthesis and Framework Development.*

The last stage involved a deductive mapping and design to produce the new artefact which was the novel framework. The palette of design was the synthesised model of MSDI/FAIR components (Phase 1). All the components were assessed and modified based on the identified requirements, constraints, and opportunities of the Omani situational analysis (Phase 2).

An example was the international best practice of centralised metadata catalogue (a findability component), which was aligned with the inter-agency requirement of Oman. This led to a design proposal of a decentralised but harmonised metadata service that does not interfere with institutional autonomy but makes national findability a reality. This was done to all the identified components, and all the elements of the proposed framework were supported by the international and the local contextual appropriateness. Section 3 elaborates on this synthesis as the four-pillar foundational framework (Governance, Technology and Standards, Data, People) is the final output of this synthesis. These components were then sequentially broken down into phases of activity that were practical and dependency-conscious thus forming the implementation roadmap.

Table 1: Tentative Marine Spatial Data Provisional Stakeholder Ecosystem, Oman.

No.	*Stakeholder Category*	*Example Institutions*	*Inferred Core Interest / Data Role*
1	*Data Producers & Custodians*	*Oman National Hydrographic Office (ONHO), Environment Authority, Ports Authorities*	*Create and store authoritative information on bathymetry, environment conditions and port infrastructures.*
2	*Primary Data Users*	*Ministry of Transport, Communications and Information Technology, Municipalities, Academia*	*Need combined information in terms of spatial planning, regulation, and scientific investigation.*
3	*Policy & Funding Enablers*	*The Research Council, ITA, Vision 2040 Implementation Unit*	*Forge national digital policy, invest and make cross-sectoral coordination.*
4	*Industry & Civil Society Users*	*Shipping companies, Fisheries cooperatives, Tourism operators*	*Require available information on operational safety, resource control and business advancement.*

Source: Authors.

3. Results.

The systematic review and situational analysis synthesis provided two main products: 1) a descriptive portrait of the marine data situation in Oman, and 2) the suggested framework on which a national MSDI should be based. The framework is clearly aimed at closing the divide between the international best practice and the local reality through the application of the FAIR principles.

3.1. *Synthesis of International MSDI Practices and FAIR Operationalisation.*

In the review, four interdependent pillars were found as the basis of any successful MSDI. More importantly, any pillar can be explicitly informed by particular FAIR principles in order to guarantee the infrastructure that provides usable, integrated data, as shown in Table 2.

Table 2: MSDI Pillars and Synthesis of their FAIR Alignment.

No.	*Pillar*	*Primary FAIR Principles*	*Key Functions & Components*
1	*Governance & Policy*	*Accessibility (A), Reusability (R)*	*Comes up with clear requirements, data sharing agreements and controls (e.g., National Steering Committee) that define access privileges and reuse licensing.*
2	*Technology & Standards*	*Interoperability (I), Accessibility (A), Findability (F)*	*Provides technical integration, machine access, and machine discovery using open geospatial standards of the type open geospatial standards (OGC, IHO S-100) as well as services (catalogues, web services).*
3	*Data & Metadata*	*Findability (F), Reusability (R)*	*Harmonises data, has deep metadata (ISO 19115), persistent identifiers (PIDs), and data identifiers to allow the data to be found and reused in a relevant context.*
4	*People & Capacity*	*All (F, A, I, R) – Sustaining*	*Creates community by engaging stakeholders, training, and champion networks to adopt and have a long-term sustainability of FAIR practices.*

Source: Authors.

Through this synthesis, it is possible to note that effective MSDIs do not view these pillars as separate entities, but as one system with FAIR principles offering the unifying philosophy through which data flows seamlessly from production to reuse.

3.2. *Omani Context: A Broken Ecosystem with strategic alignment.*

The case study indicates that there is an Omani maritime sector that has a high potential for data, but has a limitation of structural fragmentation that is directly linked to the necessity of an MSDI.

3.2.1. *Strategic Policy Drivers.*

National documents are categorical on the Blue Economy being prioritised. Sectoral plans of logistics and fisheries proposed in Oman Vision 2040 and sectoral strategies require systematic and sustainable development and evidence - based decision - making. This gives it a definitive top-down mandate of a data infrastructure that can provide the demanded evidence base.

3.2.2. *Stakeholder and Data Landscape.*

More than 15 major institutions were defined as the key data holders and users (the extension of Table 1 in the Methodology). Data types are diverse, and they include:

- Physical, chemical: Bathymetry, oceanography equipment (temperature, salinity).
- Ecologically and biologically registered fishery, Biological and Ecological fishery register (GBIF), habitat maps.
- Human-Use and Infrastructure: plans of ports, shipping routes, permits of aquaculture sites, shoreline barriers.

An important result is that these datasets are available, albeit they are institutional silos (e.g., hydrographic data with the Navy, environmental data with the Environment Authority, port data with the respective authorities). The central mechanism of discovery does not exist, and formats and standards are not consistent.

3.2.3. *Identified Core Challenges.*

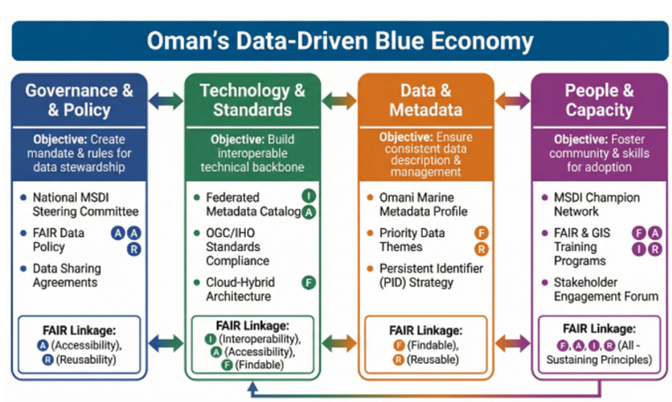
- Institutional: The absence of a coordinating mandate on the data sharing; culture of data ownership rather than data stewardship.
- Organizational: The absence of a national metadata catalogue; a low level of consistency in data models and data formats.
- Capacity: the institutions have different capabilities of GIS and data management.

On the other hand, the main opportunities are that the national digital transformation agenda under the ITA is strong, and the researchers and some governmental organisations are becoming more aware of the constraints of existing data fragmentation.

3.3. *Proposed MSDI Foundational Framework of Oman using FAIR.*

They can introduce a four-pillar base framework based on combining the global model with the Omani context, as Figure 2 demonstrates. All pillars are oriented to FAIR and specify particular, contextual elements of Oman. The structure of the framework illustrates the relationship between the pillars to form a well-integrated ecosystem that promotes the blue economy of Oman (Data-Driven).

Figure 2: The FAIR-Based MSDI Foundational Framework for Oman.



Source: Authors.

Pillar 1: Governance & Policy (Enabling FAIR)

- Goal: develop the mandate and regulations of sustainable data stewardship.
- Key Component: Have a National MSDI Steering Committee headed by a high authority (e.g., under the Supreme Council for Planning or ITA) that has the representation of all important stakeholder institutions.
- FAIR Linkage: It would ratify a national FAIR Data Policy and Data Sharing Agreement that would directly permit the controlled Accessibility (A) and, with respect to Reusability, would add clarity to the licensing (R). It makes data a national strategic asset, which is handled.

Pillar 2: Technology & Standards (Executing FAIR).

- Objective to build the interoperable technical backbone.
- Key Component - Implement federated metadata catalogue and service architecture Instead of centralising data, institutions keep their data servers (”nodes”) but publish their standingised metadata to a national portal. This has the advantage of respecting sovereignty but providing for discovery.
- FAIR Linkage: Requires that web services (WMS, WFS) of the OGC be used and the IHO S-100 standards for marine data be followed, and technical Interoperability (I) and machine Accessibility (A). The data becomes Findable (F) with the help of a catalogue.

Pillar 3: Data & Metadata (The FAIR Core).

- Objective: Create the consistent description and management of data assets.
- Key Component: Develop a profile of Omani Marine Metadata as a simplified subset of ISO 19115 to suit national requirements to make compliance possible.
- FAIR Linkage: Core fields which are required to Findability (F) are mandatory in the profile. Coupled with a strategy for Persistent Identifiers (PIDs) and together with clear provenance documentation it makes data Reusable (R). Pilot projects have to be defined in terms of initial priority data (e.g. bathymetry, marine boundaries, fishery zones).

Pillar 4: People & Capacity (Sustaining FAIR)

- Goal: Nurture the community and skills needed to be adopted.
- Key Component: Introduce an MSDI Champion Network including a liaison in each of the stakeholder institutions, through a special training program on FAIR data management and the new infrastructure use.
- FAIR Linkage: This pillar supports all the principles of FAIR through the development of human capital. The culture of sharing that is encouraged by the champion network is the basis of the Accessibility (A), and curated data is Interoperable and Reusable (I, R) through training.

This model is meant to be realistic and incremental. Instead of starting with an expensive central data warehouse, it starts with governance, lightweight standards and a catalogue that shows the presence of data and its location- the first step of integration.

4. Discussion.

The present paper has suggested a recommendation framework of a national Marine Spatial Data Infrastructure (MSDI) in Oman explicitly based on the FAIR principles. This proposal is contextualised in the discussion of its expected benefits, success factors, limitations inherent in the proposal and the next steps that would move the concept into reality.

4.1. Strategic Alignment and Benefits Expected.

It is estimated that the introduction of the suggested framework will result in transformational gains that will directly encounter the fragmentation issues discussed in the introduction (Tzouramanis, 2021; Gorringe et al., 2018). The framework will eradicate duplication of data in a costly manner and save a lot of time that agencies and researchers spend in the process of trying to locate some information because of the various policies that govern how marine information is Findable and Accidental. This directly improves the efficiency of operations and speeds up the project schedule, which is one of the primary requirements in the logistics and fisheries plans in Oman (Kadhafi, 2024; Bhat & Balushi, 2022).

More appropriately, the emphasis of the framework on Interoperability and Reusability will produce a novel and combined evidence base of decision-making (Gomez et al., 2025). As a tool to investment planning, this indicates that ports, aquaculture operators and renewable energy corporations have the ability to undertake a thorough site study based on harmonised data of bathymetry, ecology and present infrastructure. In protecting the environment, the regulators are able to conduct cumulative impact assessment as overlay of data on sensitive habitats, pollution sources and fishing activities among various custodians in a standard format (Al-Subhi & Al-Suqri, 2025). This is the essential level of integration that is currently hindered by data silos and a key to evidence-based marine spatial planning and ecosystem-based management, which are the key tenets of Oman Blue Economy vision (R. Ahmed, 2024; Choudri et al., 2016).

4.2. Critical Success Factors: Technology Plus.

Although technical architecture is essential, the analysis emphasizes that non-technical aspects will be most critical in the success of the framework, which is also in line with the international MSDI case studies (Guay et al., 2023; Munnaroo et al., 2022). These success factors directly respond to areas of failure in SDI programs that are usually highly technical in nature without equal consideration of governance, gradual implementation, and human capacity.

High-Level Mandate and Leadership: The most significant success factor is the establishment and empowerment of the proposed National MSDI Steering Committee. It should be able to make it mandatory, solve institutional conflicts, and obtain long-term funding. This governance requirement is consistent with the experience of the INSPIRE Directive and the MSDI of the Canadian Hydrographic Service (Contarinis et al., 2020; Guay et al., 2023). On the other hand, the lack of such a requirement is one of the major factors of SDI failure leading to poor adoption and disjointed implementation.

Staged, Pilot-based Process: A big bang implementation process nationally is bound to fail. The strategy is successful by the stage-by-stage nature of the roadmap, which should start with the concentrated pilot, as it proved successful in Mauritius Ocean Observatory project (Munnaroo et al., 2022). A pilot may be able to prove the value physically, gain credibility amongst institutions and polish the procedures and then scale up. This is unlike the "big bang" strategies which often exceed the institutional capacity, fail to demonstrate initial successes and lose support among stakeholders.

Sustained Capacity Building: The people and Capacity pillar can not be an after thought. The training should be continuous related to FAIR data management and the application of geospatial web services to guarantee Reusability and long-term sustainability (Tanhua et al., 2019). The creation of a community of practice via the MSDI Champion Network will create a culture of data sharing and problem-solving that most frequently serves as the biggest obstacle to SDI achievement. In the absence of this investment, any well-planned infrastructure runs the risk of being a ghost platform - technically competent but not used because of a shortage of skills and use.

4.3. Limitations and Future Research.

The paper has some limitations that outline the scope of the necessary future work. The first is the conceptual framework that was obtained by analyzing the documents and synthesizing the international practice. Although this gives a very strong ground, it has not been confirmed by direct and in-depth consultations with all stakeholders in Oman. Second, and similarly, the stakeholder ecosystem analysis (Table 1) and barriers identified are tentative, which are documentary evidence-based. Their soundness and thoroughness should be seen out by having formal interactions with the institutions themselves which could expose some of the nuances, incentives, and constraints that cannot be identified in the documents provided by the institutions (Schaap & Lowry, 2010).

Thus the action agenda and research that proceed immediately should involve:

- The Extensive Stakeholder Engagement: It will be required to conduct formal workshops and interviews with the specified institutions in order to co-design the elements of the framework and achieve their buy-in.

- Pilot Project Design and Implementation: The pilot Project should be designed in a project plan that outlines the technical specifications, roles, responsibilities and success criteria to use in its implementation during its first phase.

- Economic Impact Analysis: There should be research to quantify the economic benefits that the MSDI could have to be able to strengthen the business case to continue investment in the process due to a gap in the ocean data economics (Pearlman et al., 2016).

4.4. An Appeal to Co-operative Action.

The suggested framework is an organized and principled structure to direct this multi-year and complicated venture. To effect this process, we suggest the Information Technology Authority (ITA) which because of its cross-cutting digital transformation and e-government mandate is the first to convene the preliminarily stakeholders, to become the champion in the establishment of the National MSDI Steering Committee. This top leadership will be necessary to drive the change in considering data as an institutional resource, but as a national one, on the basis of the FAIR principles. The shift of fragmented data holdings to an integrated marine data ecosystem is one of the pillars of realisation of the Vision 2040 aspirations in the maritime field in Oman. Taking this direction, Oman will be able to not only establish itself as a regional maritime logistics hub but also as a data-driven sustainable ocean governance leader that will directly assist in the realization of the country Blue Economy and diversification objectives (Saleh and Munir, 2023; Oman Vision 2040 Implementation Follow-up Unit, 2024).

Conclusions.

Fragmented and inaccessible marine spatial data is a fundamental limitation to the sustainable development of the maritime sector, which is a strategic pillar of the Blue Economy and Vision 2040 (Oman Vision 2040 Implementation Follow-up Unit, 2024).

The present paper has met this key challenge by coming up with a context-specific framework of national Marine Spatial Data Infrastructure (MSDI) that has been specifically architected around the FAIR principles.

By means of systematic international best practice synthesis and studying the institutional situation in Oman, the study has overcome the gap in the international concepts of MSDI and FAIR and their application in the Sultanate. The suggested framework becomes the translation of the mentioned principles into a logical plan, in which four pillars are interdependent and built around the premise of Governance and Policy, Technology and Standards, Data and Metadata as well as People and Capacity. Pillsars are functionally connected to targeted FAIR goals, and the infrastructure created can be said to work as a system of collaboration for data custody and not a simple technical record store. The table of phases of implementation that is attached gives a practical implementation roadmap, which aims to reduce risk and realise early value such as establishing a governance and pilot catalogue, until the attainment of full interoperability.

The key output of the work is the provision of a personalized, practical plan on how to change the fragmented marine data resources in Oman into a unified, trustful, and value-based national resource. This framework provides a common reference model to coordinate activities of policymakers, industry leaders and researchers and it is likely to improve the operation efficiency, provide evidence-based marine spatial planning and strengthen environmental monitoring.

This vision can only be realised by combining and acting upon it. The next courses of action are to formalize the cross-sectoral governance body championed by one of the most significant national agencies like the Information Technology Authority (ITA) and to implement a dedicated pilot project to test the framework. The further work needs to concentrate on the stakeholder co-design, economic impact analysis and creation of the particular standards and policies herein. The process of achieving a mature MSDI is a progressive process that requires long-term cooperation. With this FAIR-based basis, Oman will be able to establish itself as one of the leaders in the field of data-driven sustainable ocean governance, which guarantees the stability and success of its blue economy in the long-term.

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