



Subsea Technology as a Solution for Sustainable Utilization of Marine Resources

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Abstract: The sea has great potential as a source of energy, food, minerals, and space for infrastructure development. However, the use of marine resources often poses environmental, safety, and social problems, especially when exploration activities are carried out without adequate supervision. Subsea technology offers an approach that allows underwater activities to be carried out in a safer, more efficient, and controlled manner. This technology includes underwater production systems, monitoring sensors, underwater vehicles, inspection robots, communication networks, and renewable energy and carbon storage supporting infrastructure. This perspective article discusses the role of subsea technology in supporting the sustainable use of marine resources, while reviewing the limitations of the approaches that have been used. The discussion shows that subsea technology does not automatically create sustainability. The benefits are highly dependent on governance, data quality, human resource readiness, community involvement, and consistency of environmental monitoring. The authors argue that the development of subsea technology needs to be directed from an exploitation-centric approach to one that integrates industrial efficiency, ecosystem protection, safety, and community interests. With such a framework, subsea technology can be an important part of responsible marine development.

Keywords: Subsea Technology; Marine Resources; Sustainable Development; Marine Environment; Offshore Energy

1. Introduction

The sea holds enormous resources and plays an important role in meeting human needs. Oil and natural gas, current and wave energy, minerals, fisheries, and space for submarine cable and pipeline networks are some of the potential that can be utilized. For archipelagic countries such as Indonesia, these resources have strategic value because they can support energy security, economic growth, connectivity, and the welfare of coastal communities [1].

On the other hand, underwater conditions present challenges that are not simple. High hydrostatic pressure, corrosion, ocean currents, changes in the seabed, limited access, and distance of the operation site make inspection and maintenance activities difficult. Minor damage to underwater pipes or equipment can develop into leaks that impact the environment, economic activities, and operational safety [2]. This situation shows that the utilization of marine resources is not enough to rely solely on exploration capabilities, but also requires technology that is able to monitor and control risks throughout the life of the facility.

Subsea technology is evolving to answer these needs. The presence of sensors, underwater robots, undersea production systems, and digital communication allows activities to be carried out with less human intervention. However, the use of advanced technology is not necessarily in line with the principles of sustainability. Therefore, it is necessary to take a critical look at how subsea technology is used, who benefits, and how it impacts the environment and society [3].

2. Discussion of the Main Problem

The main problem in the utilization of marine resources is the tug-of-war between economic needs and the

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ability of the environment to withstand the pressures of human activities. The construction of offshore facilities can open up access to energy sources and generate income, but at the same time it has the potential to disrupt seabed habitats, increase the risk of pollution, and cause conflicts in the use of marine space.

Offshore oil and gas activities, for example, require pipelines, manifolds, valves, umbilicals, risers, and other production systems. The infrastructure operates under aggressive environmental conditions. Corrosion, erosion, material fatigue, foreign body impacts, seafloor shifts, and connection failures can lead to a deterioration in the integrity of the facility. If not detected early, failures can result in production stoppages or the release of hydrocarbons into the ocean [4].

Subsea technology plays a role in reducing these possibilities through continuous monitoring of facility conditions. Sensors can be used to measure pressure, temperature, vibration, flow rate, wall thickness, as well as leak indications. The data obtained helps operators recognize changes in conditions before they develop into major failures. Inspections can also be carried out using Remotely Operated Vehicle (ROV) and Autonomous Underwater Vehicle (AUV), so that the need for human diving in hazardous locations can be reduced [5].

The role of subsea technology is not limited to the oil and gas industry. Underwater equipment is also needed in the construction of offshore wind turbines, subsea power cables, wave energy systems, oceanographic observation, and carbon storage under the seabed. On activities carbon capture and storage, for example, monitoring technology is needed to ensure that injected carbon remains within geological formations and does not leak [6].

Although promising, the application of such technology faces cost constraints, human resource capacity, and technological mastery. Most subsea equipment has high investment and maintenance costs. Dependence on imported devices can also make the user country only act as a market, not as a technology developer [7]. This condition becomes a problem when damage occurs, but components, experts, or testing facilities are not available domestically.

Another problem is data. Modern subsea systems generate large amounts of data, but they are not always processed effectively. Degraded sensor quality, disrupted communication, and mismatches between devices can result in inaccurate information [8]. Decisions that rely too much on automated systems are also at risk if the results of the analysis are not verified by experts.

Social aspects are often outside the main concern. The existence of offshore facilities can limit fishing areas, change fishing activity patterns, or increase public concerns about pollution. If communication is only done after problems have arisen, technology will be seen as an industry interest that has no direct relationship with community needs.

3. Review and Criticism of Existing Approaches

The approach to subsea development has been largely oriented towards improving production and operating efficiency. The success of technology is often measured by the number of productions, reduced costs, or the ability to operate in the deeper seas. These measures are important to the industry, but they are not enough to describe sustainability as a whole [9].

One of the weaknesses of existing approaches is the tendency to place environmental monitoring as a complement to compliance. Environmental surveys are generally conducted before construction and at certain times during operations. This approach can miss changes that occur between survey periods. In fact, changes in water quality, sediment conditions, or habitat disturbances can occur slowly and only become known after the impact has increased [10].

Maintenance approaches are also often reactive or based on a fixed schedule. Equipment is inspected after a fault has occurred or followed a specific time interval without fully considering the risk level of each component [11]. This can cause high-risk components to be checked late, while low-risk components receive excessive attention.

Application risk-based inspection and condition-based maintenance has been an attempt to remedy the situation. The priority of inspections is determined based on the likelihood of failure and the consequences it causes. However, the quality of the results is highly dependent on the completeness of the data, the accuracy of the model, and the ability of experts. Where historical data is limited, risk assessment can rely too much on assumptions [12].

Digitalization, artificial intelligence, and technology digital twin It is also beginning to be used to predict the condition of facilities. Although it provides a great opportunity, this approach should not be considered a substitute for engineering assessments and field supervision [13]. Digital models can only provide good results if they obtain the right data. Model uncertainty, sensor interference, and cybersecurity threats must still be taken into account.

A more fundamental criticism is the notion that any environmental problem can be solved with technology. Technology is indeed capable of reducing risk, but it cannot justify activities that are carried out in the first place in highly sensitive locations or without clear boundaries of use. Sustainability requires decisions about what activities are worth doing, not just about how they are made more efficient.

4. The Author's Perspective or Argument

The authors are of the view that subsea technology should be placed as a tool to maintain a balance between utilization and protection of the ocean. The technology should not only be used to expand exploration areas, but also to ensure that every activity can be monitored, controlled, and accounted for [11].

First, the design of the subsea system needs to consider the entire life cycle of the facility. Planning should not stop at the installation and operation stages, but should include inspections, repairs, shutdowns, demolitions, and environmental restoration. Facilities that are difficult to inspect or dismantle can leave long-term problems, even if during their lifetime they are considered efficient [14].

Second, environmental monitoring needs to be an integral part of the operating system. Production sensors should be supported by environmental sensors that can detect changes in water quality, leaks, sediment conditions, or changes in the ecosystem around the facility. The data is not only useful for companies, but also for governments, researchers, and the public in assessing the impact of activities openly [15].

Third, the development of subsea technology must be followed by national capacity building. Universities can play a role in the research of corrosion-resistant materials, underwater robots, sensor systems, risk modeling, and data analysis. Industry can provide real needs as well as testing sites, while the government provides policy support, standards, and funding. This collaboration is important so that technology development does not stop at the use of products from abroad [16].

Fourth, coastal communities need to be involved as parties with direct interests. Information about development plans, potential risks, safety zones, and emergency handling measures must be clearly conveyed. Local knowledge from fishermen can also help identify changes in currents, seabed conditions, and ecosystem patterns that are not necessarily recorded through technical surveys [17].

Ultimately, sustainability is not only determined by the sophistication of the device. A system that is simple but can be maintained, monitored, and used consistently can be more beneficial than advanced systems that are expensive and difficult to operate. Therefore, the choice of technology must consider suitability for environmental conditions, user capabilities, availability of maintenance facilities, and the resulting social benefits [18].

5. Conclusion

Subsea technology has an important role to play in supporting the safer and more responsible use of marine resources. Underwater sensors, ROVs, AUVs, subsea production systems, and digital monitoring technology allow the condition of facilities and the environment to be better monitored. The technology also supports the development of offshore renewable energy, underwater infrastructure, marine observation, and carbon storage.

However, subsea technology is not a single solution to all marine utilization problems. An orientation that emphasizes production and efficiency too much can ignore ecosystem conditions, the interests of coastal communities, and long-term management capabilities. Digitalization and automation also still have limitations related to data quality, model uncertainty, cost, and labor competence.

Therefore, subsea technology needs to be developed through an approach that brings together engineering, environmental, social, and governance aspects. Continuous monitoring, risk-based inspections, community engagement, strengthening human resources, and facility lifecycle planning must be part of its development strategy. In this direction, subsea technology is not only a tool to extract resources from the sea, but also a means to keep its utilization safe, fair, and sustainable for future generations.

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