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Research Article

Innovations in Marine Biotechnology and Their Role in Advancing a Sustainable Blue Economy

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ABSTRACT

This study investigates marine biotechnology as an emerging technology to pursue a sustainable Blue Economy with regard to the innovation that drives growth in the economy and preserves the marine biodiversity. The research questions involve: how marine biotechnology can improve sustainable practices in the Blue Economy, its economic costs, ecological, and social impact, and policy framework to scale such innovations in coast and marine resources governance practices. The study is anchored on three theoretical frameworks that are Ecological Economics, Innovation Systems Theory, and the Sustainable Development Goals (SDGs). The set of frameworks can be used to obtain an insight of the equilibrium between environmental conservation and technological advancement in the marine sectors. The conclusion indicates that marine biotechnology is key in developing fresh hubs of economic activities, including drugs and sustainable aquaculture, besides alleviating environmental degradation via bioremediation and the preservation of biodiversity. Nevertheless, issues of technology constraints, gaps in regulations and ethics of bioprospecting and genetic modification still exist. As part of advancing its potential value to sustainable development, the study suggests an improvement in policy frames, increased international partnerships as well as the adoption of ethical principles in the application of marine biotechnology. This study highlights a multi-action set of measures to enhance the sustainable exploitation of the marine sources, with some hints on possible outcomes of marine biotechnology in going forward with the Blue Economy.

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Introduction

Blue Economy is used to signify sustainable exploitation of ocean resources to achieve economic growth, better livelihoods, and employment creation without destroying the health of ocean ecosystems (OECD, 2016). With the world population and industrial activities steadily increasing, Blue Economy has become an essential part of the process of the sustainable development. Marine affects have immense economic potential such as; fisheries, aquaculture, renewable ocean energy as well as marine biotechnology. Actually, it is expected that the worldwide ocean economy will reach USD 3 trillion in 2030 (World Bank, 2017). Efficient exploitation of these resources plays a vital role in striking the Golden Mean between economic progress and steering of the environment because short-sighted exploitation has caused such problems as overfishing, air and water pollution, habitat degradation, and others (Bennett et al., 2019). The blue economy can be used to drive the need of long-term prosperity and the sustainability of marine ecosystems via sustainable practices.

Marine biotechnology is the application of marine resources and organisms to biotechnology; such resources can be used in pharmaceutical, biofuels, food, and environmental products (Aftab et al., 2020). Blue Economy is already benefiting tremendously due to the innovations in the area, such as sustainable aquaculture, bio-prospecting of new medicines, and environmental remediation (Goncalves et al., 2021). The emerging significance of marine biotechnology is based on its capacity in solving very dangerous environmental and economic problems. As a working example, marine organisms have demonstrated abilities in the bioactive compounds to treat diseases, and produce less environmentally unfriendly materials. Marine biotechnology in the Blue Economy is not only an activity aimed at promoting economic activities; it is a sustainable resource management tool promoting the maintenance of biodiversity and marine ecosystems (Ramirez et al., 2020).

Marine biotechnology is now one of the drivers of life sciences innovation. The marine bioresources algae, fish, and microorganisms are becoming more known in several fields, particularly in the pharmaceutical, food, and energy sectors, globally (Goncalves et al., 2021). After the improvement of genetic engineering and bioprocessing technologies, marine biotechnology is facilitating the emergence of sustainable alternatives to terrestrial resources (Aftab et al., 2020).

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Remarkably, Norway, the United States, and Japan conduct extensive research and development investments to make use of economic and ecological opportunities of marine biotechnology (OECD, 2016). The rise in the global demand in sustainable products guarantees marine biotechnology a significant role in the implementation of the Blue Economy goals, specifically creating new bio-based products with no detrimental effect on marine ecosystems.

This paper will help reveal the role of marine biotechnology in the development of sustainability in the Blue Economy. It will give details of the innovations in biotechnology to give a clue on how to exploit the technologies to enhance management of marine ecosystems, biodiversity and the management of the resources.

This research study will provide policy recommendations to include the marine biotechnology within the national and international Blue Economy policies. The trend in the world to pay more attention to the development of sustainability should be understood that policies advancing marine biotechnology may contributes to the more efficient exploitation of marine resources and conservation (OECD, 2016). This will play an important role in advising coastal countries on how to manage their resources in the sea in a sustainable way yet develop their economy.

Theoretical Framework

Ecological economics is the field of knowledge that gives detailed views of the relations between the economic frameworks and the environment that refers to the norms of sustainability and integration of environmental principles into economic decisions (Daly & Farley, 2011). Marine biotechnology as any field that exploits marine resources namely for any purpose has to conform to the values of ecological economics which promotes the sustainable management of materials and long-term ecological degradation as well as that economic development should not be at the cost of the environment. This particular point of view places an emphasis on the importance of appreciating the value of ecosystem services and acknowledging the inseparable nature of the state of the marine eco-systems and prosperity. Marine biotechnology developments, including bio-remediation, sustainable aquaculture, and marine pharmaceuticals, have the potential to be important in balancing the desired balance of economic input and ecosystem conservation (Goncalves et al., 2021). Evaluation of marine biotechnology inventions based on policy of ecological economics will allow the assessment of not only their economic advantages, but also their contribution to conservation of marine biodiversity in the long-term environmental sustainability.

Innovation Systems Theory (IST) has underlined the role of networks and organizational systems such as research establishments, industries and policymakers in promoting technological progress and in dealing with social provisions (Lundvall, 1992). IST can be used in the framework of marine biotechnology to identify the ways in which various players can cooperate in the process of enhancing R&D, introducing technology transfer as well as creating new solutions. The marine biotechnology connects several disciplines, biotechnology, marine, environmental management, and industry. The following recognition of the way innovation systems operate can be used to promote the understanding of how research institutions, private companies, and government bodies could collaborate to promote the commercialization of projects based on biotechnology dealing with the sea. Of particular interest is the role of intellectual property rights, regulation systems and policy interventions on the occurrence and dissemination of marine biotechnology innovations (Goncalves et al., 2021). The theory throws some light on the innovation ecosystem in the marine biotechnology industry and the dynamics involved that facilitate or impede technological innovation as well as the replication of sustainable activities in Blue Economy.

The Sustainable Development Goals (SDGs) offer sustainable goals on a worldwide scale to accomplish long-term sustainability in terms of economy, social, and environmental levels. Marine biotechnology contributes greatly to the establishment of several SDGs, specifically, SDG 14 (Life Below Water), SDG 8 (Decent Work and Economic Growth), and SDG 12 (Responsible Consumption and Production) (United Nations, 2015). Marine biotechnological innovations will help achieve the SDG 14 through providing long-term solutions to marine preservation, including the creation of marine-protective zones, environmentally-friendly aquaculture systems, and the recovery of impoverished sea life. SDG 8 is also provided by marine biotechnology, as it leads to the establishment of sustainable industries and employment opportunities in the marine biotechnology sector. Moreover, the marine biotechnology adheres to SDG 12, as its use supports lawful consumption and production trends in the Blue Economy through the production of bio-based goods and development of renewable marine sources. The given theoretical lens points out the multidimensional nature of marine biotechnology in the scope of accomplishing the global sustainability agenda and emphasizes that the multi-faceted yet balanced approach (economic growth/environmental care) should be implemented.

Literature Review

Marine Biotechnology and the Blue Economy

Marine biotechnology is defined as the technique of harnessing marine sources and their products in technological, pharmaceutical, agricultural and environmental employment. The sector also exploits the immense diversity of the marine life consisting of microorganisms, plants, and animals to come up with useful products that improve the human society, which include biofuels, pharmaceuticals, and food production that is sustainable (Goncalves et al., 2021). Marine biotechnology is also often acknowledged as an indispensable source of the sustainable Blue Economy, where the potential of marine resources is still to be harnessed without hampering their long-term health and sustainability (Bennett a et al., 2019). The field of marine biotechnological innovation can offer solutions that can match the economic growth to take care of the environment through the exploitation of the genetic potential of marine organisms.

The economic potential of marine biotechnology is strong, and has spawned new industries in pharmaceutical production, nutraceutical production and sustainable aquaculture. As an example, compounds of marine organisms have become a considerable source of novel drug discovery (particularly involving cancer), known as bioactive compounds (Goncalves et al., 2021). Also, marine biotechnology can offer a promising solution to the expansion of more effective, and sustainable aquaculture practices, which is the route forward to address the intensifying food demand of seafood in the resource-limited world (Bennett et al., 2019). It is anticipated that the sector will create new jobs, improve food security and promote coastal economy.

The importance of marine biotechnology in the reduction of environmental degradation and ensuring of the sustainable usage of marine resources as well cannot be ignored. One of these areas is bioremediation, or the application of marine microbes to cover oil spills or heavy metals (Muller et al., 2020). Moreover, marine biotechnology ensures greater sustainability as it farms and promotes eco-friendly methods of mariculture to support, and as a result, it reduces pressure on the wild fish population, restoration

and conservation of the marine ecosystem (Goncalves et al., 2021).

Innovations in Marine Biotechnology

Genetic engineering has been very crucial in the evolution of marine biotechnology. Genetic modification of marine organisms has enabled researchers to improve such traits as growth rate, disease resistance and nutrient uptake in aquaculture species (Goncalves et al., 2021). Moreover, ocean algae and bacteria genetic engineering have a promising future in biofuels and bio-based chemicals synthesis and therefore utilize other eco-friendly materials (Santos et al., 2020). These innovations are very promising, but they give rise to some concerns regarding environmental effects of introducing genetically modified organism into the marine environment.

Marine biotechnology has focussed heavily on bioprospecting marine organisms as a source of new compounds of medical, industrial and nutritional uses. Marine life, and the extreme life in particular, provides scarce compounds that have potential therapeutic applications, including cancer-fighting and anti-inflammatory ones (Santos et al., 2020). Marine-derived enzymes are also applied in most industries such as food processing and environmental recovery. This potential has already proven the existence of bioactive compounds in the marine biodiversity, which has been continually being found.

The reason why marine microorganisms are major players in terms of biotechnology is because it is able to withstand and adapt to extreme environmental conditions i.e., high salinity, high pressure and temperature. These microorganisms can have useful purposes through, e.g., bioremediation in the marine environment where they degrade pollutants, especially heavy metals and hydrocarbons (Muller et al., 2020). Besides, marine microorganisms have been explored as source of producing bio-based products including biodegradable plastics and other forms of energy such as biofuels.

Challenges and Risks in Marine Biotechnology

Though marine biotechnology is promising, a lot of ecological, as well as ethical issues, are associated with it. Of primary concern is the possibility of genetic contamination of native populations as the result of releasing genetically altered organisms (GMOs) into the environment. This may include the side effects of losing biodiversity, shifting of ecosystem functions, and transfer of the genetically modified characteristics of wild species (Bennett et al., 2019). There is also an ethical aspect associated with bioprospecting: there is the question of genetic resources ownership and the equitable sharing of the benefits arising on the use of marine living things (Tvedt, 2017).

There exist technological constraints to scaling-up marine biotechnology breakthroughs despite great achievements. These are the exorbitant cost of research and development, fewer access to marine genetic resources and difficulty in commercializing products based on marine resources (Muller et al., 2020). Moreover, lots of organisms can't be easily planted or mined in big quality making biotechnology-based demands rather hard to satisfy. Solutions to these barriers involve conducting more studies to find out the economically viable ways of mass production on a sustainable basis.

Policy and Regulatory Frameworks

Marine biotechnology is in a complex regulatory regime with international and even regional frameworks that have been employed to regulate its utilization. The Convention on Biological Diversity (CBD) and the Nagoya Protocol are helpful in governing access to the genetic resources and sharing the benefits of the resources with communities and nations where they originate (Tvedt, 2017). The role of the regional policy is important as well since bigger marine states establish their regional regulatory practices to facilitate marine biotechnology and encourage sure marine biotechnology preservation.

Alongside policy frameworks, the ethical concern is the focus of marine biotechnology development. Regulations like the Cartagena Protocol on Biosafety, which deals with the safe treatment, transport, and usage of genetically modified species, play a significant role in facilitating the fact that the marine biotechnology innovations do not affect the ecosystems or human health negatively. Moreover, ethics involved in bioprospecting are observed, so that the advantages of marine genetic resources will be distributed and that the traditional knowledge of the locals can be treated with respect (Tvedt, 2017).

Empirical Review

Roe et al. (2020) presents an empirical study identifying the use of genetic engineering with the aim of enhancing the productivity and disease resistance of aquaculture marine species. The study is based on genetically modified (GM) salmon and its effects on the growth rates, health and environmental sustainability in relation to traditional fish farming methods.

The research indicates that they genetically modified the salmon and the growth and resistance to diseases have increased substantially implying the salmon is giving a high yield in aquaculture production. Moreover, GM salmon decreased the necessity to use antibiotics, which decreased the environmental impact of fish farming (Roe et al., 2020). Nevertheless, the eventual ecological hazards of genetically modified organisms (gmo) in open seas were raised particularly the gene flow to wild organisms.

This paper highlights that the marine biotechnology especially genetic engineering has the prospect of improving the level of production of the aquaculture and tackling some of the issues of overfishing and degrading of the marine environment. Nonetheless, regulation systems must be introduced to avoid ecological hazards (Roe et al., 2020).

According to the study conducted by Martin et al. (2019), the researchers analyze the application of marine bioprospecting as the method of identifying new bioactive compounds produced by marine organisms including sponges and algae. Emphasis is laid on pharmaceutical use of these drugs, viz., and anti-cancer and anti-inflammatory drugs.

The study recognizes a number of the bioactive constituents of the marine organism, which have encouraging anti-cancer potentials. "Halichondrin B", a compound extracted by marines' sponge Halichondria, showed both distinction and ability in suppressing the proliferation of cancer cells. Moreover, the researchers observed that, unlike traditional pharmaceutical options, marine-derived substances had less side effect (Martin et al., 2019).

Bioprospecting in the marine industry can benefit the economy of pharmaceutical sectors and advance the Blue Economy to a sustainable utilization of the marine resources in the development of effective medical solutions. Such an industry does not only help healthcare but enhances biodiversity conservation due to giving incentives to guard marine ecosystems (Martin et al., 2019).

In response to the risk of olefin biodegradation, Hoffman et al. (2021) focus an empirical study on the bioremediation potential of marine microorganisms using the success of the marine bacteria that metabolize pollution, including oil and heavy metals, in marine locations. The research looks at the case studies of the Gulf of Mexico after the Deepwater horizon oil spill.

This study shows that there are certain marine bacteria, which can degrade hydrocarbons successfully and these bacteria evolve under limbic conditions. Furthermore, the study also shows how these microorganisms can be used to restore marine habitats polluted that have been damaged through the process of biodegrading pollutants into less toxic elements (Hoffman et al., 2021). The paper has also mentioned the difficulty in optimization of the bioremediation process which requires particular environmental conditions to boost the activity of microbes.

The science of marine microbial biotechnology is huge in overcoming the environmental issues of the Blue Economy, including the problem of oil pollution and heavy metal pollution. The technology enhances natural cleaning systems found in marine environment thus promoting marine habitat health as well as providing a green solution to other cleaning techniques (Hoffman et al., 2021).

Lopes-Correa et al. (2020) have developed an empirical study to evaluate ethical and ecological issues linked to marine biotechnology and especially such aspects as the utilization of genetically modified organisms (GMOs) and bioprospecting practices in the marine environment. The paper was founded on the studies that involved questionnaires and interviews of marine biotechnologists, conservationists and policymakers.

The paper established that most of the respondents raised issues regarding the environmental hazards posed by altering ecology when GMOs are introduced to the natural marine environments and where they may possibly transfer genes into the natural fish populations. Also, the concerns of commercialization of the marine genetic resources without fair sharing were expressed concerning ethics (Lopez-Correa et al., 2020). This study points out that more regulation against scientific usage, international ethical guidelines and cultivation of marine biotechnology is required to the sustainability and equitable utilisation of marine technology.

According to the study, even though marine biotechnology holds great potential to benefit the Blue Economy, its cultivation should be highly supervised so as to reduce ecological risks and well-balanced distribution of benefits. To preserve the diversity in the ocean in balance with biotechnology innovations, it is necessary to maintain solid ethical and regulatory frameworks (Lopez-Correa et al., 2020).

Discussion of Major Findings

Marine biotechnology has played a great role on building the economy of coastal areas by both the introduction of new industries and diversification of ongoing economy. New opportunities to work in new industries, such as aquaculture, pharmaceuticals and bioprospecting become available as machinery of these industries becomes introduced and aquaculture especially in coastal regions where traditional industries like fishing are losing value. As an example, in Norway and Iceland, genetically modified organism (GMO) development of aquaculture has enhanced local economies due to high productivity and production in seafood, resulting in the emergence of new jobs and export activity (Bjordal et al., 2022). In the same way, marine bioactive compounds bioprospecting has boosted biopharmaceutical industries, which are part of the local economy, thereby leading to investments (Martin et al., 2019).

More so, marine biotechnology is also assisting in the diversification of the blue economy by mixing sustainable practices and economic development, supporting the exploitation of marine bio-resources into the generation of renewable energy in the form of algae-derived biofuels (Hoffman et al., 2021). These innovations contribute to economic sustainability since they lessen dependence on the non-renewable resources.

The implications of marine biotechnology on the environment are two-fold offering both a positive and a negative implication to marine environments. Biotechnology innovations, on the positive side, can be very instrumental in terms of conservation of the environment. As such, bioremediation processes whereby marine microorganisms are utilized to break down pollutants including oil components, and heavy metals present have been shown to hold a lot of potential in the cleanup of polluted marine ecosystems (Hoffman et al., 2021). This will assist in returning the ecosystems that are polluted to become habitable again thus supporting the biodiversity and allowing a sustainable exploitation of marine resources.

But what draws concern are the adverse environmental effects of some of these applications of biotechnology, mostly the applications of genetically modified organisms (GMOs) in the ocean. It is also a possibility that GMOs will destabilize ecosystems in the region(s) by hybridizing with wild arenas, which may have unintended outcomes that result in genetic pollution or species shortage (Lopez-Correa et al., 2020). Moreover, intensive fish farming, not even excluding genetically modified species, can lead to destruction of habitat and population pressure of local fish species.

To sum up, marine biotechnology is a hopeful solution in relation to protecting the environment; yet, it requires to be well managed and regulated to reduce ecological risk (Roe et al., 2020).

Challenges and Barriers to Advancement

Although marine biotechnology may experience tremendous role with regard to the breakthroughs, the aspect of technological constraints is still a critical step towards its widespread implementation. The high cost of research and development (R&D) of marine biotechnology products is one of the main challenges as it may be extremely high. The creation of genetically modified organisms to be used in aquaculture or marine microbial groups to be used in treating the environment are some of the examples that need advanced technology and test using (Bjordal et al., 2022). Moreover, scaling of such technologies may encounter technical challenges associated with the complex nautical environment, e.g., an ability to achieve the favourable conditions of biotechnological process, particularly in the offshore context (Hoffman et al., 2021).

The high production cost coupled with inadequate infrastructure as well as specialized know-how in marine biology and genetic engineering also impede the commercial scalability of the marine biotechnology innovations. These aspects may inhibit the competency of small- and medium-sized enterprises (SMEs) to proceed with the biotechnology area, which restricts innovations and the use of these technologies in numerous coastal communities (Lopez-Correa et al., 2020).

The other critical issue that affects the progress of marine biotechnology is the influx of its proper and standardised regulatory systems both nationally and internationally. Creating or setting new laws remains a challenge because the existing ones are outdated or cannot effectively regard marine biotechnology unique issues, including ethical implications of genetic modification of marine organisms and accessibility to marine genetic elements. Also, the legal regulations concerning intellectual property (IP), particularly with regards to bioprospecting, vary according to the region and thus may give rise to disputes regarding the rights of ownership of marine genetic resources and biotechnological breakthroughs (Lopez-Correa et al., 2020).

Also, relations between countries in marine biotechnology research and development are hampered by national policies existing in various countries some are more prone to biotech start-

ups than others whose regulation policies are so much restrictive that they can bar any innovative procedures. It requires a more integrated international system to bring every aspect into this situation and to enable marine biotechnology to progress in the way that is anchored at the benefit of all the stakeholders with protection of marine ecosystems (Bjordal et al., 2022).

Finally, it will be important to address technological, financial, and regulatory obstacles to accessing the full benefits of marine biotechnology and making sure that its use will deliver sustainable and inclusive Blue Economy.

Gaps in Literature Review

Although much has been cited about the technology and ecological topographical impact of marine biotechnology, very less has been written on its socio-economic consequences especially in the coastal areas that are rather traditional in terms of their application as in the case of the fishing industry. The possibilities of marine biotechnology in making the job sustainable, increasing food security, and sustaining economic diversification have not been discussed in detail (Hoffman et al., 2021). There is need to carry further research about the effect by the biotechnology creating industries like the aquaculture and the biopharmaceuticals on the local communities whose economies are largely affected by their existence.

Though there have been well-recognized environmental advantages of marine biotechnology as in the case of bioremediation, the lengthy ecological issues are not clearly examined. Studies rarely explore the unanticipated outcome of mass use of genetically modified organisms (GMOs) or the impacts it might have on marine ecosystem due to biotechnological interventions (Lopez-Correa et al., 2020). Long-term, detailed ecological surveillance and evaluation is essential to establish the building impact of biotechnology on marine biodiversity and ecosystem service.

Marine biotechnology brings together two or more sciences such as marine biology, genetics, environmental science, and economics. Nonetheless, literature on these disciplines fails in many instances to provide integrated work. The cross-cutting, interdisciplinary perspective to the issue, namely how innovations in marine biotechnology can be used to accelerate economic development, preservation, and conservation of the environment, and social welfare must be adopted (Bjordal et al., 2022). Such disparity also highlights the need of cross-field cooperation to realize the potential of marine biotechnology in sustainable blue economies.

Although there are studies on the national level detailing policies regarding marine biotechnology, the gaps remain in terms of comparisons between countries and regions looking at whether marine biotechnology is regulated and how governance assists marine biotechnology. As an illustration, what is the situation in the countries such as Norway, South Korea and Canada in terms of their regulations and their investment in such a field as marine biotechnology research? By developing comparative policy studies, policy-makers could gain insights into best practices, discover the gaps in their current policies, and collaborate with international organizations to facilitate better development of the marine biotechnologies field (Bjordal et al., 2022; Martin et al., 2019).

The underscoring demand in the literature is on the lack of attention to the obstacles to scaling up marine biotechnology discoveries to trial-level and large-scale commercialization. Although technology is as far as some people get, is expensive, and there is not enough infrastructure in place, not many studies dwell on how to overcome these challenge factors. The barriers should be addressed by studying the ways to eliminate them, including finding cost-effective production technologies, enhancing infrastructure, and facilitating the cooperation of the private industry, governments, and research institutions to make innovations scalable (Lopez-Correa et al., 2020).

Summary

This paper on Innovations in Marine Biotechnology and Their Role in Promoting a Sustainable Blue Economy has covered the valuable input of marine biotechnology in terms of creating a sustainable economic growth, protection of the environment and in upholding marine resource management. Major importance to the development of the Blue Economy is the marine biotechnology that aims at the use of the natural processes of marine life as a source of products and solutions to solve more problems and economic diversification creating new markets such as pharmaceuticals as well as focusing on the major problem of overfishing and pollution of seas.

In this study, technological innovation in marine biotechnology which entails genetic engineering, bioprospecting and microbial biotechnology have proved to be a significant field where innovations have altered marine sectors. There are though setbacks especially when it comes to expanding these innovations, making regulations robust and sorting through ecological and ethical consequences of the application of biotechnology. Along with it, the research revealed the fact that marine biotechnology can have a considerable effect on both economic and environmental performance; however, the development of this technology is impeded by technological, financial, and policy-related challenges.

Conclusion

This provides a huge potential in marine biotechnologies to sustain economic development and preservation of marine biosity, which is at the core of a sustainable Blue Economy. The possibility to exploit marine resources in environmentally harmless ways which could not have been done previously due to innovations in that sphere are currently opening up. Nevertheless, there are a number of challenges which should be encountered so that the potential of marine biotechnology could be fully exploited. These are multiple technological and financial challenges to the large-scale adoption, stronger regulatory regimes and more policies, and more research concerning the long-term ecological consequences of biotechnology applications in the marine environment.

The study notes that in as much as marine biotechnology is vital in the realization of the Blue Economy sustainability, a multi-stakeholder approach which brings governments, industry, and research institutions to bear together is important in surmounting these challenges. Moreover, government should incorporate marine biotechnology in their green agendas to ensure that it is utilized to the maximum in marine conservation, development, and economy.

Recommendations

Both governments and private industries need to develop stronger partnerships, so that the innovations in marine biotechnology could be commercialized. Research, development, and widespread use of biotechnology products can be promoted under the activities of the public-private partnership and be economically viable and sustainable.

Policy makers should establish and enact regulatory policies that capture environmental, ethical, as well as socio-economic effects of marine biotechnology. Such plans ought to incorporate formulas to lessen ecological hazards, shield biodiversity, and guarantee moral bio-prospecting and gene adjustment rehearses.

Marine biotechnology research and development will have to be boosted in order to break the bottleneck in technology and enable innovations that could be scaled up to generate business. This comprises the implementation of more economical manufacturing techniques, enhancement of infrastructure in biotechnology, and enhancement of process in biotechnology treatment in gaining control of marine resources.

To evaluate the ecological effects of the implementation of the biotechnology in the sea, the governments and research facilities should develop long term monitoring systems. The programs must be monitored to keep their records of biodiversity in our ecosystems, the good health of the ecosystems in the seas, and sustainability of biotechnological approaches to providing solutions to marine ecosystems.

Marine biotechnology is a discipline that needs cooperation between several fields of science. It is advisable that there should be interdisciplinary studies involving marine biology, environmental science, economics and technology by the academic institutions and research centers to ensure that the maximum output of biotechnology is utilized within the Blue Economy.

Capacity building activities should be established so that the coastal residents get the opportunity to be educated and trained on matters related to biotechnology so that the local populations can enjoy the fruits of marine biotechnology. Such programs will go beyond providing new jobs to society but will develop the capacity of the marine biotechnology applications through knowledge and skills.

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