Environmental Impacts of Offshore Geothermal Energy

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ABSTRACT

Offshore Geothermal Energy can be considered as a non-polluting source of renewable energy, in relation to harmful emissions that are associated with burning fossil fuels to generate electricity. The geothermal brines of the mid-ocean ridge hydrothermal vents are believed to be potential sources of offshore geothermal energy. These fluids represent one of the most abundant energy resources worldwide, due to their enormous quantity, infinite recharge, and high temperatures. However, all forms of electricity generation impact the environment in some way. The ecological and biological importance of the vents restricts the number of areas that can be utilized to produce electricity.

Most of the marine areas with these vents are benefitted with some form of protection. Most of them are included in the networks of marine protected areas (MPAs), which stands as the foundation of marine conservation policies. While most of the scientific studies focused on quantifying the exploitable energy from the hydrothermal vents, the environmental impacts of harvesting the energy from these vents have not been explored till date and remained unanswered. For the offshore geothermal energy to develop, the uncertainties about the effects

on the marine environment must be assessed. Therefore, this study attempts to assess the potential environmental impacts using the MOHID framework of hydrodynamic modelling along with some personal views and assumptions from various studies.

This is the first of its kind of study in the offshore geothermal energy production, and the results demonstrate the marine ecological footprint that could quantify the impact on the marine environment by exploiting hydrothermal vents for energy production.

1. Introduction

Oceans yield a wide range of vital supplies to the humanity, including energy, minerals, food, life fulfilling conditions and life-supporting processes. The natural capital (oceans) is often referred as the key drivers that support the smart, sustainable, and inclusive growth of the global economies. Renewable energy is one of the vast resources that oceans could provide to meet the needs of today's society along with promoting sustainability. Ocean energy technologies are rapidly advancing to exploit the offshore energy potential (Ocean Energy, 2016). The significant sources of ocean energy include wind, tides, waves, OTEC and offshore geothermal.

Geothermal energy has been utilised on land for over a century. The world´s geothermal resources have the potential to be one of the most significant sustainable energy options. Offshore geothermal energy has remained highly underdeveloped energy resource with massive potential. With rising energy prices and increased knowledge of geothermal utilisation, the idea of developing and using offshore geothermal energy becomes increasingly attractive. The baseload characteristic of geothermal energy makes it more promising and competing with baseload feedstocks.

Unlike the Inland resources, the offshores constitutes significant quantity and quality of resources, provided with readymade challenges for exploitation. The complexity increases with the located depth and region of the resources. As discussed in the biogeographic theory, species richness increases with habitat area, and the oceans cover 71% of the Earth's surface (Costello et al, 2017). The oceanic zone is subdivided into the epipelagic, mesopelagic, and bathypelagic zones. Oceanic zones (see fig 1) harbour a wide range and diversity of species that are zone specific, making it complicated and susceptible to exploit the resources.

The ocean floor and its bathymetry are mostly a result of the plate tectonics. The ocean basins are decorated with several features that include the mountainous ocean ridges, deep-sea trenches, linear fracture zones. Other essential characteristics of the ocean floor include aseismic ridges, abyssal hills, and guyots. The seamounts associated with spreading centres, mid-ocean ridges and the hotspots are significant for geothermal energy prospecting. These resources are of profound interest to several entities and researchers. The examples include the proposed Italy's offshore geothermal energy project of the Marsili Volcanic Seamount (Southern Tyrrhenian Sea) (Italiano et al, 2014); Hydrothermal Vents and Energy Generation (Hiriart et al, 2010); the study on offshore energy and metal production from geothermal brines of Portugal (Pedamallu et al, 2017). It is an undeniable fact that many of these offshore geothermal resources are mostly associated with the seamounts, which constitutes the least understood habitats on the planet.

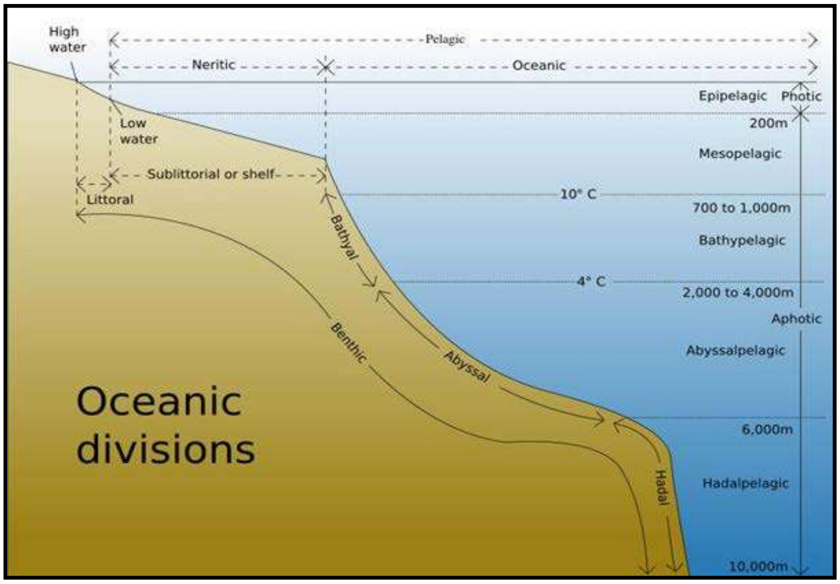

Figure 1: Oceanic Zones, (Brighthub, 2013)

In conjunction with the early stages of development and rapidly growing interests on offshore geothermal energy exploitation, research is needed to determine the associated environmental impacts. The development of environmental impact assessments frameworks for offshore geothermal energy exploitation would benefit various entities in overcoming the critical environmental barriers to establish marine, geothermal energy projects. The purpose of this report is to identify and determine the impacts of offshore geothermal energy exploitation using the MOHID framework of hydrodynamic modelling.

2. Seamounts and Their Characteristics

The seamounts possess a volcanic origin that are related with spreading centres, mid-ocean ridges and the hotspots. The primary factors that control the formations include the chemistry, depth, age of seafloor and the proximity areas of upwelling mantle. These are the most ubiquitous landforms on earth and are present in the uneven densities in all the oceans basins. They represent a significant fraction of 5-10% of the volcanic extrusive budget. Many seamounts have an active hydrothermal convective system that may have remarkable effects on the cycle of the elements involving seawater (Wessel, 2007). The seamounts participate in the dissipation of residual heat from the formation of both seafloor and seamount (Harris et al, 2004). Among the three categories of seamounts (intraplate, mid-ocean ridge and island arc) that are located at greater depth, and the ecological role of this seamounts are poorly understood (Pitcher et al, 2008). The seamounts are also of profound interests to several entities for the geological, oceanographical, biological and mining procurements.

Seamounts are one of the least understood habitats on the planet. They are believed to be very important "Way Stations" for many migratory species (fish, cetaceans, seabirds, and cephalopods). Most seamount fish, corals, & sponges are very long-lived making their recovery slow and hence any possible impacts on seamounts raises serious concerns. Representing the obstacles of flow, the seamounts stimulate local currents to increase upwelling. This may bring up nutrients from the deep ocean and enhance primary productivity supporting a wide variety of life (Rogers, 1994). On the other hand, most of these are benefitted with some form of protection, making it more complicated for resource exploitation. Therefore, for the offshore geothermal energy to become a reality, the uncertainties about the environmental impacts should be assessed.

3. Marine Renewables – Their Impacts, Frameworks & Legislation

As defined by the (UNEP, 2002), impact assessments are made to identify the environmental, social, and economic impacts of a project before decision-making. Impact assessment is a process of examining the anticipated environmental effects of a proposed project or development considering their inter-related socio-economic, cultural, and human-health impacts, both beneficial and conflicting. The environmental impact assessment of marine energy projects is a process that should be carried out by the project developers to inform the stakeholders and regulatory bodies in their assessment and decision making from concept to decommissioning (Ingram, 2011).

3.1 Tools and Frameworks of Assessment

Many legal frameworks exist for evaluating impacts at different levels of a project, the widely adapted frameworks of assessment include the *Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA), Environmental Risk Assessment (ERA) and Life Cycle Assessment (LCA)*. Both EIA and SEA are legal tools used for the impact assessments at different levels of a project. SEA is a recently established mechanism for identifying and assessing the likely significant effects of a project and its alternatives. EIA is a traditional approach to assess impacts. SEA considers the cumulative effects of a project and EIA refers to direct and indirect effects of the project. Though both EIA and SEA share the common roots of impact assessment, the difference is due to their focal point of assessment.

The environmental risk assessment (ERA) tool is a well-established tool for management for dealing with uncertainty. It is used to determine the environmental and health-related problems connected to several activities and substances; technological assessments or to determine the effectiveness of different control and mitigation techniques designed to reduce risks etc., (Cohrssen et al, 1989) whereas the LCA is used to determine the cumulative environmental impacts resulting from the product lifecycle from the stages of cradle to grave (ISO, 2006). In contrast to the different legislation and practice around the globe, the principal components of EIA would fundamentally involve the following phases as shown in Figure 2.

Screening and scoping studies inform the entities regarding the associated environmental impacts of the project. The subsequent phase is to extend this analysis throughout the assessment of the potential impacts scale. The impact analysis is composed of three main levels that include, identification, valuation, and significance (Ingram, 2011). Several standard tools exist for the assessment such as checklists, matrices, mathematical/statistical model, Maps, and GIS. The end product of the valuation of impacts could be qualitative and quantitative. According to the habitats directive, an appropriate assessment is required for projects that are likely to have significant effects on any of the Natura sites (Special Protected Areas, Special Areas of Conservation in Europe). It is usually at the scoping phase of a study that the requirement for an appropriate assessment is determined.

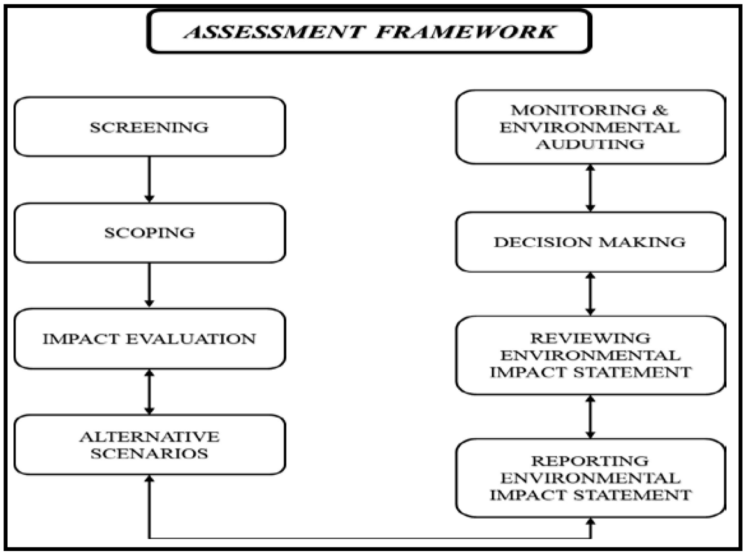

Figure 2: Generalized framework of impact assessment

3.2 Classification of Marine Energy Impacts

Environmental impacts associated with marine energy harvesting can be classified into three categories, the first impact relates to the interaction of aquatic animals with the marine energy technology (Clark et al, 2009). It possesses a significant threat to the animals colliding with the ocean energy devices. The devices could affect the natural movements or migration patterns of the animals. The second category impact correlates to the noise disturbance generated from ocean energy devices in the subsea; this could profoundly influence the behaviour of marine animals, like whales, dolphins, seals, sea turtles, and migratory fish. The impact is due to the characteristic quality of the marine animals to use underwater sound for communication and navigation. Therefore, any ambient noise underwater can affect their ability to perform these functions (Copping et al, 2014). The final category of impacts is associated with the construction/installation, operation, and maintenance phases of ocean energy devices. This is due to the obstruction and disturbance in the natural moments of ocean currents and energy removal from the natural flow of water (ex – wave energy, tidal energy).

The further categories of impacts could also include the EMF (electromagnetic fields) generated from the cables, impacts of flux regime modifications (hydrothermal fluids) loss of habitat, degradation of habitat quality, light-induced impacts, decreased productivity, decreased local diversity, changes in community structure, loss of larvae, visual landscape and seascape impacts, marine uses like navigation, fishing, cultural heritage, recreation etc., The environmental impacts associated with marine energy harvesting is predominantly technology specific, locationspecific, depth-specific, structure-specific (above the surface, in the water column, on the seabed).

4. Generating Power Using Offshore Geothermal Resources

The generation of electricity using geothermal energy employs technology that is fundamentally identical to most other power generating facilities. Specifically, an electrical generator is powered by a turbine that converts thermal or kinetic energy into electricity. Though there exist several sources, the geothermal energy exploitation from the seamounts and hydrothermal vents has gained more importance in recent years due to the ready accessibility of the resources. The focus on the exploration of the offshore geothermal energy from the hydrothermal fluids has highly increased due to its higher temperature potential and ready accessibility.

Even though the inland geothermal power generation technology is widely developed, the offshore geothermal technology is still conceptual. Few examples include, the proposed submerged binary plant (Hiriart et al, 2010); the concept from the Marsili project in which the offshore wells will be connected, through an appropriate thermodynamic cycle, to steam turbines that together with condenser system, power generators and transformers that will be hosted on a platform suitably built (Armani et al, 2013) and few others as shown in the figure below, the conceptual technologies constitute different principles of exploitation, all using the hydrothermal fluid that is venting at the hydrothermal vents and from drilling deep into the seamounts. Both the seamounts and the hydrothermal vents are considered environmentally sensitive areas and any human activity in these locations could significantly impact the biodiversity. Hence a deeper understanding of the exploitation activities in these regions is essential.

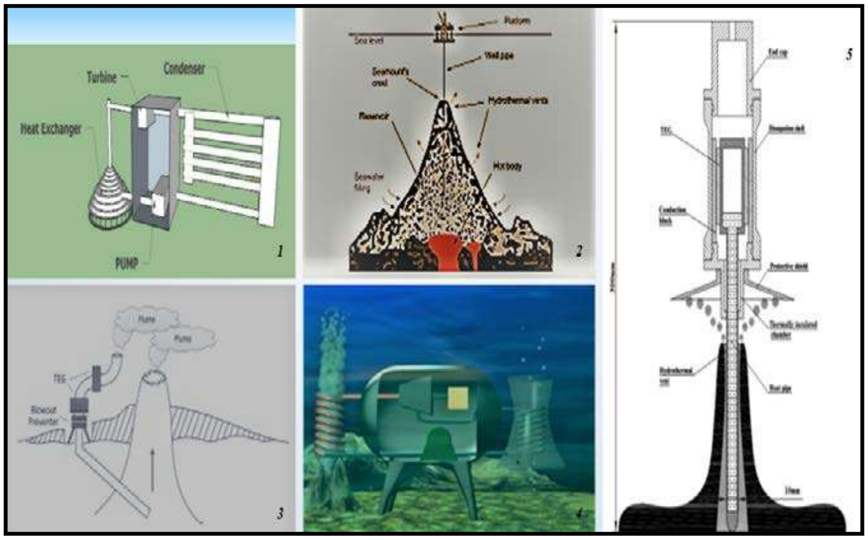

Figure 3: Conceptual technologies for offshore geothermal energy harvesting – (1. Aryadi et al, 2016); (2. Armani et al,2013); (3. Parada et al, 2012); (4. Hiriart et al, 2010); (5. Xie et al, 2016).

5. MOHID Hydrodynamic Modelling for EIA

MOHID is a three-dimensional hydrodynamic modelling system, developed at the MARETEC (Marine and Environmental Technology Research Center) at Instituto Superior Técnico (IST) from the University of Lisbon, Portugal. It has been applied in many studies related to coastal and estuarine areas, oceanic processes, and reservoirs, and has proven to be capable of simulating complex features of the flows.

The framework of modelling is as presented in Figure 4. As explained previously, most of the technologies are aimed at utilizing the hydrothermal fluids fuming out from the vents. These hydrothermal fluids support a wide range of biodiversity and considered the only source of sustenance for the chemosynthetic animals that are spread among the vent field, these chemoautotrophs are the base of the food web (Van Dover, 2014). Vent-associated organisms are resilient to a variety of natural disturbances like tidal variations to earthquakes. However, the human-induced impacts could be fatal to the ecosystem. Specifically, changes in the fluid concentrations could show large-scale impacts like loss of habitat, degradation of habitat quality and even species extinction.

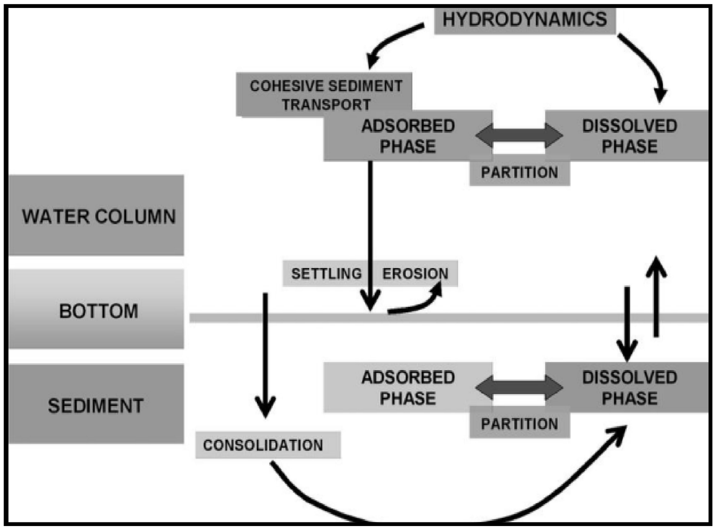

Figure 4: MOHID Framework of Hydrodynamic Modelling – (Neves et al, 2008)

Henceforth the hydrodynamic modelling in this study is aimed at assessing the variations in dispersion and disposition of the particles in the fluids. Here we have considered two scenarios, the first is aimed at the utilizing the resource that is venting from the hydrothermal vents and the second scenario is aimed at drilling the production wells in the seamount for resource extraction (conventional method). The input parameters of assessment for both scenarios and for both the cases are as presented in table 1.

Table 1: Inputs for the chosen scenarios

	Base Case	***Impact Case***
Scenario 1	Quantity of Venting Fluid Fluid Composition Area of Dispersion Species (density & type)	Change in quantity of fluid Change in composition of fluids Change in Area of Dispersion
Scenario 2	Area of Seamount Species (density & type)	Area of use (Plant Area) Area of dispersion (sediment & fluids)

6. Expected Results & Conclusions

The actual assessment of environmental impacts for the scenarios described above is still in the undergoing phase of research. We expect that the results will present the impacted total area in sq.km and the density/type of species that would be affected in each case as depicted in figure 5. For example, the impact assessment modelling using MOHID Lagrangean module, MOHID Jet and MOHID 3D from the MIDAS project (Managing Impacts of Deep Sea Resource Exploitation) suggests that the plume dispersal from the mining activity may have a horizontal footprint of about 70 sq.km and subsequently a larger vertical footprint. The figure below demonstrates the probability of plumes exceeding the dilution threshold and the extended footprint beyond the licenced area of resource utilisation. The simulations outputs were overlayed with commercial fish species distribution models to eassess the potential overlap of the activity with pelagic fishing activities. The obtained results could be further used to estimate the loss of habitat, degradation of habitat quality and to understand the resilience of the species.

The application of these techniques in the above-described scenarios (table 1) could certainly lead to quite significant findings that can revolutionize the offshore geothermal field. We hope that this kind of studies would certainly help the governments and several entities to overcome the barriers of offshore geothermal energy exploitation. The progress in this domain can help to open new frontiers and create new opportunities in the field of offshore geothermal energy and marine resource utilization.

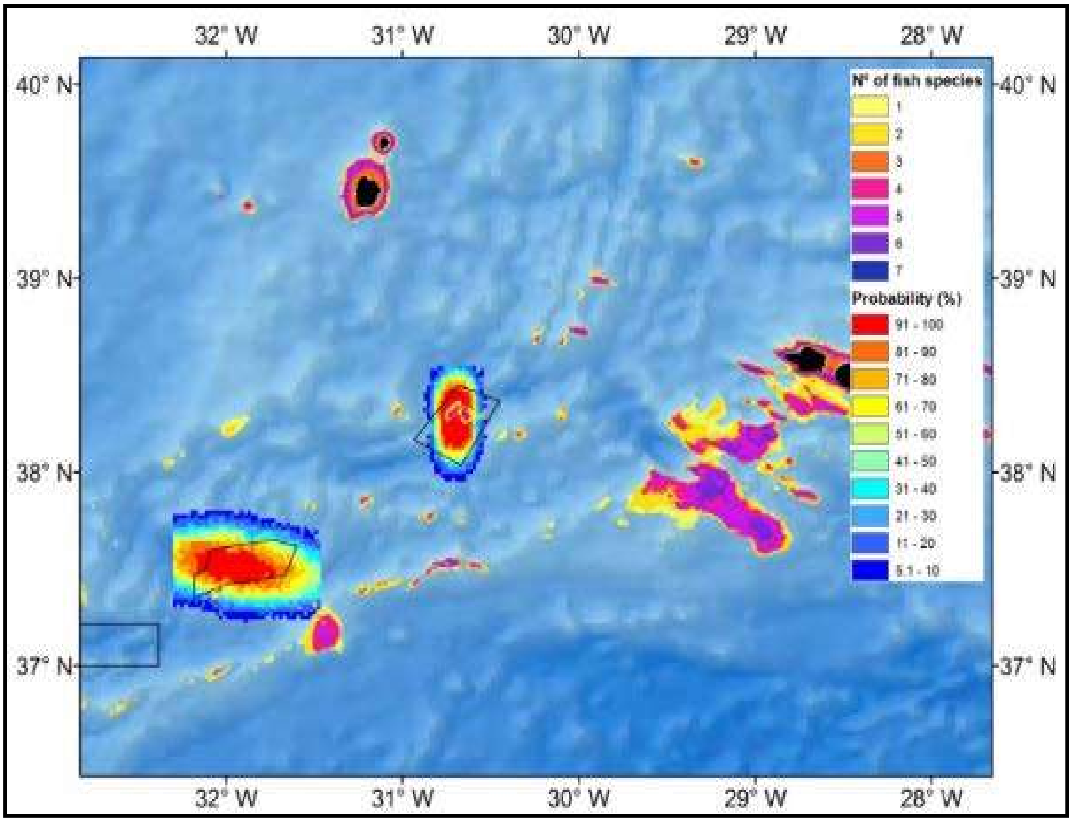

Figure 5: Plume dispersal impacts measured in terms of area - an example from the MIDAS Project

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