Economics of Offshore Geothermal Energy and Mineral Extraction

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Keywords: Offshore geothermal, energy, minerals, economics, cogeneration.

ABSTRACT

LCOE of Lucky Strike and Rainbow Vent fields are estimated at 7.7 & 11.1 US cents/ kWh; Submarine cable costs dominates the offshore geothermal project especially when the resource is far from land.

1. INTRODUCTION

Geothermal energy is the form of energy that is sourced from the heat of the earth; it is a well-characterised form of renewable and baseload energy that is predominantly used onshore for electricity generation. The geothermal energy is mostly used by those countries that live near the boundaries of earth tectonic plates due to the abundance and ready availability of geothermal energy. The geothermal energy-rich areas are not only confined to land but also extends to the offshore. The scientific advances have proven the offshore potential in terms of geothermal energy and the qualitative presence of metals in the geothermal fluids. The data on submarine environments suggests that the volcanic activity along mid-ocean ridges is associated with the release of large volumes of hydrothermal fluids or plumes (Baker et al. 1995). These fluids potentially represent one of the most abundant energy resources worldwide, due to their enormous quantity and virtually infinite recharge, high temperature and relatively low-salinity (Caso et al. 2010).

The interest group of the resource hotspots included the seamounts (such as Marsili), black smokers and abandoned offshore oil & gas wells (Italiano et al. 2014) (Hiriart et al. 2010) (Pedamallu et al. 2018). To this point, the concept of offshore geothermal resources has been restrained to theoretical research due to several barriers and misinterpretation of exploiting these resources. The hurdles to overcome include technical, economic, socio-environmental and infrastructural which are needed to inspect the viability of the offshore resources (Mofor et al. 2014).

Geothermal power is sometimes mistaken to be an expensive source of electricity. Even though the geothermal power plants require a large amount of start-up capital and government support in the earliest phases of exploration, the total capital costs and operating costs of geothermal power are significantly lower than any other energy technologies. Geothermal power plants generate a large volume of brine that is the product of prolonged water-rock interactions at high temperatures which contain dissolved critical and strategic mineral commodities at various concentrations. Regardless of the low concentrations of the critical and strategic minerals, significant quantities of select minerals can be recovered from these large volumes of brine. The potential economic benefits of mineral recovery from geothermal brine have long been identified, and the concepts of combined production could present us with an opportunity to make this resource more economically efficient.

Geothermal power could be one of the most economical and standing technologies when the entire lifecycle of the plant is considered (Matek et al. 2014). EIA also describes that geothermal power as the distinct generation technology that has a Levelized Avoided Cost of Electricity (LACE) greater than Levelized Cost of Electricity (LCOE) (Cost 2014). Many studies have proven the economics of the land-based geothermal resources; however, that of the offshore geothermal resources remained unanswered. The study at hand presents the economics of resource exploitation of the Azorean Mid Ocean Ridge hydrothermal vents. The study further presents the economic advantages of cogeneration.

2. STUDY AREA OF INTEREST

The Mid-Atlantic Ridge (MAR) near the Azores consists of four known major hydrothermal vent fields namely, Menez Gwen, Lucky Strike, Saldanha, and Rainbow. Each presenting specific geological, chemical, hydrothermal, and biological characteristic. This study excludes the Saldanha hydrothermal vent field since no focused flow vents of geothermal interests are identified (Pedamallu et al. 2018).

The Lucky Strike Hydrothermal Field is the first Atlantic site discovered in 1992 during the US mission Fazar. It is the largest known hydrothermal field within the Azorean archipelago, with 21 active vents with numerous black smokers out of which 16 are considered for analysis in this study. Lucky Strike hydrothermal field extends over approximately one kilometre along the sea floor (at a width of ca. 700 m) at a depth of 1700m (Langamuir et al. 1997).

The Menez Gwen hydrothermal vent field located at 850 m depth was discovered in 1994 during the DIVA expedition. The active vent field is located at the topographic high of the ridge segment. The central part of the volcano is at 2*6 km and 300 m deep axial graben filled with fresh lava (Saldanha et al. 1996). The hydrothermal activity at Menez hydrothermal activity is mainly concentrated over small areas, essentially on a small volcano located at the top central area of the field (Macron Y et al. 2013).

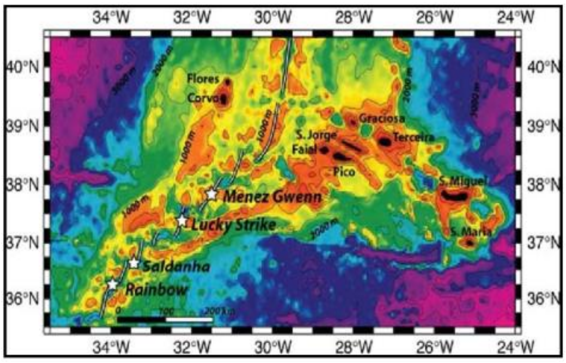

Figure 1: Location of the hydrothermal vent fields (white stars) near the Azores Triple Junction (Colaço et al. 2010).

The Rainbow field is located at a depth of 2270 m was discovered during the FLORES diving cruise in 1997 (Fouquet et al. 1997). Rainbow is based on ultramafic rocks, causing the fluid to be more acidic with higher metal and methane concentrations. The active vent field is spread over an area of 15 sq.km and assumed to have ten groups of active black smokers. At Rainbow, the vent fluids constitute uniform chemical composition of major, minor, trace elements (Douville et al. 2002).

2.1 Energy and Mineral Quantity Estimates

The estimated energy potential of the chosen hydrothermal vents is as presented by Pedamallu et al. The obtained results as shown in figure 2, suggests that the hydrothermal vents in the Lucky Strike hydrothermal field have greater power potential of 9.1 MWe for single vent followed by Menez Gwen with 8.8 MWe and Rainbow with 8.7 MWe. However, considering the total number of vents in the hydrothermal vent field, Lucky Strike hydrothermal vent field constitutes greater power potential of 145 MWe followed by Rainbow with 87 MWe and Menez Gwen with 8.8 MWe. The observed differences are explicitly due to the variations in fluid temperatures, depth, and number of vents in the hydrothermal vent fields.

A preliminary assessment is made to estimate the mineral resource potential of Azorean hydrothermal vents. The analysis is presented for the complete study area, and the chemical composition of the hydrothermal venting fluids considered for analysis are as presented in the table below. The assessment assumes of hydrothermal fluid flow rate of 6.7 mm^3/year, the flow rate is assessed using the parameters that are same as presented in properties table 3.

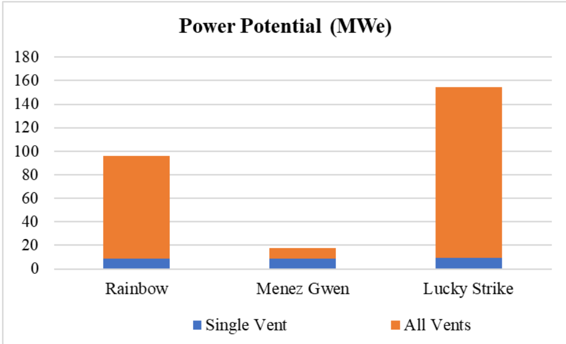

Figure 2: Preliminary energy estimation (Adopted - Pedamallu et al. 2018)

The available mineral potential is measured using the mass balance equations considering the parameters fluid composition and Mineral concentration. The fluid chemical compositions considered for analysis are as shown in Table 1,

Table 1: Fluid chemical compositions (Charlou et al 2002).

Vent Field		**Rainbow**	**Menez Gwen**	**Lucky Strike**
pH		2.8	4.2	3.5/3.7
Element Type	Si (OH)4 (mM)	6.9	7.7/11.6	11.5/16.3
	Br (µM)	1178	666/710	735/924
	Li (µM)	340	238/274	278/357
	Rb (µM)	36.9	20.3/29.4	22.7/39.1
	Cs (nM)	333	330	200/280
	Sr (µM)	200	100/111	67/119
	Ba (µM)	67	12	*10/52
	Mn (µM)	2250	59/71	84/446
	Cu (µM)	121/162	0.6/3	*4/26
	Zn (µM)	115/185	2.4/4.3	*5/57

Table 2: Quantity estimates of extractable metals from individual vent/single vent (this study)

Individual/Single Vent				
Vent Field		***Lucky Strike***	***Rainbow***	***MenezGwen***
Mineral Type *(output in kg/Year)*	*Si (OH)4*	*0.00*	*480.22*	*671.61*
	Br	*0.00*	*98.60*	*57.58*
	Li	*305.95*	*327.63*	*246.69*
	Rb	*2.42*	*2.89*	*1.94*
	Cs	*0.01*	*0.02*	*0.02*
	Sr	*7.10*	*15.26*	*8.05*
	Ba	*1.51*	*3.26*	*0.58*
	Mn	*32.26*	*273.93*	*7.91*
	Cu	*1.58*	*14.73*	*0.16*
	Zn	*3.17*	*15.34*	*0.34*

3. METHODOLOGY

The economic assessment has been carried out using the frame work of Geothermal Electricity Technology Evaluation Model (GETEM) that is developed by Idaho National Laboratory. Since this tool is designed for onshore geothermal assessments, few modifications were made to adopt the tool for offshore scenario.

The modifications are focused on the inclusion of offshore additional costs such as subsea cables, offshore platforms, towing etc., The modified framework of assessment is as presented in the Figure 3. The major inputs used for the economic assessment includes that of power plant costs, operation and maintenance costs, offshore costs. The powerplant costs are assumed like that of the onshore scenario, however the additional offshore costs like subsea cable and other offshore expenditure.

3.1 Parameters and Assumptions

The considered properties for the energy, mineral quantity and cost estimates are as presented in the Table 3.

Table 3: Parameters and Assumptions considered for the study

Properties	Units	Hydrothermal Vent Fields		
		Menez Gwen	Lucky Strike	Rainbow
No.of Active Vents		10	22	10
Fluid Temperature	^{0}C	281	333	360
Depth	m	850	1700	2250
Pressure	bar	86	171	226
Rock Density	kg/m^3	2000		
Porosity	%	10		
Fluid Flow Rate	m/s	3		
Vent Diameter	m	0.3		
Subsea Cable Costs (Lazaridis 2005)	$/km	336987		
Nearest Land	km	1500		

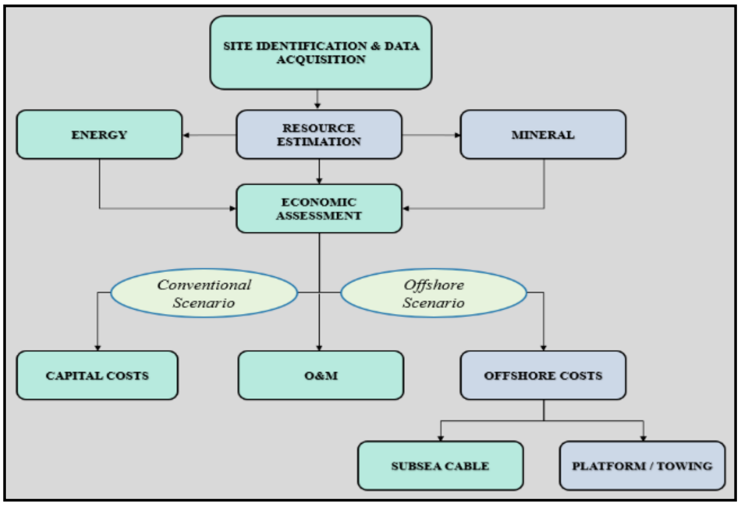

Figure 3: Framework of Assessment.

4. RESULTS

The assessment is made for the lucky strike and rainbow hydrothermal vent fields. Menezgwen hydrothermal field is excluded from the analysis due its lower economic potential. The assessed scenarios for the chosen vents represent the inclusion and exclusion of offshore costs for both the lucky strike and rainbow hydrothermal vent fields. The obtained results are as presented in the Figure 4 & Figure 5.

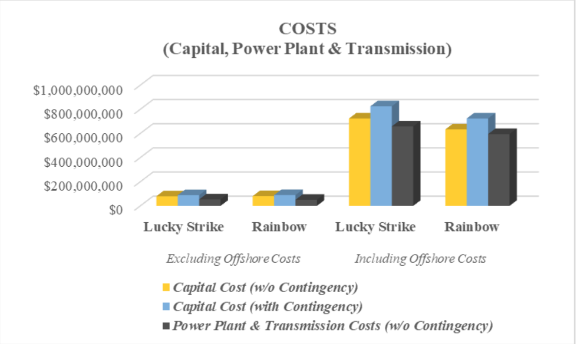

Figure 4: Capital costs, powerplant costs and transmission costs of simulated cases.

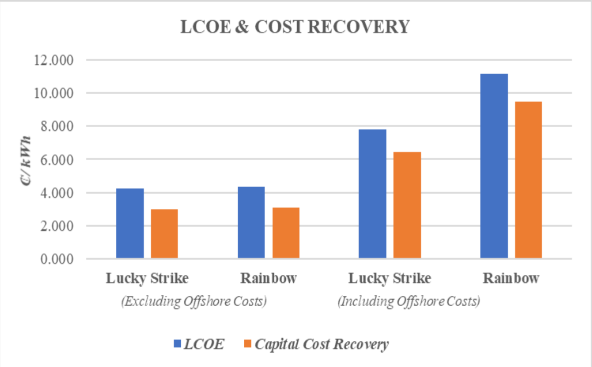

Figure 5: LCOE & Capital Recovery Costs of the simulated cases

5. CONCLUSION

Many factors affect the costs associated with the offshore geothermal power production. An in-depth analysis on necessary infrastructure, permits, etc are needed to simulate scenario that is closer to the reality. However, with the assessment performed in this study suggests that the power plant costs compared to onshore are significantly high due to the location of resource. The transmission costs highly dominated the overall costs of project and could play a crucial/ deciding role in making these projects economically sustainable. Mineral extraction from these fluids could provide additional revenue and could probably contribute to the reduced costs of energy production. The further part of the study is planned to progress with the experiences from the offshore oil and gas industry which could provide us with more significant inputs and accurate costs of the project. Finally, we believe that considering the concepts of cogeneration and levelized avoided cost of both energy and mineral production could positively influence the economic feasibility of the offshore geothermal projects.

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7. ACKNOWLEDGEMENTS

The authors acknowledge the financial support from FCT/Portugal for the PhD scholarship PD/ BD/ 128055/ 2016 under the MIT-Portugal Program & Energy for Sustainability Initiative, University of Coimbra, Portugal, as well as the logistical support from the Research Institute of Volcanology and Risk Assessment from the University of the Azores, Portugal.