Onshore and Offshore Geothermal Energy Resource Potential of Portugal – A Case Study

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ABSTRACT

The world is experiencing a severe and rapid climate change involving significant challenges. Energy is a crucial area for actions to help address the challenges. Global demand for energy continues to rise, reflecting the global economic growth, rapid industrialization, population growth, urbanization, and enhanced energy access. Simultaneously, the undesirable social, economic, and environmental impacts that result from heavy reliance on fossil fuels are obliging governments to look for more sustainable options to meet energy demand. Enhanced energy security and climate change mitigation for nations and regions are vital elements of developing a sustainable future. Decreasing global interdependence on import/export balances and increased diversity and resilience of energy supply have been adopted as key energy-related metrics.

Renewable energy tends to be a crucial and growing part of the world's ongoing energy transformation. Governments all over the world are joining the consensus. The use of renewables has become the readymade choice for enhancing access to affordable, reliable, and cleaner sources of progressive energy services. Over 170 countries have established renewable energy targets, and nearly 150 have enacted policies to catalyze investments in renewable energy technologies. Though wind and solar power, have dominated about 90% of 2015 investments in renewable power, other options are growing in prominence as well, such as geothermal energy, modern bioenergy (using residues from agriculture and forestry, among other fuels), and energy from waste. The world is also experiencing a rapid growth in geothermal investments due to its reliable base load character.

Portugal is one such country which has always shown keen interests in developing an eco-friendly and sustainable communities. The country has witnessed a renewed interest and continuous development in reforming its energy sector in the past decades. Since the country's fossil fuel industry is depended mainly on imports, to enhance the energy security and to address climate change, the country has established the National Renewable Energy Action Plan (NREAP) that is driven by the Directorate-General for Energy and Geology (DGEG). As a result, the renewable energy sector of the country experienced continued growth, contributing to an increase of 1.5% of renewable energy production in the year 2014.

In the scope of the expansion of the utilization of renewable energy sources of the Portugal, geothermal energy can be considered as a potential and significant source for development. Even though the country witnessed an adequate number of high-temperature geothermal resources, the geothermal potential remained untapped for several reasons, one of which is a lack of information and awareness. To overcome the gap and to reduce the barriers in utilizing the geothermal resources, this study aims at presenting an adequate assessment of onshore and offshore geothermal potential of Portugal. The further part of the study also addresses the directives and legislative instruments of geothermal energy production in Portugal.

1. BRIEF OVERVIEW OF PORTUGAL

Portugal is geographically situated on the west coast of continental Europe, in the Iberian Peninsula. It borders Spain to the north and east, and the Atlantic Ocean to the west and south. Major population centres include Lisbon (the capital city), Porto, Braga and Coimbra. In addition to the continental territory, Portugal includes the two autonomous regions located in the Atlantic Ocean, the islands of the Azores located to the west and Madeira to the south-west. The GDP per capita of Portugal in 2016 was $19,800 with an observed growth of 1.4% ("Portugal GDP - Gross Domestic Product 2017", n.d.).

The country covers an area of 92,000 km^2 with a population of about 10 million and has an oceanic exclusive economic zone of 1,700,000 km^2 most of which associated with the Azores and Madeira archipelagos (Pereira, H. M., et al, 2004). It has one of the largest maritime areas in Europe. According to Law No. 17/2014, related to maritime special planning and management, the national maritime space extends from the baselines as defined by United Nations Convention on the Law of the Sea to the outer limit of the continental shelf beyond 200 nautical miles (UN, 1982). It also submitted a claim to extend its jurisdiction over an additional 2.15 million square kilometres of the neighboring continental shelf in May 2009 (Madureira et al, 2011). Which would result in a maritime area with a total of more than 3,877,408 km ("Maritime spatial planning country information, Portugal", n.d.).

2. KEY ENERGY TRENDS IN PORTUGAL

Portugal, despite the difficult economic situation, has continued to develop and reform its energy policy with comprehensive benefits over the last decades. The outcomes of the reforms bring in a greater economic activity in the energy sector, the rapid increase in renewable energy deployment and a greater emphasis on energy efficiency in policy making. In the process of overcoming these significant barriers in renewables deployment, the country has made remarkable changes, which resulted in developing National Energy Efficiency Action Plan (NEEAP) and the National Renewable Energy Action Plan (NREAP) that is driven by the (DGEG) Directorate-General for Energy and Geology (NREAP, 2010) (IEA, 2016).

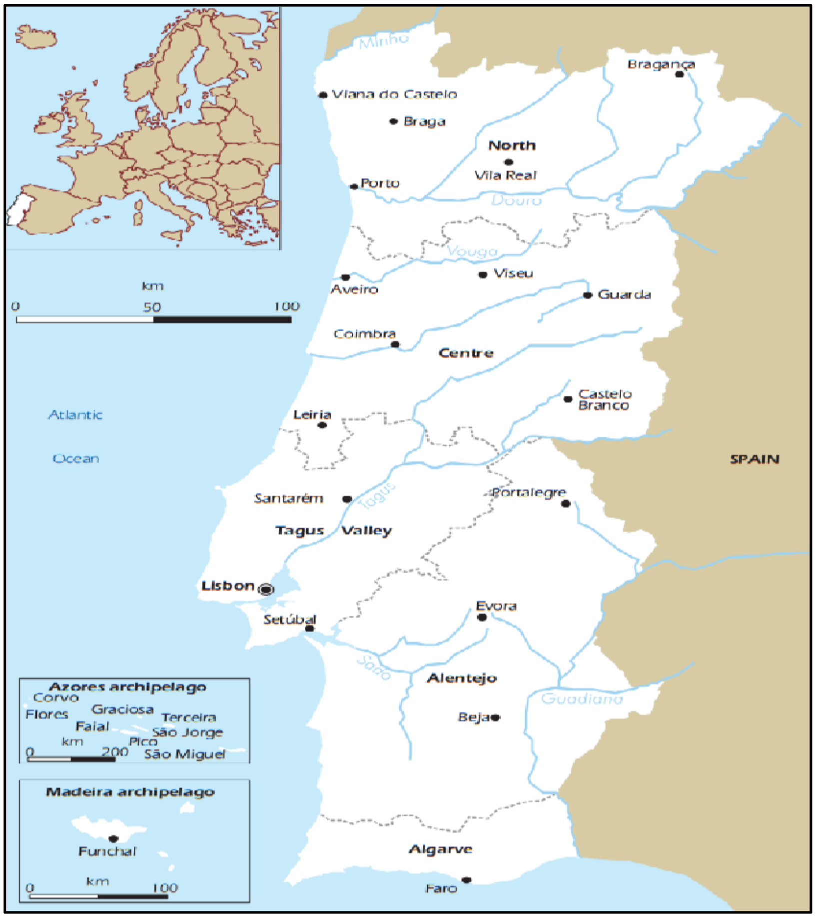

Figure 1: Map of Portugal including the autonomous regions of Azores & Madeira (Source – IEA, 2016)

The renewable energy sector of the country experienced continued growth, which contributed 26% of the total gross final energy consumption during 2013. In the electricity sector, Renewable energy sources accounted for around 63% of installed generating capacity in 2014, contributing to 61.5% of final electricity supplied. The penetration and growth in electricity production from renewable energy sources have produced multiple benefits, like reduced reliance on imported fossil fuels and decreasing carbon dioxide emissions in the electricity sector (IEA, 2016).

Portugal has also shown significant commitment to addressing the challenge of climate change and has adopted an ambitious 20% greenhouse gas (GHG) reduction target compared to a 1% increase permitted under the EU-Effort Sharing Decision. The National Low Carbon Roadmap of Portugal (RNBC) includes a set of road maps for achieving long-term, cost-effective Green

House Gas emissions reductions. The Green Growth Commitment and the Strategic Framework for Climate Policy (including a new National Climate Change programme and a new National Climate Change Adaptation Strategy).

2.1 Energy scenario in Portugal

The primary energy consumption in Portugal accounted for 20921 kilotonne of oil equivalent (ktoe) in the year 2014, with a reduced consumption of 3% compared to 2013.The country has seen a reduced energy dependency of 2% from the year 2013 to 2014 (“Energy with Intelligence, Iberian Data”, 2015). The total primary energy supply included oil, natural gas, coal, biofuels, and waste, hydro, wind, geothermal, solar and imports as shown in Figure 2.

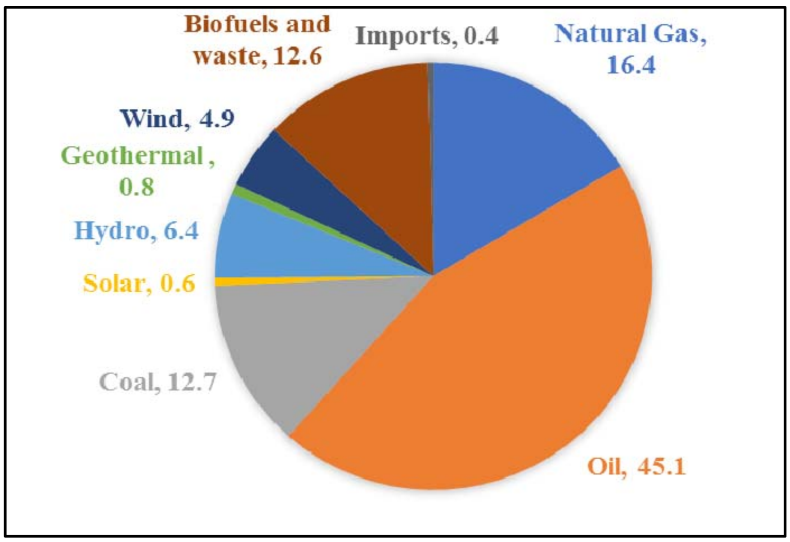

Figure 2: Percentage share of total primary energy supply in Portugal (Data Source – IEA, 2016)

The domestic production of energy in Portugal accounted for 5.8 million tons of oil equivalent (Mtoe) in 2014, which is mainly obtained from renewables. The energy is produced from biofuels and waste (52.2%), hydro (23.9%), wind (18.5%), geothermal (3.1%) and solar (2.3%) as shown in Figure 3. Portugal has no fossil fuel production (including coal, oil and natural gas). Wind, solar, geothermal, and biofuels and waste increased at an annualized rate of 31%, 20%, 8.4% and 0.2%, respectively during 2013-14 (IEA, 2016). The final energy consumption in the country has seen an increase of 1% from the year 2013 to 2014 along with an increased share of renewables with 1.5%.

2.2 Energy-related CO_2 emissions

According to the United Nations Framework Convention on Climate Change (UNFCCC, 2015), the heading greenhouse gas (GHG) in Portugal in 2012 was carbon dioxide (CO2), accounting for 73.2% of total GHG emissions, followed by methane (CH4) at 17.8% and by nitrous oxide (N2O) at 6.5%. Hydrofluorocarbons (HFCs) and Sulphur hexafluoride (SF6) together accounted for 2.5% of the overall GHG emissions in the country. The data estimates that Portugal’s energy sector accounted for 69.6% of total GHG emissions, followed by the waste sector (11.9%), agriculture (10.5%), industrial processes (7.7%) and solvents (0.3%).

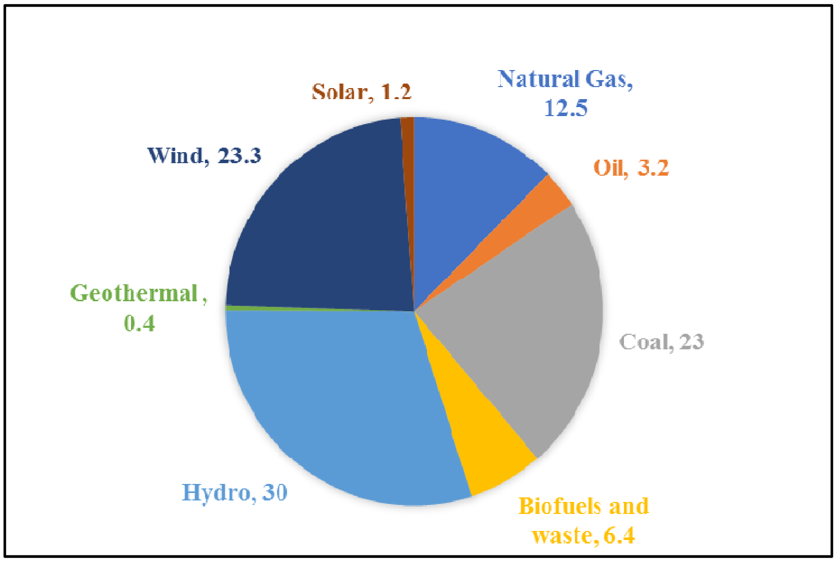

Figure 3: Percentage share of electricity generation in Portugal (Data Source – IEA, 2016)

3. ONSHORE GEOTHERMAL SCENARIO OF PORTUGAL

In Portugal, the main investment in geothermal energy is dominated by the Azorean Islands due to the greater availability of high-temperature geothermal resources. The low enthalpy geothermal resources in mainland Portugal have been utilized for direct use, whereas geothermal manifestations in the Azores are utilized for electricity production along with few direct uses ("Portugal - World Energy Council", 2016).

The geological characters of the country significantly influence the different conditions for geothermal energy manifestation. In the mainland, where crystalline rocks dominate over 60% of the area, thermal waters are related with active faulting. Around 27 springs are identified with discharge temperatures ranging between 25ºC and 75ºC. Low-enthalpy occurrences are distributed throughout the Portuguese mainland (as shown in Figure 1) and have been utilised for small district heating schemes, greenhouse heating in addition to bathing and swimming (including balneology). A significant number of feasibility studies are being carried out to support the suitable conditions for additional operations. In the sedimentary basins, mostly in the Lisbon area where major heat consumers are located, Lower Cretaceous reservoirs with temperatures up to 50ºC are suitable for minor multipurpose geothermal operations, but technical difficulties resulted in the slowdown of the existing processes ("Portugal - World Energy Council", 2016). However, the already studied potential for developing geothermal heat pumps over proven aquifers is high all over the country.

The mainland use of the geothermal resource in Portugal can be distinguished by the use of existing thermal limits (temperatures between 20 and 76 ºC) and the deep aquifers of the sedimentary basins like the geothermal project of the Air Force Hospital in Lisbon. The examples of the use of existing thermal limits include the Chaves, and S. Pedro do Sul with about 3 MWt at temperatures of about 75 ºC to operate Since the eighties (Geothermal Finance and Awareness in European Regions-GEOFAR, Country Profile, Portugal, n.d.) (Portal das Energias Renováveis, n.d.).

On the other hand, a total of twelve areas with potential for advancing geothermal electricity production have been recognised on the islands of Faial, Pico, Graciosa, Terceira and São Miguel in the Azores. The exploitation of geothermal resources for electric power generation has been initiated with the operation of the 3 MWe Pico Vermelho power plant on São Miguel that began in 1981. A second plant came into operation in two phases in 1994 and 1997 and by end-2008 gross geothermal capacity had achieved 28.2 MWe, generating 192 GWh (Portugal - World Energy Council, 2016). The Ribeira Grande field (about 250°C) has an established total capacity of 28 MW, meeting about 40% of the electricity demand of the island (23 MW net). It is expected to double the contribution of geothermal electricity in the coming years (Carvalho et al, 2015).

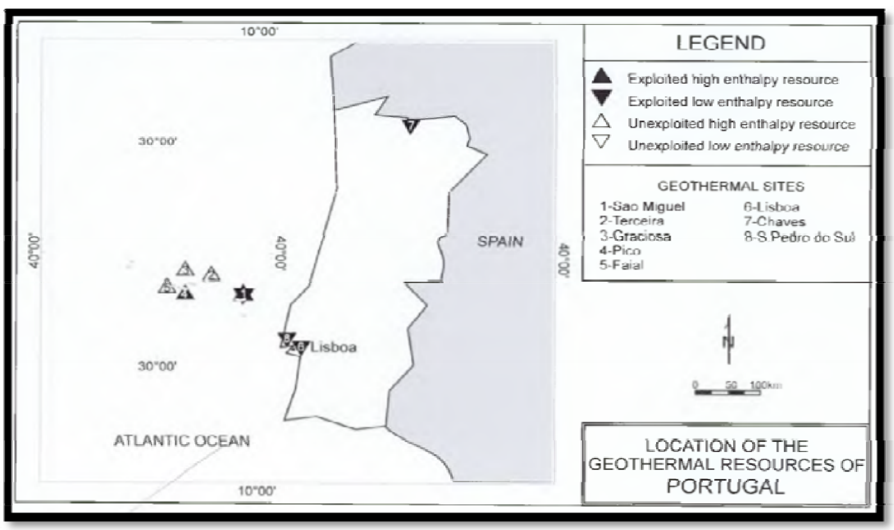

Figure 4: Location of geothermal resources in Portugal (Data Source - blue book , 1999)

In the recent years, a high-temperature resource suitable for power generation were identified in the Terceira Island. Resulting in a new geothermal power plant project of 12 MW (Pico Alto Field, where the temperature greater than 300°C have been confirmed), along with the additional expansion of Ribeira Grande, with an estimated investment of 200 Million Euros (International Geothermal Association: Portugal, The Azores, n.d.). Direct use in the Azores does not include district heating. To date, there has been little interest in geothermal heat pumps. The current status of the geothermal installed capacity and the geothermal production in the country are as shown in Table 1, Figure 5.

GEOTHERMAL INSTALLED CAPACITY (MW)		GEOTHERMAL PRODUCTION (ktoe/year)	
Electricity Generation	*Direct Use*	*Electricity Generation*	*Direct Use*
25	35.2	17.6	11.4

Table 1: Geothermal installed capacity and production in Portugal (Source - World Energy Council, 2016)

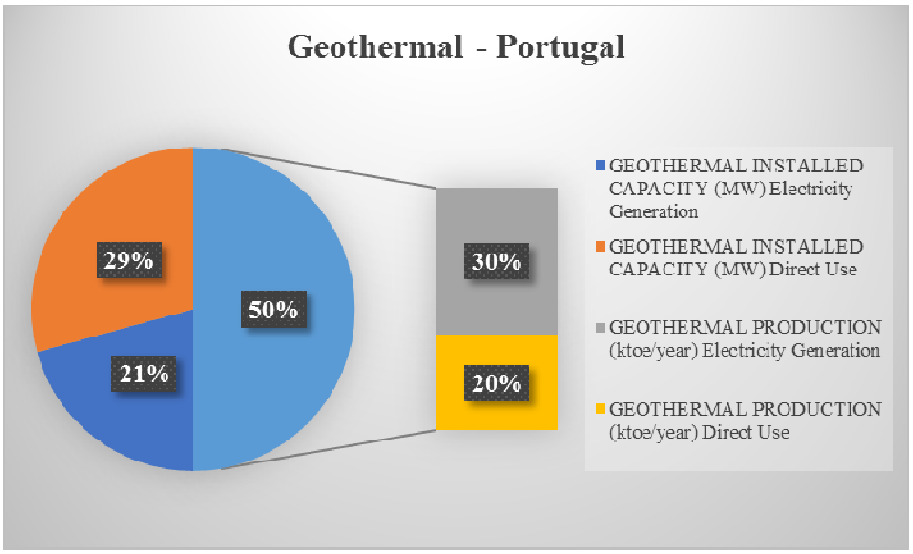

Figure 5: Percentage share of geothermal energy use in Portugal (Source - World Energy Council, 2016)

3.1 EGS Prospects in Portugal

Enhanced geothermal systems (EGS) / Engineered geothermal systems refers to a variety of engineering techniques used to artificially create hydrothermal resources (underground steam and hot water) that can be used to generate electricity. The theoretical EGS potential assessment made by (Chamorro et al, 2014) has shown a significant opportunity for geothermal exploitation in the mainland of Portugal. The results were classified based on the region of resource (as shown in Table 2) and multiple depths temperature (as shown in table 3) proves to be a significant potential of geothermal resources.

Region in Portugal	Surface Area (Sq.km)	Depth		
		3-5km	3-7km	3-10km
		GWe	GWe	GWe
Continental	89259	5.7	33	110
Norte	21350	5.2	17	41
Algarve	5016	0	1.6	6
Centro	28299	0.5	7.1	31
Lisboa	2918	0	1.4	4.1
Alentejo	31677	0	6.2	32
Total	***178519***	***11.4***	***66.3***	***224.1***

Table 2: Regional estimation of EGS theoretical technical potential, above 150 oC, expressed as potential installed electrical power (GWe) for Portugal (Source - Chamorro et al, 2014)

	T (oC)	3-4 km	3-5km	3-6km	3-7km	3-8km	3-9km	3-10km
		GWe	GWe	GWe	GWe	GWe	GWe	GWe
Portugal Mainland	>350	0	0	0	0	0	0	1.2
	>300	0	0	0	0	1	4.3	7.7
	>250	0	0	0.9	3.5	6.4	11	19
	>200	0	0.7	3	9	20	40	63
	>150	1.6	5.7	16	33	58	85	110
	Total	**1.6**	**6.4**	**19.9**	**45.5**	**85.4**	**140.3**	**200.9**

Table 3: EGS theoretical technical potential, expressed as potential installed electrical power (GWe) considering multiple variations in depths and temperatures.

4.OFFSHORE GEOTHERMAL POTENTIAL OF PORTUGAL

The ocean contains huge amounts of stored energy that can be used for the generation of electric energy. The forms on which this energy is present includes waves, salinity gradients, temperature gradients, hydrothermal energy, (geological cracks at the bottom of the sea), tides and oceanic streams (Khan et al., 2009). Tidal and wave energy technology represents the most advanced offshore energy technologies, and those expected to become commercially viable in the short-medium term (Mofor et al., 2014). However, the existence of a substantially exploitable submarine resource and the world's pressing need for alternative energy sources, make the submarine geothermal resources deserve a closer look.

The considerable amount of data acquired in the past decades on the 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), (Lupton, 1995), (Elderfield et al, 1996).The focus on the exploration of the thermal energy of hydrothermal fluids has obviously increased due to the observed higher potential of heat fluxes (Di Iorio et al, 2012), (Parada et al., 2012). For example, the investigators of the IMPULSA project of Mexico proposed the utilization of the thermal energy of hydrothermal fluids as renewable energy sources for seawater desalination (Hiriart et al, 2010). The US company CREAK developed a turbo-Rankine power system, which harvests deep-sea hydrothermal energy ("Navysbir,Turbo-Rankine Power System for Deep Sea Hydrothermal Vents", n.d.).

On the super-fast spreading sections of mid-ocean ridges, vent sources can be so extensive that plumes are continuous for upward of 100 km along the axis. An average width of this equivalent vent of 10 cm and flow velocity of 1 m/s at 250 °C, generates a heat flow of 400 TW thermal using as a sink temperature 30 °C (Baker et al., 1989). The energy in the seabed can be extracted from a wealth of sources with various energy conversion systems: In the hydrothermal venting system, there are two potential energies: hydrodynamic (kinetic) energy and hydrothermal energy, hydrostatic pressure from the deep water (Parada et al., 2012).

Portugal constitutes an oceanic exclusive economic zone of 1,700,000 km^2 mainly associated with the Azores and Madeira archipelagos (Pereira et al., 2004). The Azorean region is abundant with hydrothermal vents with higher potential of energy and mineral resource. This could be of a significant source of exploiting offshore geothermal energy.

The hydrothermal vents and seamounts of the Azores (Portuguese: fontes hidrotermais e montes submarinos dos Açores) as shown in Figure 6, are a chain of Atlantic seamounts and hydrothermal vents that are part of the Mid-Atlantic Ridge system, giving rise to the archipelago and bathymetric region of the Azores. There are seven large hydrothermal fields and a shallow hydrothermal field within the waters of the Azores ("Vents-Interridge Data Base", n.d.), namely: Lucky Strike, discovered in 1992 (Langmuir et al, 1993); Menez Gwen, discovered in 1994 (Fouquet et al, 1994); Rainbow Hydrothermal Field, discovered in 1997 (Ribeiro, 2010); Monte Saldanha Hydrothermal Field, discovered in 1998; Ewan Hydrothermal Field, discovered in 2006; Seapress Hydrothermal Field, discovered in 2009; Moytirra Hydrothermal Field, discovered in 2011; Dom João de Castro Bank, discovered in 1995 (Santos et al, 1996).

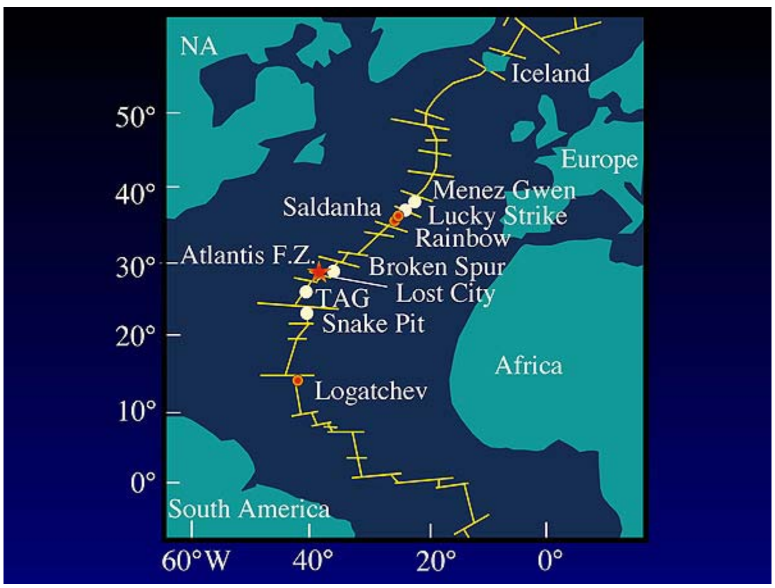

Figure 6: Hydrothermal vents of Azores (Source – Ocean Explorer, n.d.)

The sites Menez Gwen, Lucky Strike, Saldanha, Rainbow, and the Ewan differ by their depth (850m to 2800m), the composition of their host rocks, the nature of associated volcanism, their tectonic setting and fluid temperatures (150-400 ^{o}C). The ecosystems they associate with are also distinct at least in four sites, the biodiversity and biomass being greatest at the Lucky Strike (Desbruyères et al.,2001).

The offshore prospects of energy from the vents are often neglected and remains untapped due to the complex environments and life in the ocean. Though the development of technology to sustainable exploitation of geothermal energy from the vents will increase the geothermal resource, as a preliminary step, it is necessary to make estimations of the magnitude of the potential of hydrothermal vents on a regional scale. The amount of energy at the hydrothermal vents is vast and renewable, although power generation entails a small environmental impact, it could be a viable source for the society. The exploitation of energy resources from the hydrothermal vents has challenging but essential prospects of growth in the upcoming future.

5. LEGAL REGIMES AND ENVIRONMENTAL PROTECTED AREAS (EPA'S)

As part of the application of the European Directive 2009/28/EC, renewable energy sources in Portugal are related to special regime generation (SRG). This special regime includes generation of electricity such as cogeneration, generation from renewable and non-renewable endogenous resources, distributed generation and generation without the injection of power into the network. The European Directive 2009/29/EC is transposed at the national level by the prioritization of renewable energy sources in relation to generation in the standard regime, both for access to the network, and for dispatch, except in situations where this puts at risk security of the supply. These directives are applicable all over the country, however the autonomous regions have their own legal regimes which are based the Portuguese directives. The maritime legal regimes also includes the law of seas (UNCLOS).

Marine Protected Areas (MPAs) are considered fundamental tools for biodiversity conservation, sustainable fisheries management, and cultural preservation of coastal societies (Vasconcelos et al, 2015). They have been established worldwide in an effort to halt marine ecosystem degradation. Initial steps for the establishment of MPA were mainly initiated in the1980s, with a few pioneer nations such as Australia, the USA and the islands of the Azores in Portugal. In the Archipelago of the Azores, over 110,000 km2 of marine areas presently benefit from some form of protection, including a suite of coastal habitats, offshore areas, seamounts, hydrothermal vents, and large parcels of mid-ocean ridge. These areas are integrated in the recently established network of marine protected areas (MPAs) as shown in Figure 7, which stands as the cornerstone of Azorean marine conservation policies (Abecasis et al., 2015).

Portuguese Protected Areas includes, Portugal mainland (protected areas & Natura 2000) sites with an area of 2.017.803 ha; Azores and Madeira Regions (Natura 2000/Sites of Community Importance) with an area of 76.758 ha. Azores and Madeira Regions (Natura 2000/Special Conservation Areas) with an area of 49.296 ha (Portugal, Fourth National Report,2010).

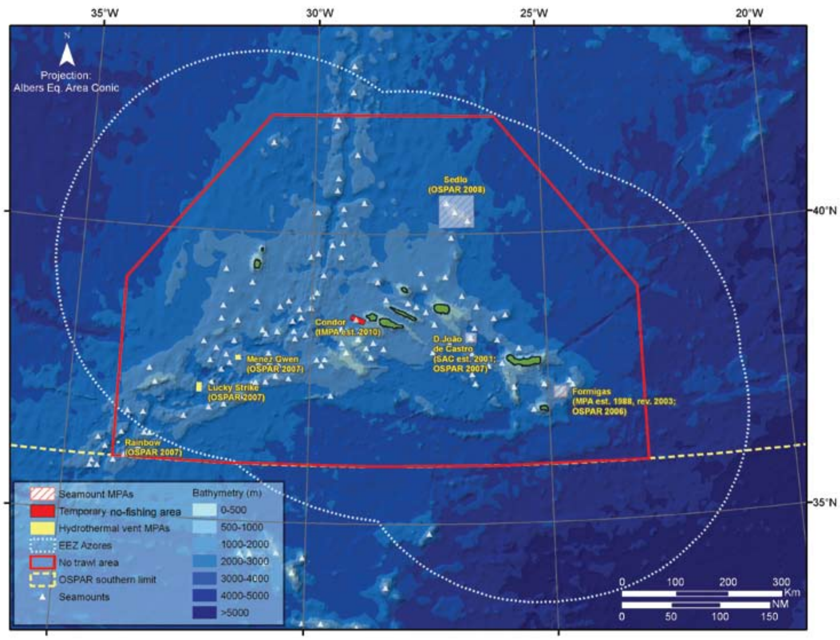

Figure 7: Marine protected areas (MPA's) in Azores (Source - Morato et al., 2010)

6.CONCLUSION

Geothermal energy has many attractive qualities ranging from its renewable and fossil-fuel free nature, as well as the ability to provide constant and reliable baseload power at a relatively low cost. From a global environmental perspective, the benefits of geothermal energy development are beyond dispute. Carbon dioxide emissions from geothermal power generation, while not always zero, are much lower than those of power generated from burning fossil fuels. Being abundant, geographically diverse and renewable. Offshore geothermal resources could play a significant role in meeting the growing challenges. The exploitable geothermal energy potential in numerous parts of the world is far greater than the current utilisation.

Given the advantages of onshore and offshore geothermal power, the question remains unanswered why the level of its utilisation today is not higher than it should be. A possible answer could be due the existing barriers, complexity and environmental concerns (mainly on the offshore explorations). Several barriers occur in exploiting these resources. These barriers can be specific to both technology and phases of development, and often overlap. They include: financial, economic, political, governance, environmental, social and technical. Approaches can be developed to address and overcome these barriers, above all, it is important to consider a thorough analysis of resource information of geothermal potential.

A significant amount of data is available on the onshore geothermal prospects of Portugal. However, an exhaustive quantitative analysis of offshore areas of Portugal could provide vital information on the resource potential and possible scenarios to overcome the constraints that would ease sustainable exploitation of resources. The further part of the work aims at assessing the potential of offshore geothermal and mineral resources of Azorean hydrothermal vents including the legal regimes, socio-economic and environmental aspects of the resource exploitation.

7. ACKNOWLEDGEMENTS

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