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Wellhead Unit Technology in the Development of Geothermal Energy in the Caribbean

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ABSTRACT

The benefits of geothermal energy in the transition of the power sector in the Caribbean region, are undisputed. The region's commitment to reducing its high dependence on imported fossil fuels is critical to achieving affordability, reliability, sustainability, and resilience in the energy sector. Burdened by high electricity tariffs, the electricity sector is obligated to transition to indigenous renewable energy resources for a sustainable transition to be secured. High penetrations of intermittent renewable energy pose operational challenges for existing grid infrastructure to ensure a reliable and affordable supply of power. Geothermal energy for electricity generation is touted as a critical piece of the transition puzzle as it provides baseload power, is marked by a relatively low land footprint, offers higher resilience against climate and other vulnerabilities, and provides additional benefits through direct utilization. Globally, the proven benefit of the technology continues to encourage the relentless development of the Caribbean geothermal industry despite inherent challenges, including long gestation periods and high upfront costs. However, in the Caribbean region, the issue of diseconomies of scale and competing uses of land has plagued the region's development of geothermal electricity projects.

The Caribbean has a long history of pursuing the development of the resource through the conventional power plant approach towards developing centralized plants and associated steam field gathering, transmission and fluid reinjection systems. This approach has resulted in high cash outlays for de-risking the projects, and to date no power plant except in the overseas territory of Guadeloupe has been constructed. The geothermal projects in the Caribbean, despite having received extensive funding support for de-risking, continue to experience long lead times. This study confirms that wellhead technology offers a power conversion process applicable to the Caribbean islands. Despite the potential technical, operational, and environmental downside of the well-head units as longer-term solutions, they offer unique benefits to the Caribbean islands, through lower financial risks and a quicker return on investment. Wellhead unit technologies for the Caribbean context will help to ameliorate the issue of diseconomies of scale and challenges to attract reputable developers and industry experts, consequent of the intrinsic and relatively low energy demand profiles and high intra-hourly demand variability in island states. For small scale centralized geothermal power plants, the upfront design, fabrication, and mobilization costs are economically unattractive. Wellhead units would result in significant cost savings because of a reduced designed complexity and therefore offer faster returns on investment.

With Kenya pioneering the wellhead technique to prevent drilled wells from remaining idle for years the Caribbean stands to learn from the associated best practices. Being disadvantaged by limited human capacity, adopting wellhead technology will benefit the Caribbean islands with an opportunity to steepen the learning curve for geothermal project development, learn about the resource and build capacity in geothermal development.

1. INTRODUCTION

The Caribbean region is poised for significant renewable energy development based on a readily available mix of indigenous renewable energy resources. This is particularly true in the Eastern Caribbean which consists of an archipelago of islands of volcanic origin, making geothermal energy a viable option to meet the region's needs.

While the Caribbean islands face an urgent need to transition from the conventional dependency on fossil fuels to large scale utilization of renewable energy, to date the rate of transition has been slow. Hence, the longstanding use of fossil fuels for electricity generation, transportation and other commercial and domestic activities has induced geo-political, environmental, and socio-economic challenges within Caribbean countries.

Caribbean economies, like other Small Island Developing State economies, remain extremely vulnerable to external shocks in addition to being highly vulnerable because of more frequent and intense macro-economic attacks related to the negative effects of climate change. Recent shocks to small island economies resulting from the global covid pandemic and the more recent Ukraine war provide a strong reminder to Caribbean governments that efforts to transition to a more sustainable energy sector must be catalyzed. The year 2021 saw an annual change in global oil prices of approximately 55% increase from the previous year. The year 2022 also saw a record high of $123.70 (USD) per barrel of oil - the second highest value ever recorded - second to the historic high of $145.31 per barrel in 2008.

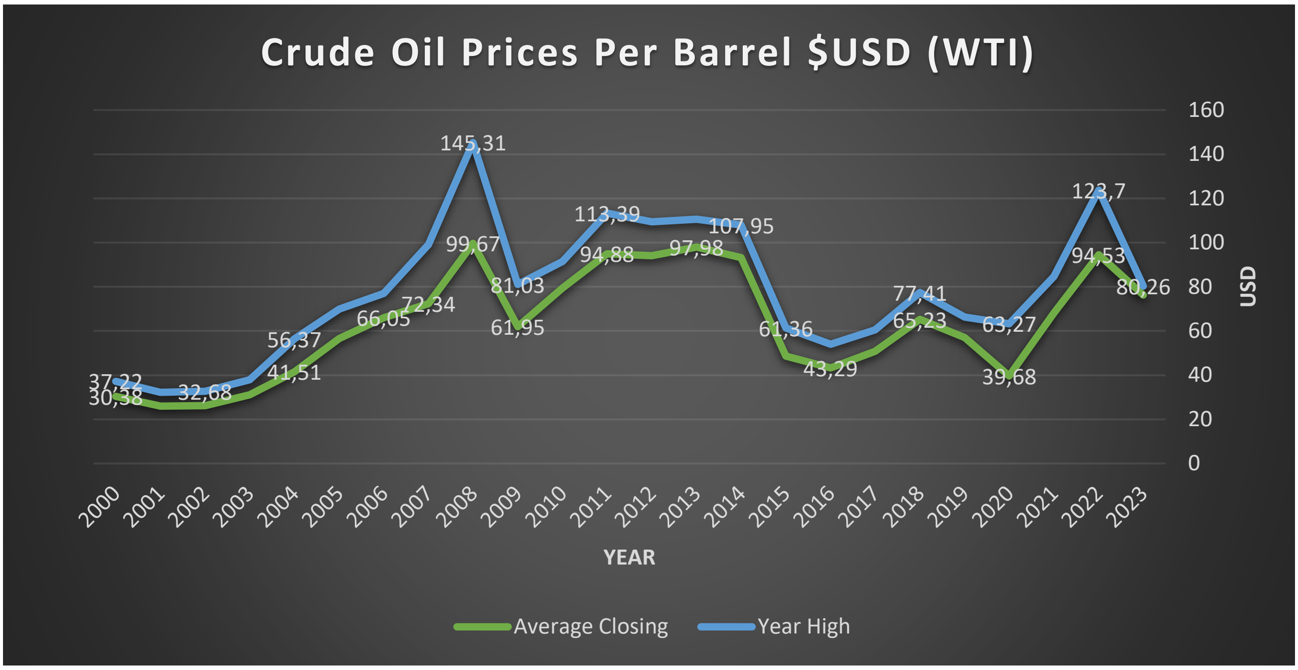

Figure 1 Historical crude oil prices

Data Source: **(Macrotrends, 2023)**

Figure 1 demonstrates the historical volatility in global crude oil prices. It can therefore be deduced that dependency on imported fuel oil can result in energy security uncertainties. The Caribbean more than ever, absolutely must development its indigenous energy sources with extreme urgency. The development of green energy must be pursued on the basis of affordability, sustainability, and resilience.

SIDS are affected by many challenges which have dampened the pace of uptake of renewable energy in the region. These include inadequate local fiscal flexibility to meet high upfront costs, an insufficient and under capacity workforce, land availability and competing uses of land, a lagging regulatory environment, and diseconomies of scale consequent of the small scale of projects, among others. Despite these challenges, islands continue to pursue the development of solar, wind, hydro, geothermal, and biomass to meet their energy needs. Land footprint, intermittency of supply of some technologies, climate variability, and the need for storage systems to create dispatchability are factors that must be considered when exploring renewable energy technologies as viable solutions for the region's power systems. Geothermal power, with a high capacity factor and a lower footprint easily fits the criteria of a sustainable energy source.

Geothermal potential has been confirmed in the islands of the Eastern Caribbean, with a total of 6,280 MW. (Ochs, 2015) Figure 2 shows the geothermal potential of each Eastern Caribbean state. Although the total potential varies from source to source, the estimated potentials are always in the order of magnitude sufficient to drastically change the energy mix of these islands and in most cases even transform them into energy exporters.

Geothermal energy in countries world-wide has proven its ability to respond to the disruptive needs of current and future power systems. With capacity factors as high as 95%, geothermal power also passes the test for climate non-variability, steady daily supply and even climate resilience, making it a great solution for transitioning base load from conventional fossil-fuel based systems to clean energy. Geothermal is therefore a top technology solution to provide firm, dispatchable electricity to meet the needs of Caribbean utilities.

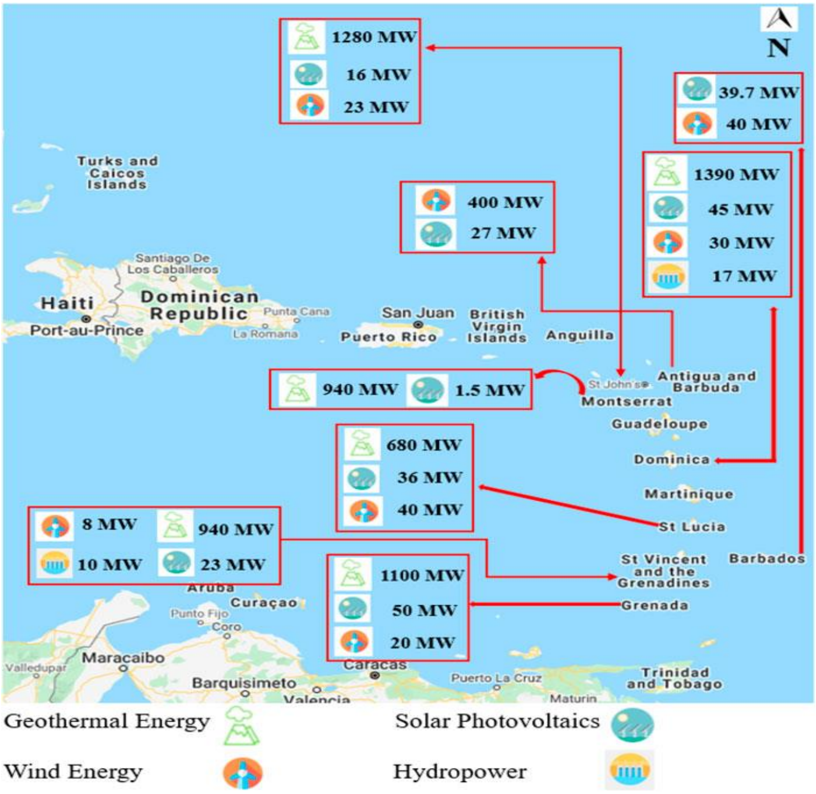

Figure 2 Geothermal, wind, solar and hydro energy in potential the Eastern Caribbean

Source: (Ochs, 2015)

2. STATUS OF GEOTHERMAL DEVELOPMENT IN THE REGION

Despite large, estimated potentials of geothermal resources in the Eastern Caribbean, and after years of exploration in some islands, only overseas French territory, Guadeloupe, has an operational power plant to date. Geothermal development is characterized by inherently long project development timelines, which in the Caribbean context have been exacerbated by the localized context of the region. These challenges range from legislative and regulatory challenges to the inadequacy of a suitable local workforce with geothermal-specific competencies. Other critical challenges include the high costs associated with the de-risking phase of geothermal development and the diseconomies of scale that confront the smaller sized Eastern Caribbean States. The latter is a critical issue as it also impedes attracting the industry's more experienced and reputable developers. The figure below shows the planned capacity of geothermal power in the Eastern Caribbean States, ranging from as low as 2.5 MW in Monserrat to 50 MW in Martinique.

Figure 3 Planned geothermal capacity development in the Caribbean region

Source: OECS

Surface exploration efforts in the Caribbean have been recorded from as far back as the 1950's in Saint Lucia. First drilling operations date back to the 1970's. More recent exploration drilling operations have confirmed viable resources in at least 3 of the Eastern Caribbean States; Dominica, Monserrat, and Nevis. Saint Lucia's exploration project is ongoing as the island is on the cusp a drilling operation to confirm the commercial viability of its resource through the drilling of 3 slim wells.

Table 1 Status of Geothermal development across the Caribbean islands

COUNTRY	DRILLING	YEAR	RESULTS
Dominica	3 slim holes, 3 full size (2 production 1 reinjection)	2012	Temperature: 246ºC Commercially viable resource confirmed
Monserrat	3 full size wells	2013	Temperatures 230, 265, 255 ºC Commercially viable resource confirmed
Nevis	3 slim holes	2017-2018	Temperature: 255 ºC (Minimum of 10-12 MW per production well confirmed)
Saint Lucia	2 slim holes 2 full size wells	1970's 1980's respectively	Commercial viability not confirmed
St. Vincent	3 full size wells	2019	Temperatures: 220-230 ºC Commercial viability not confirmed because of insufficient permeability

Source: (Osborn, 2014), (Partners, 2022) ((IWN, 2022)

The table above summarizes the drilling activity of the Caribbean region to date. In some cases a commercially viable resource was confirmed as long as a decade ago through these drilling exercises. Typically, long gestational periods and high capital costs for geothermal projects, along with other contextual challenges have resulted in these long delays in moving from exploration drilling to appraisal and/or production drilling and power plant construction in the Eastern Caribbean. These delays leave high opportunity costs, with having productive wells capped for many years.

3. THE CARIBBEAN REGION'S CHALLENGES WITH GEOTHERMAL DEVELOPMENT

Conventional approaches to geothermal exploration and development for electricity generation require significant upfront capital expenditure, exposure to technical and financial risks and specialized knowledge and skill sets, all of which have proven challenging to Caribbean small island developing states.

The conventional developmental and utilization stages of a geothermal power project comprise the following:

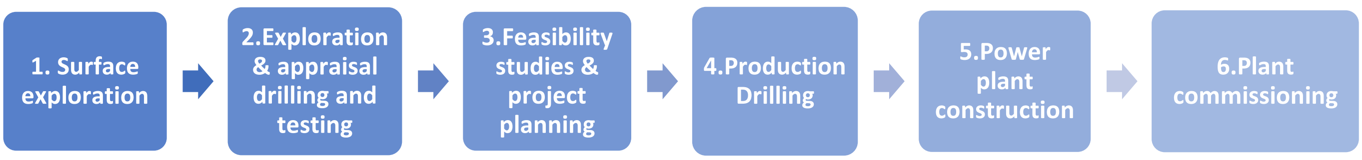

Figure 4 Stages of geothermal development

This development process takes on average 8 years, and the availability of ready financing can significantly reduce the lead time by as much as 3 years. The development programme from project identification to power station commissioning takes about 8 years but can be reduced to 5 years if finances are readily available. At the same time the preliminaries (stages 1-3) of the above stages have associated risks and financial burdens which can extend the time frame of a project or in some cases result in project abandonment. However, utilisation of geothermal wellhead plants can improve the financial viability of a project by reducing the engineering, procurement and construction (EPC) costs when compared to a conventional plant design.

Figure 3 shows the relatively small size geothermal plants planned in the Eastern Caribbean, accordingly in keeping with the small economies of the region. This poses a challenge for the region to attract the more experienced and suitable developers. With no power plant in operation with the exception of Guadeloupe, building and retaining capacity among the workforce is particularly difficult as there are significant hiatuses between exploration and plant operation. This causes a loss of interest of skilled personnel in the projects.

The list of challenges mentioned are surely not exhaustive, however another common challenge has been land acquisition for geothermal development in some jurisdictions. Some of the region's geothermal resources have been scientifically identified through exploration studies to be located on privately owned lands.

4. WELLHEAD POWER PLANTS

Wellhead units can be defined as small, modularized geothermal power plants with installed capacities between 1MW and 10MW. Steam generated at the well is converted to electricity without having to be transported by steam pipelines to a centralized powerplant. Contrary to central geothermal power plants, wellhead plants require no steam field development. What is required are brine and cooling tower blowdown disposal systems. The technology options for the generation of electricity in wellhead units are the same for centralized power plants and include condensing, back pressure and binary or organic Rankine cycle (ORC). The main components of a wellhead unit include the production well, steam pipes and cooling towers, turbine and generator set, separator and silencer, and control systems. The figure below illustrates the main components of a wellhead power plant.

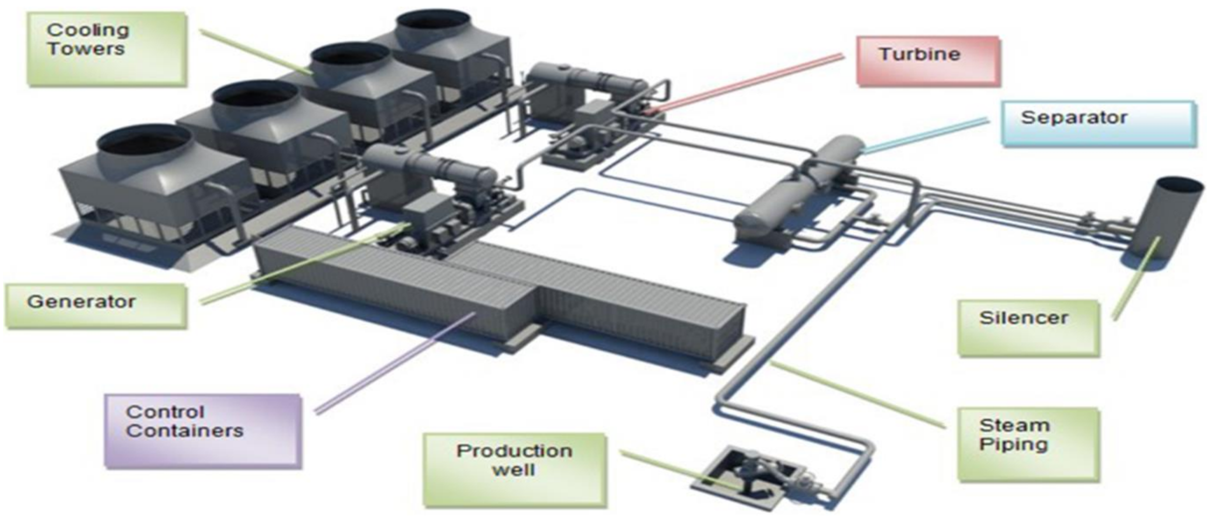

Figure 5 Components and configuration of a wellhead power plant

Source: (Kabeyi M. O., 2021)

4.1 Temporary wellhead power plants

Wellhead units are not new to the industry and have typically been used for early power generation in geothermal field development, replacing them with a centralized, large scale power plant once field development is advanced and enough steam has been secured. A central geothermal power plant consists of several interconnected geothermal wells which serve one common turbine to generate electricity. Wellhead units are typically used as temporary installations in geothermal fields and once replaced by larger power plants, are relocated to new wells.

Temporary wellhead power plants can provide power to the grid while geothermal fields continue to be developed or can provide power for drilling operations for near-by wells within the same field.

Small wellhead power plants can also be used as complementary power plants to exploit the wells in a steam field that are either in the high-pressure end or the low-pressure end. Post drilling, they can help to balance the pressure and flow from the wells in a steam field to get the optimum operation for the entire steamfield, (Carlos Gierdal, 2013)

4.2 Permanent wellhead units

Wellheads can also be used as permanent power plant solutions. These are typically used in cases where resource locations are far apart, or site topography poses challenges. Permanent geothermal wellhead power plants can also be utilized for the purpose of satisfying electricity demand in isolated or remote areas; away from the national grid. In addition, it may occur that wells are deemed unsuitable for large commercial projects, in which case permanent wellhead units may be used to leverage smaller scale applications of the power generated.

4.3 Pros and cons of wellhead units

Advantages of wellhead units

1. Wellheads result in a significant reduction in the time between the exploration phase and electricity generation. Wellheads can therefore significantly decrease the time between high-risk exploration investments and generating

revenue. In some cases turnkey wellhead plants can be installed within as little as 2 months. Contrarily, a central plant usually can only be operated 6-7 years or more after drilling the first well

2. Wellhead plants offer an advantage over centralized plants where integrated investment is concerned. Wellhead units can more easily be incorporated with other economic activities.
3. Wellhead units, due to the modularized configurations are easy to install, uninstall and transport.
4. Because they are customized according to the prevailing conditions at each well, they can maximum and optimize electricity generation.
5. With less complex configurations and parts, they require less maintenance, individually.
6. The use of portable wellhead generators can reduce or eliminate the use of diesel for drilling operations. This supports the use of cleaner fuel and therefore lower emissions throughout the lifetime of a geothermal development project.
7. Wellhead power plants can be used to optimize production by being customized to given well-specific conditions. They significantly overcome the shortcomings of traditional methods of exploiting geothermal resources such as long gestation periods and underutilization of some interconnected wells in central generation that have unique properties within a steam field.
8. Wellhead plant has its own individual control system, making monitoring simpler for individual units.
9. While wellhead power plants do have a negative visual impact because of the transmission lines from the plants to the substation, the cross-country steam gathering system of large-scale power plants has a much bigger visual impact. In addition, grounding transmission lines is an option in the case of wellhead plants but is not considered viable for steam pipelines.
10. Wellhead plants are leaner on civil works and other labor.
11. Wellhead plants can be used as permanent plants for wells that are too far apart and therefore uneconomical to develop steam gathering system. They are also ideal for wells with too low or too high pressure within a given steam field.

Disadvantages of wellhead units

1. Control and monitoring of several wellhead power plants is more complex and laborious since operations are distributed across the field under development as opposed to a centralized power system with a centralized monitoring system.
2. Each wellhead generating unit is a new technology; therefore, the equipment is relatively expensive and there are limited spare parts on the market.
3. Installation of the wellhead plant is carried out in one well pad so that more wells in one well pad will pose a challenge for the operation and maintenance team.
4. Operating the modular and small wellhead units cost more than operating larger centralized units.
5. In the case of using temporary wellhead units to provide power to the grid, longer and impractical power transmission lines may be required because of the need to install transformers and extensive transmission networks.
6. Wellhead plants operate at lower efficiencies than central geothermal power plants
7. A reinjection system is not a component of most wellhead plants, making it less sustainable than central plants.

4.4 Comparison of wellhead units and conventional centralized power plants

	PARAMETERS	CONVENTIONAL POWERPLANTS	WELLHEAD POWERPLANT
1	Set up period	The plant construction takes more than 2 years to complete and commission	The installation and commissioning generally take between 3 and 6 months
2	Customization	The plant design is not specific well dependent.	Wellhead generators are designed for a specific production well conditions
3	Production wells needed	Central power plants receive steam from multiple wells	Often use steam from a single production well
4	Power plant capacity factor (CF)	The conventional powerplants enjoy higher capacity factor	The wellhead generators operate at a lower capacity factor compared to central powerplants
5	Unit cost of power	Central powerplants enjoy economies of scale hence enjoy lower unit costs	Wellhead powerplants have higher unit cost of power since they do not enjoy economies of scale
6	Electricity evacuation and transmission	Usually at high voltage to grid transmission system	Can be evacuated at lower voltage and connected to distribution grids
7	Non condensable gases	Specific well dependent	Specific well dependent
8	Power plant Flexibility and mobility	Central power plants are fixed and rigid in design	Wellhead generators are flexible and can be relocated to different sites
9	Generation specific steam consumption (SSC)	The central powerplants operate at a lower specific steam consumption hance have better steam economy	Wellhead powerplants have a higher specific steam consumption hence consume more steam for same output
10	Power plant availability	Higher availability factor	Lower plant availability

Figure 6: Comparison of wellhead units and centralized power plants

Source: (Kabeyi M. O., 2021)

Figure 6 outlines a 10-parameter comparative analysis between conventional and wellhead geothermal plants. It can be seen that overall conventional power plants present higher operational and financial returns on investment when compared to wellhead plants. However, the table does show that wellhead plants offer advantages of shorter construction and commissioning timeframes, can be relocated to other well sites and can be directly connected into distribution grids. These advantages can be significant in the Caribbean context.

5. ECONOMIC AND FINANCIAL VIABILITY OF WELLHEAD UNITS: A CASE EXAMPLE

The Caribbean can explore the use of well-head units to capitalize on idle steam from wells that are already drilled, while full centralized power plants are being pursued. It takes over 2 years to develop a centralized power plant, and some sources estimate as much as 7 years. In the context of the Eastern Caribbean, in some cases, as many as 10 years have elapsed between confirmation of commercially viable geothermal resource through drilling and power plant construction. For example, in Dominica approximately 10 years ago, a commercially viable resource was confirmed, through the drilling of 3 slim wells and 2 production wells.

In Kenya, many temporary wellhead units have supported the development of the country's geothermal resource. A study which assessed the economic and financial feasibility of two electricity grid connected wellhead units in Kenya – an Olkaria wellhead unit, OW-43, with 12.8 MW installed (Kigen, 2016), and a wellhead unit at Eburru of output 2.4MW- suggested strong financial feasibility with a payback of 4.4 years. The study also concluded that the return on investment (ROI) was significantly shortened with the installation of temporary wellhead units. (Kabeyi, 2020). It is notable that the net profit derived from these wellhead units extended over a 3-to-4-year period.

Table 2 Revenue and operating profits for Eburru and Olkaria wellhead power plants - Source: (Kabeyi, 2020)

	YEAR (USD)		
	2013/2014	**2014/2015**	**2015/2016**
Revenue (USD)	2,488,395.29	6,592,900.73	6,397,391.31
Annual budget expenditure	(201,312.52)	(134,655.18)	(429,085.93)
Gross Revenue	2,287,082.77	6,458,245.55	5,968,305.38
Tax at 30%	(686,124.83)	(1,937,473.67)	(1,790,491.61)
Net profit	1,600,957.94	4,520,771.88	4,349,292.83
Rate of return $= \frac{\text{NetProfit}}{\text{Revenue}} * 100$	= 64.3	= 68.6	= 65.3

To determine whether the economic viability would be as promising in the Caribbean as it is in Kenya, further studies would have to be conducted. One major difference would be economies of scale caused by differences in market offtake of geothermal power in Kenya and Caribbean small island states.

An economic case can also be made for the use of wellhead generated power for consumption during drilling operations. A study estimates 350, 000 liters consumption of diesel from the start to completion of a geothermal well. This incurs a cost of roughly $430, 000 USD. Connecting wellhead generators to these wells, potentially saves more than a quarter of drilling and facility costs as the geothermal field development continues. (Kibet) The use of portable wellhead generators therefore reduces or eliminates the cost associated with the use of diesel and is also environmental friendlier.

5. CONSIDERATIONS FOR WELLHEAD POWER PLANTS FOR THE EASTERN CARIBBEAN

A number of factors must be taken into consideration when considering the use of wellhead units in the Caribbean.

1. The use of wellhead units as part of geothermal development projects in the Caribbean should be incorporated at the planning stage in the project development cycle. Decisions on whether wellhead units will be temporary or permanent must be made early on by developers and investors
2. Caribbean geothermal fields are located on small islands, hence steam gathering, transportation and balance of plant infrastructure must occupy a small footprint. Wellhead plants can meet this requirement
3. The reduced capital outlay and construction timeframe associated with wellhead plants augers well for Caribbean island applications given the present stages of greenfield development within small island economies. Deployment of wellhead technologies can also be a risk mitigation strategy, allowing for retention of capital while proving the operational characteristics of a geothermal reservoir
4. This approach permits quicker learning and development of localized expertise in geothermal power systems design operation and implementation, which is essential in accelerating the energy transition from conventional fossil fueled generation technologies such as diesel power plants. This also creates a learning curve and ensures a local cadre of professionals for the subsequent operation of the centralized power plant
5. In some cases, smaller localized wellhead units are better able to be integrated into existing grid infrastructure without requiring grid updates. Wellhead power plants often operate at low voltage and can facilitate stable grid connections. This enables decentralization, which is essential to achieving higher degrees of energy resiliency for the islands.
6. There is no significant difference in the capital cost per unit of power of wellhead units as opposed to that of central power plants. However, the latter is more efficient than the former. Well-head units have capacity factors of roughly 70% compared to 90 to 95% for centralized geothermal power plants. Nonetheless there are a number of other benefits of wellhead units including higher flexibility and less complexity. This makes well head generating units suitable for replacing fossil fuel generated baseload for the region’s clean energy transition.
7. Due to its comparatively lower capital intensity and significantly reduced lead times between drilling and revenue generation, access to capital and less risky repayment plans improve the economic viability of wellhead applications versus centralized plants. With competing national fiscal priorities in the tourism-dependent economies of the Caribbean, especially with a focus on economic recovery from the recent global pandemic, this can encourage allocation of national budgets towards geothermal development. In the same way private investors may be more encouraged.
8. The modular characteristics of wellhead units enhances access to small value capital lending and may present a unique opportunity to attract more suitable investors, making it more attractive to smaller scale investors.
9. With the Caribbean region currently exploring the incorporation of direct use of geothermal energy into geothermal development projects, the opportunities of integrated investments posed by wellhead units, can be explored to pair agriculture or recreation revenue generating activities. This creates more ownership and even acceptance of geothermal development among Caribbean communities through the creation and enhancement of livelihoods.
10. In cases where drilling sites are far apart, wellhead units should be considered depending on the technical and economic feasibility

6. A CASE EXAMPLE

6.1 The Saint Lucia Geothermal Project Context

Three drilling sites have been identified in Saint Lucia; two sites within 'Area 1a' and one within 'Area 1b'. (See figure 8 below) Substantial parts of Areas 1a and 1b are identified as significantly steep terrain and have no access roads, which presents a huge obstacle in developing that field extensively. This means high costs for civil works and road infrastructure will be incurred. Due to the obstacles of accessing the geothermal field in these areas, it is best to adopt a no-go decision for development even if a commercially viable resource is not found in the more accessible sites as shown on the map. The economic viability of the project will therefore be significantly diminished if extensive development is pursued in these difficult areas.

It is also worth noting that the distances between the 3 potential drilling areas are extensive (over 10 km in some instances). A centralized power plant to connect the 3 drilling sites, should an exploitable resource be confirmed in each area will require an extensive steam piping network, in addition to investments to make grid connection feasible. Steam collection systems would have to be adapted to overcome difficult terrain.

The results of the slim hole drilling in each of the sites will provide further insight on the many possibilities for power plant development. The prefeasibility study for this drilling operation mentions the possibility of a centralized power plant being fed by a resource gathering systems from all 3 sites, (Phased approach with two 15MW plants). It also considers one plant being fed by its immediate vicinity through directional drilling from one or two well pads, on the premise that if the resource conditions allow, 3 to 5 production wells will be drill. It is not possible at this time to determine well distribution and field configurations to support the development of the planned 30MW given a commercial resource. However, grid interface conditions at each of the three sites is favorable, with a single-circuit 66 kV transmission line existing within a few km of each proposed site. The geothermal plant would be integrated into the existing transmission system with some additional interconnection infrastructure. Source: (Author's own experience and interview with technical team)

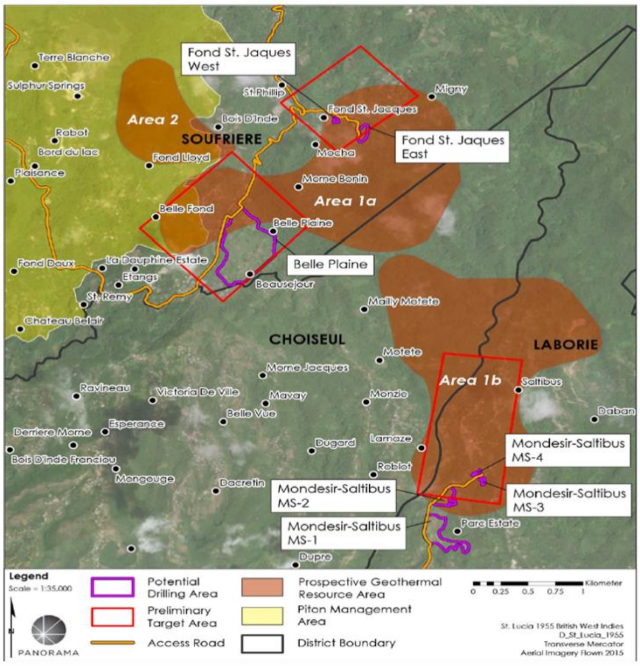

Figure 7 Drilling areas in Saint Lucia

Figure 8 Map showing potential drilling sites in Saint Lucia

6.2 Wellhead power plants applied to the Saint Lucia project as a proof of concept

All of the above scenarios and considerations surrounding this project indicate an opportunity to explore modularized wellhead units either as temporary installations or permanent solutions. In the case of a centralized system, temporary wellhead units on the 3 to 5 production wells until the steam collection system is developed for centralization, could make the project more financially viable. Wellhead units which can immediately begin producing electricity to the nation grid, or to support continued drilling operations in the same vicinity, can generate revenue shortly after drilling. In the case of the remote areas within Area 1a, with notable terrain and site access challenges, permanent wellhead units can also be considered.

Wellhead technology has the potential to increase community buy-in and local ownership. The Saint Lucia project has also come under scrutiny and has not received full acceptance from all sections of the populace, given the long exploration history without confirmation of resource viability. In addition, Saint Lucia, like most Geothermal hotspots in the Caribbean has a significant demand for enhancing the local geothermal workforce. Wellhead units can provide an effective opportunity for workforce development by accelerating the learning curve with practical experience while the geothermal field is being developed.

7.CONCLUSIONS

Geothermal energy is catalytic towards achieving a global energy transition from primary use of fossil fuels towards proliferated utilization of indigenous renewable energy resources. In this context, Caribbean small island developing states which have identified and proven geothermal resources, are poised to realize a true energy transition by displacing conventional diesel-powered plants with stable baseload geothermal generation. However, the conventional geothermal plant developmental process requiring significant capital outlays and infrastructure development has proven burdensome for small island economies, and therefore prohibitive to the acceleration of the Caribbean island energy landscape transition. With reference to case studies in Kenya and other regions, the research and content of this paper has conclusively presented a case for the adoptation and deployment of wellhead geothermal plant technologies within the Caribbean island chain, as an approach towards surmounting the financial and technical obstacles impeding geothermal development in the region. It has been deduced and concluded from research that well head plants provide a least risk, least cost, earliest return on investment pathway, while permitting island nations to prove their geothermal resources and at the same time develop local expertise in geothermal exploration, development and also plant operation and maintenance. While the research has shown that conventional plants in the long term provide higher operational efficiencies and benefits, wellhead plants can be considered as bridging technologies, providing a segue towards a sustainable future of proliferated geothermal energy utilisation amongst Caribbean nations. Wellhead plants can also, in specific cases, provide more permanent solutions for remote resource locations.

It is recommended that further research be done in the Caribbean to develop an easily replicable proof of concept and wellhead deployment blueprint. It is understood however that thought this paper proffers a suggested mechanism, this is contingent on the intervention of external expertise and financial mechanisms, to kickstart the Caribbean region geothermal wellhead plant deployment.

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