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Regional and International Cooperation: A Strategy to Overcoming Longstanding Challenges in Geothermal Development in the Caribbean

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ABSTRACT

For decades several Caribbean islands have been working to develop their geothermal resources. Despite these efforts and scientific evidence that suggests viable resources, with the exception of Guadeloupe, no other island has achieved commercial operation of a geothermal plant to date. The Caribbean is particularly affected by high electricity costs which are in some instances as much as five times higher than electricity costs in the United States and other regions. This is primarily a result of the region's high dependence on imported fossil fuels. Successful geothermal energy development would redound to multiple benefits for the region, however several challenges, mainly due to small scale of projects and limited technical capacity need to be successfully addressed. Most of the proposed power plants have a nameplate capacity of less than 20 MW, which poses economic challenges and challenges to attract reputable developers and investors. This paper identifies the techno-economic challenges to geothermal development and utilization common to Caribbean islands with geothermal potential for electricity generation. The paper also proposes a pathway towards achieving the region's geothermal energy goals primarily through combining several national geothermal projects and through regional and international collaboration on geothermal exploration and development in the region.

The paper examines where it is most useful to combine efforts on geothermal, how this can be achieved, and the prerequisites for success, to benefit from economies of scale. Opportunities are identified for all stages of geothermal energy development, taking into consideration existing institutional structures, regulatory frameworks, existing and emerging business models and financing models. Such an approach will improve the economic viability of the projects and will allow for the identification of innovative solutions and the adoption of best practices.

Iceland has long been recognized as an industry leader in Geothermal Energy. In recent years the Caribbean region has benefitted from specialized geothermal training from Iceland. At present the human resources on each island are limited and, in some cases, the trained personnel are not actively working on the ongoing projects. A regional approach to tapping into this pool of technical expertise could prove to be a key factor in successful project development for the region. Developing a proactive system to engage regional geothermal experts would support sustainability for the future.

Regional and international collaboration on geothermal energy could be expanded beyond geothermal power to other direct uses of geothermal resources, helping to create new economic opportunities through a multi-stakeholder approach and collaboration across non-energy sectors.

The authors collectively have diverse decades long backgrounds in most aspects of geothermal energy in Iceland and the Caribbean.

1 INTRODUCTION

The global energy crisis of 2022 has further underscored the need for energy security particularly for small islands who are dependent on fossil fuels for their energy needs. In addition to the vulnerabilities to the vagaries and fluctuations on the global oil market, dependence on imported energy results in a considerable amount of the region's GDP being expended on energy. High energy costs limit the growth and competitiveness of a country, and therefore affects the general quality of life. The Eastern Caribbean region is convinced by the benefits that can be derived from the successful development of its indigenous renewable energy resources such as solar, wind, hydro and geothermal. Although still underexploited, successful development of the region's geothermal energy potential could significantly add to the region's energy mix. Based on the idiosyncrasies of region's energy sector, geothermal energy has emerged as an important area of development which could benefit from improved regional collaboration for the region.

Like other forms of renewable energy, geothermal energy can support energy independence and improve reliability of electricity supply. It is also expected to result in reduced energy costs as well as improve the predictability of electricity supply. This will not only improve the quality of life for Caribbean citizens but also encourage direct foreign investments required to stimulate economic growth. The environmental benefits of geothermal energy are also important for the Caribbean including the mitigation of the effects of climate change. Given the general positive impact geothermal energy could have on the region as whole, it is worthwhile to explore how to support its exploitation and development, with an effective approach.

2 CARIBBEAN ISLANDS WITH GEOTHERMAL POWER GENERATION POTENTIAL

The Eastern Caribbean is a volcanic arc which presents an area conducive to the development of geothermal electricity production, making it the main contributor to the region's total potential. A number of exploratory stage studies on geothermal energy have been

conducted from as early as the 1950's (Saint Lucia) and exploration is still ongoing in some of the islands. Currently eight out of the eleven Organisation of Eastern Caribbean States (OECS) Member States are actively pursuing geothermal energy projects and have made advances in resource assessments for geothermal electricity generation. These are namely: The Commonwealth of Dominica, Grenada, Guadeloupe, Martinique, Montserrat, Saint Kitts and Nevis, Saint Lucia and Saint Vincent and the Grenadines. Figure 1 below provides an estimation of the planned geothermal energy projects for the region. Although estimates vary, it is projected that geothermal energy could provide upwards of 300 MW to the region , See Table 1. (OECS 2019). Preliminary studies on direct use geothermal resources have also been done in some OECS countries (Jacobs New Zealand Ltd 2021) .

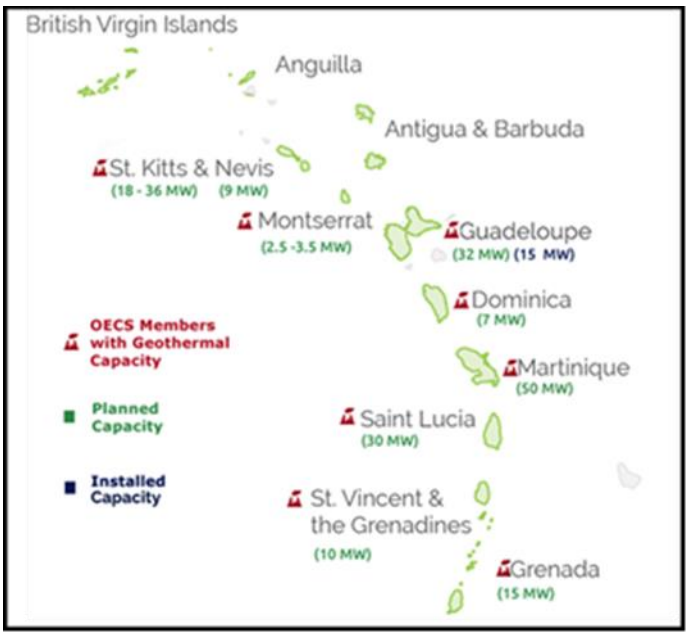

Figure 1: Geothermal power generation potential in the OECS (Source: OECS 2019)

2.1 Current Status of Power Generation

Today power generation in the Eastern Caribbean region is mainly based on diesel run generators with a small percentage of solar energy on most islands, and to an even lower extent, wind energy and hydropower.

The following information is gathered from IRENA, Energy profiles for the OECS islands in 2020 and from the Energy Transition Initiative, U.S. Department of Energy. Energy Snapshots, 2020

	System Peak Demand (MW)	Total Installed Capacity (MW)	Total Conventional Capacity (MW)	Total Installed Renewable (MW)	Geothermal installed capacity (MW)
Anguilla	16				
Antigua & Barbuda	50.0	87.5	78.3	9.2	0.0
British Virgin Islands	34.0	57.4	56.4	1.0	0.0
Dominica	16.0	27.4	20.1	7.3	0.0
Grenada	31.9	55.3	52.0	3.4	0.0
Guadeloupe	247.0	556.0	435.0	121.4	14.7
Martinique	235.0	543.0	411.0	132.0	0.0
Montserrat	2.1	7.3	7.1	0.3	0.0
St. Kitts & Nevis	38.4	68.6	65.9	2.7	0.0

St. Lucia	59.0	93.1	88.4	4.7	0.0
St. Vincent & the Grenadines	24.8	53.2	44.4	8.8	0.0

Table 1: Yearly electricity production in OECS islands

Data Source: CCREEE, and Energy Transition Initiative, US State Department of Energy

2.2 Long- term Energy Forecasting and Planning

A long-term energy forecast which covers at least until 2050 is essential for the successful planning and realization of the sustainable energy transition in the Caribbean. The transition, also supports the fight against global warming, and is expected to result in an almost complete replacement of the existing electricity production from imported fossil fuels. The intention is greatly expand energy production from the harnessing renewable energy on the islands. Coupled with renewable energy development, energy saving technology is expected to reduce the growth in energy demand when compared to the business-as-usual scenario.

Given that like most small island developing countries(SIDS), the Caribbean region is highly vulnerable, the region's electricity sector must adequately meet the future energy needs of its people. As such, energy planning must incorporate the region's resiliency needs. Energy resilience not only includes the resilience of infrastructure, but also economic resilience through affordable, reliable, and sustainable energy supply (Ephraim-Schmidt et al 2021). This requires pursuing the development of the appropriate renewable energy technologies towards a "least regret "scenario. The latter is the basis of the integrated resource and resilience plans (IRRPs) being mainstreamed throughout the Caribbean. The CCREEE for instance is currently working on IRRP that iterates on the traditional integrated resource planning process that electricity sector utilities regularly undergo by integrating analyses of climate vulnerability. The CCREEE, during this process, will help to raise the human and institutional capacity for systems modelling and planning in governments and utilities and these studies will ultimately show how geothermal energy can fit into the energy mix.

In the meantime, renewable energy development is at a very early stage in the Caribbean. In comparison, Latin America has developed extensive hydro power and other forms of renewable energy including geothermal. So, the Sustainable energy transition in the Caribbean will be a steep climb compared to many other nations in Latin America. To achieve the region's sustainable energy targets and the Nationally determined contribution targets , the region will most likely have to deploy a combination of geothermal, solar and wind energy development together with the associated energy storage. All this tied to careful phasing out of fossil fuel energy. To match future energy demands and to ensure affordable energy in the region, the ideal mix of technologies must be assessed and developed, to include both variable renewable energy technologies and crucially, non-variable baseload enabling technologies. An optimal development of renewable energy, using suitable analysis and planning tools, is key to ensuring economical electricity and carbon neutrality in the future. Given that large scale power generation projects like geothermal usually take at least 10-20 years from the initial idea until commissioned. A robust electricity forecasting and planning process for the Caribbean islands seems therefore to be timely.

2.3 Recent Geothermal Energy Activity

In recent years there has been heightened activity in geothermal energy in the Caribbean. The Commonwealth of Dominica has advanced plans for a 10 MW plant to be led by the Dominica Geothermal Development Company . In 2022, the Government of Dominica signed a $33.7-million contract with the Iceland Drilling Company to drill two additional well in preparation for the plant construction (Richter 2022). In 2019 Saint Vincent undertook exploratory drilling of 3 wells. These wells produced heat but not the permeability needed for electricity generation at the required level (Richter 2020). Since then, efforts have been focused on technology which will allow the country to use its geothermal resources including the closed loop system. Under the Energy Transition in the Caribbean project a remapping and reassessment of the geothermal resource use new innovative technology was undertaken in 2022. The results of this work should help determine whether the volcanic activity on the island in 2021 have impacted the permeability and enhanced the chances for geothermal development (Peters, Lance Pers Comm November 2022). The Government of Saint Lucia has obtained US$21.9 million for the Renewable Energy Sector Development Project for Saint Lucia from the world Bank (World Bank 2021). This grant financing will help the Government of Saint Lucia assess the viability of its geothermal resources for power generation and strengthen the business environment for the private sector to pursue clean energy projects. The project will also support exploratory drilling, capacity building, technical assistance, and market engagement. The Government will be undertaking a drilling programme as part of this project which will look at 3 new drilling areas(World Bank 2022).

One of the smallest islands in the Caribbean, Montserrat has embarked on two bold initiatives in 2022 to attract direct investment in Geothermal energy after 7 years hiatus in geothermal energy development. Firstly, Montserrat has awarded the contract for the maintenance of the existing Geothermal Wellhead equipment which aims to revitalize the existing geothermal infrastructure on the island, and to provide a technical baseline for the status of the existing wells. Montserrat has also launched a Request for Proposals (RfP) for the Economic Development of Montserrat's Existing Geothermal Wells (Discover Montserrat 2021). The island of Nevis ,

the smaller island of the St. Kitts and Nevis Federation has also announced plans for geothermal drilling with support from the Caribbean Development Bank (CDB) . The grant financing for the project will help the Government of St Kitts and Nevis pursue the drilling of up to two geothermal production wells and one injection well. The project's goal is to establish a geothermal power plant of capacity of ten megawatts, more than enough to meet all the domestic electricity demand in Nevis(Richter 2023). The project scope includes support to the Government and Nevis Electricity Company Ltd (NEVLEC) for project preparation, such as, preliminary surveys, surface exploration and environmental and social impact assessments, which are already ongoing, as well as infrastructure works, engineering, construction services and project management, and drilling services. It is expected that the Nevis Island Administration (NIA) will embark of the drilling phase of Nevis' geothermal project in June 2023 GOSKN (2022) .

3 CHALLENGES FACING GEOTHERMAL DEVELOPMENT IN THE CARIBBEAN

The Caribbean region have set some ambitious renewable energy targets in support of its intended sustainable energy transition. These targets are based on the estimated potential for renewable energy projects but the realization of these project can be delayed due to a number of challenges. Geothermal energy as a renewable energy, faces several unique challenges for development globally and this is also the case for geothermal energy in the Caribbean. Although the individual geothermal projects are at different stages and may have slight variations, overall, the region experiences important shared similarities in circumstances and needs for geothermal energy. The following table summarizes some key challenges to geothermal energy in the Caribbean.

Challenge	Description
Political risk	Changes in national or local government leads to delay or cancellation of geothermal projects. Halfhearted/minimal support of the project from relevant authorities results in costly delays. Disagreement within the Joint Venture Group islands can negatively impact the project.
Environmental Impact Assessment, EIA. Licensing	Delays due to appeals and project possibly rejected. Institutional barriers due to lacking regulation for geothermal development. Competing uses of land may affect approvals in some cases.
Resource and drilling risk	Geothermal resource quality risk. Drilling risk.
Small, uneconomical project	Expensive financing. Expensive drill rig mobilization. Few and low-quality bids and unfavorable Contractor offer. High levelized costs of electricity resulting from capital intensity.
Energy market related risks	Inadequate coordination with other power producers (diesel, solar, wind) can hinder project feasibility. Geothermal must contend and contest with fossil fuel technologies and supply chain institutions that have diverse linkages within Caribbean economies. (Profit margins, corporate social responsibility)
Staff training	Inadequate staff training can severely effect plant reliability and increase electricity cost. Plant future development and improvement is dependent on highly skilled staff.
Social	Private land ownership of resource location hurdles Perceived hazards of geothermal development including threats of seismic action and air and noise pollution, creating a NIMBY effect among communities.

Table 2. The table above lists of some of the challenges facing geothermal development on the islands.

4 REGIONAL GEOTHERMAL COOPERATION OPPORTUNITIES

The challenges related to geothermal energy development can be significant for small islands like those of the Caribbean that have limitations with financing, policy and human capacity. The Caribbean region has long realized that a regional approach would be best for addressing existing geothermal hurdles as well as for leveraging opportunities for cooperation. The Caribbean Centre for Renewable Energy and Energy Efficiency has nine energy thematic hubs, including for geothermal energy, that serve to support regional collaboration on energy. There is already some existing and successful cooperation on geothermal energy which can be further explored and enhanced. The following are two significant geothermal related initiatives that foster a regional approach for development.

4.1 The OECS GEOBUILD

In 2022, the Caribbean welcomed the commencement of OECS Geothermal Energy: Capacity Building for Utilization, Investment and Local Development Programme (GEOBUILD), a 3 year intervention designed as a direct response to the capacity building constraints of the region with respect to geothermal energy. The GEOBUILD is a regional capacity building initiative which seeks to enhance the human capacity, existing institutions and process for geothermal energy. The GEOBUILD Programme will support capacity building in the scientific and engineering aspects of providing geothermal energy and ensuring that its uses are fully explored and utilized. It will also seek to enhance the legal and transactional aspects of geothermal energy development in the region, ensure that business models are developed, and agreements negotiated to provide clear and advantageous benefits to its people (OECS 2022). The GEOBUILD is also expected to further facilitate greater coordination, sharing and collaboration of geothermal energy in the OECS.

4.2 Caribbean Geothermal Center of Excellence

As the only island with an operating geothermal plant, Guadeloupe has knowledge, expertise and experience in developing a geothermal plant in an island context which can be useful to the rest of the Caribbean. Cognisant of this opportunity, the Regional Council of Guadeloupe through the INTERREG IV Energy Transition in the Caribbean project has established the Caribbean Centre of Excellence on Geothermal Energy (CECG) to accelerate and facilitate future geothermal projects in the region. The Center is expected to support the region as a resource center and facilitate training, cooperation, communication and pooling of resources and expertise(TEC 2023). In addition the center is expected to assist with environmental studies and sharing of best practices (LaFFont 2019), The Center of Excellence will operate as part of regional knowledge initiatives led by the University of the French West Indies, the Caribbean Centre for Renewable Energy and Energy Efficiency (CCREEE) and the Organisation of Eastern Caribbean States (OECS) (Guadeloupe Energie 2023).

5 A MULTI-ISLAND JOINT GEOTHERMAL VENTURE FOR THE CARIBBEAN

As outlined above, collaboration amongst the islands with geothermal interests is seen as a major prerequisite for successful development of geothermal energy in the Caribbean. As shown in Section 4, regional collaboration is happening for geothermal energy but deepening this collaboration through joint development would add another dimension that has not yet been explored in the region. This can be realized through the formation of a multi-island joint venture for geothermal development in order to improve the economic viability of the projects. The key elements of a joint geothermal venture would entail combining several island geothermal plants projects into a single joint venture project in order to attain project economy of scale. In addition to the economic benefits, such a venture would also facilitate technology transfer in geothermal technology amongst the islands. Contractual agreements can also be addressed under this approach and can be designed to include clauses on participation of local subcontractors. The joint venture approach would also provide benefits through shared knowledge and training in the field of geothermal utilization.

5.1 Proposed Operationalization of a Joint Geothermal Venture

The following are the key elements needed for a joint geothermal venture in the Caribbean and how it could function:

a) Number of Islands: Two or more islands are needed to form the joint- venture to pursue geothermal development in order to reap the benefits of close cooperation, coordination and economy of scale.

b) Nature of Joint Venture Partner: The participants from each island could for example be the island government, the island electricity company or a private company trusted with the geothermal development of the island. In any case, the partner should have a leading role in geothermal energy on the island and is expected to represent the island's interest and have the authority to take decisions on behalf of the island The appropriate representation for each participating island will have to be carefully negotiated when forming the Joint Venture.

c) Phased Development as Part of the Joint Venture Project: Due to the uncertain quality and size of the geothermal resource a cautious, phased, approach is often recommended for a geothermal project and that also include development using a joint venture project approach. Icelandic energy companies, for example, have been applying the stepwise development approach in their latest developments(Armannsson et al 2011, Steingrimsson, 2014),. In designing the Joint Venture Project agreement, the first phase should be well-defined and fixed but subsequent phases are more flexible and can be negotiated later. It is expected that the first phase in the joint venture will be smaller in scope and intended to assess the geothermal resource before a decision is made about the size and design of the next phases.

In a phased approach, the generating unit used in phase one is relatively smaller in size compared to the later units and can be put into operation much earlier than a "full size plant". It is recommended that at least 2-3 years should pass between the first and second phases. If the joint venture project consists of power plants located in more than one island, then it is recommended to finish one plant first and use the experience gained from the first plant to improve the design of the subsequent plants. Multi plant projects should preferably be constructed almost continuously to reduce cost of unnecessary staff and construction breaks and mobilization between islands. For economy of scale the whole project should be in a single contract for all the plants and phases. As such this will require detailed planning and coordination amongst the participating islands at several levels. Based on global experiences, the he first development phase is expected to be the most expensive but the later phases will be gradually less expensive as experience is gained in the region. There are several examples of geothermal projects worldwide that show that a stepwise development strategy for geothermal resources has considerable economic benefits compared to full utilization of the geothermal filed in one big step (ESMAP 2012).

5.2 Selected Guidelines for a Caribbean Joint Geothermal Venture

The administration of the joint venture must be clear and agreed upon to facilitate ease of participation and ultimately success. Whilst the procedures for operation will be developed based on best practice and unique circumstances of the participating islands , below are some proposed guidelines to be considered:

- A single contract covering all participating islands and plants to achieve economy of scale. The contract should include all phases and all participating islands.
- After each phase, a decision should be taken about the design of the next phase.
- Given that costs are reduced for each subsequent phase, a formula must be devised for balancing out the cost between islands and sharing economic benefits.
- The contract costs for each phase, plant and island must be kept separate and recorded. There will be some unexpected cost changes for each phase that have to be accounted for accurately to facilitate to settlement between the islands.

5.3 Financing and Project Size

Development of geothermal energy projects in general can be significant financial undertaking that is often difficult due to the risks typically involved in geothermal projects. In the context of small islands with smaller project the financing is even more difficult. In addressing the financing for geothermal energy, the Caribbean must explore both new and traditional funding sources for both grants and favorable loans. Climate Finance, particularly for climate change mitigation is becoming an important part of financing for sustainable energy. The small size of energy project in the Caribbean can be a hurdle to attracting climate financing when compared to other larger developing country projects. Accessing climate financing for the geothermal projects in the Caribbean would be easier if they were some achievements of scale by bunding or pooling of projects under a joint venture geothermal project. For example, the planned geothermal projects in the Caribbean are all below 50 MW but taken jointly it is estimated that the geothermal plants on 6 islands would total almost 300 MW representing a yearly CO2 emission reduction of about 1 million ton. This would provide a much more attractive project for climate finance,

With respect to geothermal energy, the Caribbean has traditionally obtained financing from development partners including the Caribbean Development Bank, the Inter-American Bank, New Zealand and the World Bank. The European Union Climate Facility is also providing support, however there may be additional support avenues to be explored, Cooperation with the Nordic countries would be of special interest here due to their outstanding track record regarding renewable energy projects. Here Iceland stands out, especially regarding geothermal utilization.

5.4 Project Preparation and Procurement

Much of the project preparation work such as feasibility studies, design work and procurement will be much more economical if undertaken in a joint venture involving two or more islands instead of a single island project. The legal component is a critical part of geothermal development. Contracts for geothermal projects are complex and specialized requiring significant of expensive legal work by lawyers experienced in power plant contracts. A multiple island geothermal Joint Venture will provide the economy of size to justify adequate legal representation. Such an approach may also be useful in negotiating Power Purchase Agreements (PPA) by leveraging the collective expertise and experience of the participant islands. Under this approach, the region could in addition capitalize on proven experience of design engineers, contractors, project managers and other key players in previous successfully completed projects for a successful project. The pooling of the project is advantageous as it is difficult to attract top notch geothermal experts to a small single island project. With respect to procurement, a **c**omprehensive **c**ontract (PPP or other type) framework/policy should be developed early in the project preparation work for the joint venture. No contract (PPP or other) arrangements should be entered unless a contract framework/policy is developed and approved by the participating government.

5.5 A regional Approach To Human Resources and Technology Transfer

Adequate human capacity with respect to both quantity and quality is very important for the success of geothermal projects. Trained personnel is needed in all aspects of geothermal development, hence a multidisciplinary team is needed. It is, however, unrealistic to expect a wide range of skills on any one small island. As such a regional approach for human resource which promotes collaboration is proposed. The countries that have been most successful in developing geothermal energy in recent decades have put heavy emphasis on the training of local staff in all aspects of geothermal utilization. One of many indications of this is the number of students from these countries attending the Geothermal Training Program in Iceland. As an example, 90 students from China have attended the program in Iceland, 134 from Kenya and 42 from El Salvador. These countries have been especially successful in training their staff and as a result in operating their power plants reliably and economically. Many of the students that have studied in Iceland have become leading experts in their field in their countries. (Jiurong, 2008) "The Chinese UNU Fellows are playing a very important role in the geothermal development in the country, and many of the former UNU Fellows have become leading experts in their specialties in different parts of the country. The contribution of UNU-GTP on the geothermal development in China has long been recognized." (Georgsson, 2018).

Geothermal energy is still a novel and relatively complex undertaking for the small islands of the Caribbean. The connection of geothermal plants to the existing electricity grids in the region will require an appropriate level of technology transfer to support a smooth transition in operations. This should cover all stages including the exploration phase, the design of power plants , maintenance and future improvements. A regional approach in this regard would help overcome several barriers and produce clear tangible benefits. In December 202, the GEOBUILD programme together with IRENA provide training in Power Purchase Agreements for the Caribbean and this proved to be very beneficial for cost effectiveness and sharing of experiences in the region(IRENA 2022). Such a model could easily be adopted for other areas of geothermal training. Some key considerations are outlined below:

Training and Economy of project size.

Thorough training of Operating & Maintenance, O&M, staff is needed for reliable operation of a geothermal plant. This would entail training of promising engineers and other specialists in all aspects of geothermal utilization. Specialized training of this nature is needed for approximately 25-40 persons per project. This training is expensive and as a result, such training is not feasible for small power plant project on a single island of a few MW in size. A larger project under the joint venture project approach would reduce the cost of training.

Plant availability and training.

Staff training usually has a huge impact on plant reliability and availability. If training is lacking and qualified specialists are not available locally it can be expected that unscheduled outages and long repair times result in yearly outages that last several weeks and even months longer than otherwise is to be expected.

Plant availability is key in ensuring low electricity tariffs. This is particularly important for Caribbeans countries who already have relatively high energy costs and are desirous of developing their indigenous renewable energy sources to reduce their electricity prices. Through improved plant availability the payback of the comprehensive O&M training investment will be a few years or even less than a year in some cases for a large project. Unreliability and abnormally long unscheduled outages can easily result in a very low-capacity factor and thus a 10% - 20% increase in electricity price. Hence a regional joint venture for geothermal energy could support a higher number of trained personnel for collaborative O&M for the region.

Training and the Evolving Nature of the Geothermal Reservoir

The optimal operation of a Geothermal plant is a never-ending Research and Development task. Geothermal plants are very individual in terms of the quality of their resources and management needs. Each plant is therefore largely a custom design. Geothermal power projects also require continuous development and optimization throughout their lifetime, with sophisticated management of the reservoir and production wells and repeated power plant improvements to ensure output meets expectations. The behavior of the geothermal plant and its reservoir evolves almost constantly over time in a way that is much more challenging than, for example, wind or solar photovoltaic (PV). The process of extracting reservoir fluid and reinjecting it over the life of the project creates a dynamic situation where reservoir fluid migration will likely change over time, with implications for the productivity of individual production wells. This makes high demands on O&M staff and results in higher O&M costs. A regional joint venture provides advantage of having more staff for training, research and design than small single plant .

Diminishing expertise in a small project.

Adequate training is difficult to maintain in a small project. In a small project there will be few and far between opportunities to exercise skills and talents acquired in training. The expertise gained in training will therefore gradually diminish affecting plant availability and thus electricity price. A Regional joint venture provides much more opportunity to problem solve and to apply the knowledge acquired helping to support professional growth and development of the human resources.

Contractor responsibility for the plant operation in the first years

During plant commissioning, testing and during the first years of operation highly experienced geothermal power plant staff is needed, i.e., key staff that has successfully operated one or more geothermal power plants for a decade or longer. This experienced staff shall be responsible for the plant operation for a few years, perhaps for a guarantee period of 2 or 3 years or longer, and at the same time train local staff so that they will fully be qualified to operate the plant reliably when the contractor staff has left. A regional approach with more than one geothermal plant allows for faster more efficient hands on training of local staff.

Technology transfer and local subcontractors

The participation of local subcontractors in the projects should be emphasized due to benefits of cost and quick maintenance. The procurement process may have to be adapted to this, i.e., dividing the procurement into subtasks that are suitable for the capability of local subcontractors. The participation of local subcontractors facilitates technology transfer to the subcontractors. They will gradually gain knowledge that's useful for servicing the power plants and for future geothermal projects. The quality and speed of local service will thus improve and in the long run subcontractor cost should be reduced resulting in lower electricity cost.

Only one small plant it not economical to train local sub-contractor but many small plants it is economical to train a subcontractor. It is cheaper and faster to mobilise a local or regional subcontractor.

Spare Parts Inventory

Spare parts are relatively costly for a small project and due to the weak economy of a small project spare part stock may be inadequate due to cost. Most spare parts can be shared between participating islands in a large multi-island project resulting in savings and better spare parts inventory. This again will be reflected in better plant availability and thus lower electricity cost.

Staff Sharing and Control Centre Savings

Staff sharing between two or more islands reduces operating costs. Through extensive remote monitoring and control of the power plants a joint control center for multiple islands will be feasible, saving on monitoring and operation costs. A well -manned control center also leads to quicker more focused response to operational problems and shortens downtime.

5.6 Economic Benefits of a Joint Venture Summary

As described above the benefits of a joint venture approach to geothermal energy in the Caribbean would produce several cross-cutting benefits. To summarize, the economics of scale and improved project feasibility would mainly be achieved through the following:

- Larger projects result in more efficient and economical project preparation, design work, financing, procurement and contract negotiations and project management and more.
- Favorable green financing may be easier to obtain for larger projects.
- Larger contracts lead to increased competition and lower prices.
- Most spare parts could be shared between participating islands resulting in savings.
- A large project facilitates technology transfer to local contractors that should result in lower service cost and lower cost for future projects.
- A large project facilitates improved, cost-effective training resulting in improved plant reliability and uptime. This results in more profitable operation.
- Staff sharing between two or more islands reduces operating costs.

6 OPTIMAL INTEGRATION OF GEOTHERMAL

The energy sources that are of most future relevance to the Caribbean islands are renewable energy such as geothermal, wind and solar in combination with some form of energy storage. Diesel generators or other fossil fuel will probably also exist as backup when renewable energy is not available for some reason or is insufficient.

An optimal integration of the various power sources must be found for each island, through the use of an advanced energy system analysis tool.

The optimization result will mainly be governed by the different characteristics of the different energy sources, mainly their different capacity factors and predicted energy price. Also taking eventual energy storage cost into consideration.

In this context, techno - economic optimisation seeks to balance a time bound dispatch of the most reliable energy resources at least cost while satisfying national GHG emission targets. In the context of Caribbean SIDS with identified geothermal potential, while geothermal will progressively satisfy long term RE and GHG targets, the transition can be bridged through an upscaling of variable RE technologies, backed by battery storage and dual fuel (Natural gas and Diesel) thermal generators.

7 DIRECT USE AND CASCADE USE FOR IMPROVED PROJECT ECONOMY

Geothermal direct use has gained credit for supporting decarbonization beyond the electricity sector and across many industrial sectors in many countries across the world. The Caribbean has focused mainly on the development of its geothermal resources for electricity generation. However, recent studies by both Deloitte through US State Department and Jacobs New Zealand Limited, have investigated immediate and medium-term opportunities for islands of the Eastern Caribbean to pursue direct use projects. As the Caribbean continues to explore innovative approaches to advancing their geothermal development projects, the potential of direct use to boost local industries and economies must be capitalized to enhance the business case for these projects. The inclusion of direct use projects stands to improve community and political level acceptance and championing of Geothermal projects nationally, as well as improve economies of scale. A number of islands have already drilled wells or planning to commence exploration and production drilling programmes. This provides an opportunity to explore both cascade and standalone systems for direct use applications at the regional level. In the case of the former, through which sequential operations at varying temperatures after electricity generation is practiced, the economics of small-scale of geothermal power projects can be significantly improved.

Based on the climatic, socio-economic and physical context of the Caribbean, several applications are suitable for the Eastern Caribbean. These are centered on applications related to tourism services, agro-processing, building cooling, and production of export items and the food and beverage sector. Direct use of geothermal energy can also be explored under a joint venture or collaborative approach to reap the benefits of scale. The following table exerted from a (Jacobs New Zealand Limited , 2021) report, highlights the specific applications relevant to the Eastern Caribbean islands.

	Process	**Potential Application**
High Temperature >100°C	Sterilization	Meat processing, soil sterilization, food processing (blanching/peeling)
	Refrigeration	Cool storage, ice making
	Distillation	Liquor & essential oils
	Building cooling	Air conditioning for hotels, malls, hospitals
	High temperature drying	Lumber
	Evaporation	Sea salt, fruit concentrate
Medium Temperature 50 – 100°C	Drying	Local fruits & vegetables, spices, cocoa, coffee, herbs
	Cool storage	Produce
	Pasteurization	Fruit juice, goat milk
	Food processing	Cooking, canning
	Washing laundry	Hotels, hospitals
	Melting	Candles from beeswax
Low temp <50°C	Bathing	Tourism and local uses
	Aquaculture	Shrimp, tilapia
	Growing	Mushroom culture
	Washing	Domestic

Figure 1: Potential applications of geothermal heat in the OECS

8 THE WAY FORWARD FOR CARIBBEAN JOINT GEOTHERMAL VENTURE

The development of a regional joint venture for the geothermal energy development in the Caribbean seems logical and feasible based on the arguments and rationale described above. This strengthened form of cooperation would make sense at this time given that there are plans for drilling for instance on more than one island. It would therefore be worth exploring such a venture amongst the islands of Saint Lucia, Nevis, Montserrat, Dominica and Saint Vincent for example who are at a similar stage. The following summarizes some proposed next steps that should be undertaken to realize a joint venture.

Step 1-Explore interest in the proposals for a joint venture for geothermal energy among OECS islands with geothermal development potential.
Step 2-Identify Pre-feasibility Study Funding. If two or more islands show interest then, together with selected consultants, seek funding in Iceland and the European Union for a pre-feasibility study for a Joint-Venture geothermal development project.
Step 3-Conduct Pre-Feasibility study**.** Key issues covered would be:

a. Gather and peruse existing data on the geothermal source in the participating island.
b. Visit by key Caribbean geothermal development stakeholders to Iceland to inspect exemplary geothermal development projects and to draft outline plan for eventual Joint-Venture.
c. Complete pre-feasibility study report and decide whether to continue and plan a bankable feasibility study.

Step 4-Conduct Feasibility study financing to identify potential financiers of a feasibility study if decision is to go ahead.

Step 5 -Build Awareness and Sensitization for a Joint Geothermal Venture to build appreciation, ownership and champions**.**

9 CONCLUSION

Caribbean SIDS have been historically dependent on imported fossil fuels imports to drive socio-economic functions. However, to remain competitive the region must explore energy options that provide a reliable, affordable energy source that makes use of the region's indigenous renewable energy source. Geothermal in this regard provides a strong opportunity for the region . Successful development of geothermal will however require a strategic approach that recognizes the unique circumstances of the Caribbean region including the region's small scale and limited resources. Key to this strategy is a defined role for regional and international cooperation and for the pooling of projects and efforts. Significant time and resources have already been expended on geothermal energy in the region yet some longstanding challenges remain. The analysis of these challenges in the Caribbean context point to a need for a paradigm shift of methodology in undertaking to surmount the ongoing challenges facing geothermal development in the region. The analysis presented in this paper lead to the overarching conclusion that techno-economic collaboration of the Caribbean islands under the oversight and guidance of a governing body that supports collaboration will accelerate geothermal energy utilization in the Caribbean in the region. Capacity building through training and development of local expertise will be instrumental towards achieving the above stated objective.

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