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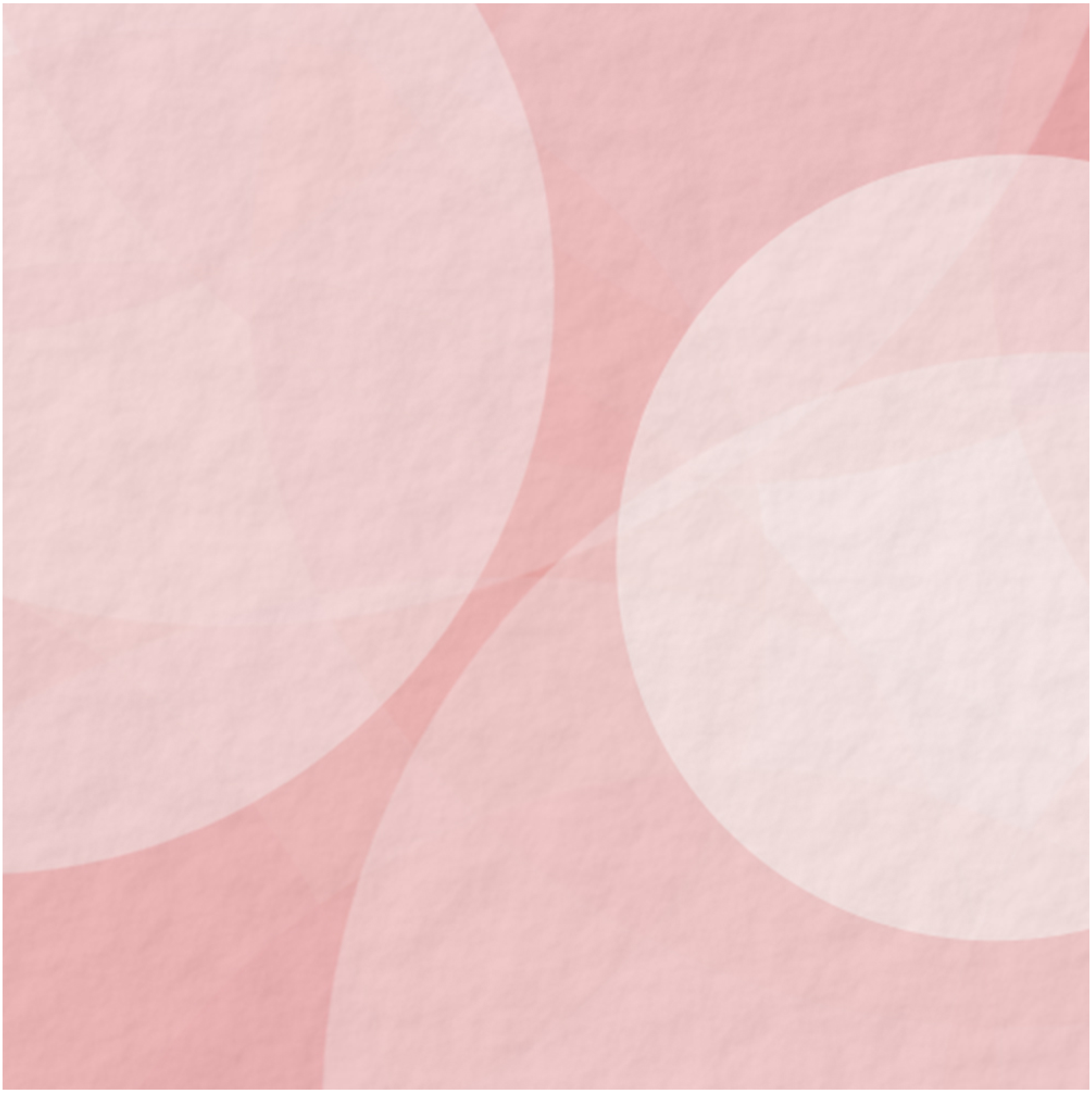

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I. Editor's Preface

Minoru Inaba
Chief Editor, GRM Journal
Professor, Graduate School of Science and Engineering, Doshisha University

It is my great pleasure to announce the publication of the seventh volume of Global Resource Management (GRM) Journal. The aim of this annual journal is "the realization of a society in which people having different culture background can live and cooperate together by providing a space to publish new findings and achievements from activities of interdisciplinary nature with a viewpoint of resource management or development". This volume features two Research Notes and several Student's Course Reports.

The world is still suffering from the outbreak of the COVID19 virus, and the economy all over the world has severely stagnated. Many countries in the world are now seeking to overcome this stagnation, and EU, USA, China, and Japan started moving to the era of post-COVID19. The keyword is "Carbon Neutral", which means zero-out of the global warming carbon dioxide (CO_2) emission. We should not view this word negatively, but think it positively because it can create new businesses to overcome the stagnation caused by COVID19. Japanese target is the establishment of Carbon Neutral in 2050, and Prime Minister Suga recently announced the prohibition of the sale of gasoline engine vehicles in the mid-2030s. Japan has excellent global automobile companies and many battery manufactures, and the technology of electric vehicles (EVs) and batteries is the most advanced in the world. It is also necessary to reconsider the power supply configuration. At this time our life highly depends on the electricity from thermal power plants (75%) in Japan, and we should introduce more renewable energies including solar, wind, and hydraulic power plants to achieve the target. I hope that Japan will play a central role in establishing Carbon Neutral societies and industries in the near future, and contribute to the zero-out of CO_2 emission all over the world. I also expect that the spirit of GRM will facilitate the technical cooperation with other countries.

Finally, the submission of Articles and Research Notes to this journal has been open to all authors in the world since 2020. We welcome submission from authors who are interested in the work and education of GRM.

Factors Affecting the Entry of Foreign Operated Companies in the Philippine Telecommunications Industry

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Abstract

This study investigates channels and obstacles influencing the successful entry of DITO as a first potential partly foreign-owned competitor in the Philippine telecommunications market. It also discusses the history of private ownership in the telecommunications industry. During this history, the telecommunications market is under the duopoly of local companies PLDT and SMART. We explore the transition of Philippine telecommunications toward broadband utilization under the influence of the current conglomerates, as well as attempts at foreign entry into the market. These involved changes in usage from GSM- to SIM-based broadband to fixed-line and wireless connection. We investigated recent legislations concerning the management and approval of market competitors. These legislations directly influence the ease of doing business in the country, which lead to easier access to infrastructure expansion of current, as well as future, companies entering the market. We also discuss the effects of the entry of DITO on the reactions of the public, also identifying public concerns of data breaching and privacy compromise as the main factors hindering the acceptance of the partly foreign-owned company in establishing its infrastructure, which promises significant speed boosts along with cost reduction. We calculated the reactions of the conglomerates, as well as the government. We found that the primary effects of foreign entry in the Philippines were responses from the incumbent companies in the forms of rapid infrastructure investment and service improvement. We classified responses into "direct constructive" and "indirect constructive" on the basis of the effective projected quality of goods and services after a foreign company enters the market. This paper moreover discusses the politicization of the telecommunications industry where the actions of the public sector are highly dependent on the government. Recommendations include open collaboration between the public and private sectors while maintaining competition to increase the quality of goods and services.

Keywords: Philippines, telecommunications, private institutions, policy

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I. Introduction

As of the present, the Philippines has one of the slowest and the most expensive internet connectivity in Asia. With the increase in demand for internet connectivity, this issue continues to worsen especially during the COVID-19 pandemic, where online services become the sole form of communication. As these services extend to almost all forms of instant transaction such as banking and retail, disruptions, or even intermittent downshift of the speed at which these are performed, significantly hinder rapid response, specifically during periods of rapid disaster management. With the arrival of a new competitor in the market, the effects of infrastructure-related issues are perceived to be mitigated. A company partly funded by the Bank of China, DITO, previously known as "Mislatel," has been approved for a 25-year franchise for operating in the Philippines under House Bill 7332 (Rey 2020). As this company is partly foreign-owned, possible imminent conflict between the company and its potential consumers is also discussed. For these reasons, it is imperative to investigate the origins and factors that influence the entry of this rising competitor. This paper has the following objectives:

- To investigate the attempts of foreign companies in their entry in the Philippine telecommunications market; and
- To enumerate the responsibilities of governing bodies, as well as the aspects involved with regard to foreign companies' approval.

By identifying the factors that contributed to the entry of DITO in the market as well as those involved in the government's role in the emergence of the company, these can be utilized by future investors in telecommunications service, as well as towards identifying market responses due to the introduction of new competitors.

II. The Philippine Network Industry: History and Private Ownership

The Philippine private telecommunications sector has endured a long history of reform since the early 1900s when PLDT (Philippine Long Distance Telecommunications) served as the sole proprietor of telephone service in the archipelago. In 1992, 2G service was released, where the short-messaging service for mobile phones was introduced. The monopoly of PLDT caused a significant lag in ICT development in the country, where the telephone penetration rate was under 4 percent in 1999 (Kim 2003). After liberalization of telecommunications markets via the implementation of Executive Order (EO) 59 in March 1993, additional private competitors such as Smart Communications and Globe

Telecom entered the market, significantly increasing the number of subscribers to 3.1 million in 2001 (Kim 2003). Following the boom of SMS, multimedia service (MMS) was introduced but adoption was slower than the former due to the higher costs of operation (Lallana 2004).

After the success of text messaging and multimedia messaging, the country adopted the usage of broadband internet as one of the main forms of communication. Philippine internet connectivity began in 1994 with the Philippine Network Foundation (PHNet) along with the first commercial internet service provider (ISP) Mosaic Communications (ITU 2002). where the first established internet connection was publicly funded by the Department of Science and Technology (DOST) in collaboration with Philippine universities including Ateneo de Manila University (AdMU) and the University of the Philippines (UP) (PHNet 2011). According to the report by the International Telecommunication Union in 2002, subscribers could connect to the internet by means of cable modem, asymmetric digital subscriber line (ADSL), and fixed wireless systems (ITU 2002). With the adaptation of the internet towards instant communication, shifts in messaging service via internet became more evident. There was a further transition from SMS message servicing to broadband in just around a matter of a decade, and cell service providers such as Globe, Smart, and PLDT also explored the expansion of their offers towards being internet service providers (ISP), with companies offering bundle internet and landline subscription. Internet connection was coupled to landline subscription as a postpaid service, with the aim of increasing consumers of the latter subscription. Internet connection was also made available via prepaid plans, where the SIM card is inserted into a dongle connected via a USB on the computer, which acts as a wireless internet access antenna.

Currently, the options for internet connection fall under 2G, 3G, 4G, 5G, and LTE. Briefly, 2G began in 1992, and involved text messaging service (GSMArena n. d.). The subsequent adoption of 3G in the country began in 2008 where video call was enabled (Phys 2005). Support for the 4G network for modern smartphones was enabled after its launch in August 2012, which was done by SMART Communications, enabling high-speed internet (Smart Communications 2012). Long-term evolution (LTE) availability was launched around the same time in Aklan Province. However, in 2019, Globe was able to first release 5G broadband service in the country, as well as in Southeast Asia (*Manila Standard* 2020).

III. Mobile Consumption

After the introduction of analog and, subsequently, digital cellular phones for SMS, the mobile density in 2004 (number of telephone connections for every one hundred individuals) reached 27.77 percent, which is 25 percent higher than that of 1999 (Lallana 2004). The increasing number of subscribers from 6.45 million in 2000 to 167 million in 2019 is shown in Figure 1 (Ceicdata 2020). Rural regions also benefited from the availability of SNS, which is an indispensable tool for communications within the family (Pertierra 2007).

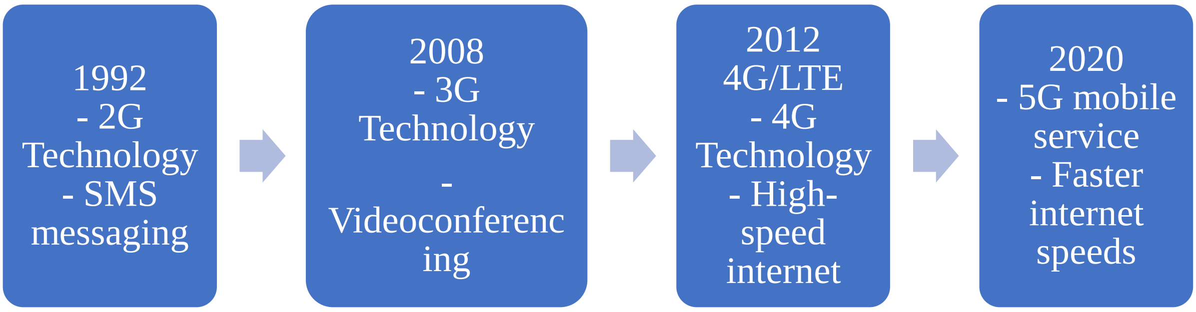


Figure 1. Timeline of mobile internet access in the Philippines

Demand for Philippine mobile network subscription has rapidly risen since the early 2000s. The growth of mobile phone subscribers has reached around 167 million ever since 2008, as shown in Figure 2. The Philippine telecommunications industry is currently dominated by two conglomerates: Smart-PLDT and Globe Telecom. As early as 2001, while PLDT monopolized the landline sector, the mobile phone market was overtaken by Smart Communications and Globe Telecom, forming a duopoly, as shown in Figure 3.

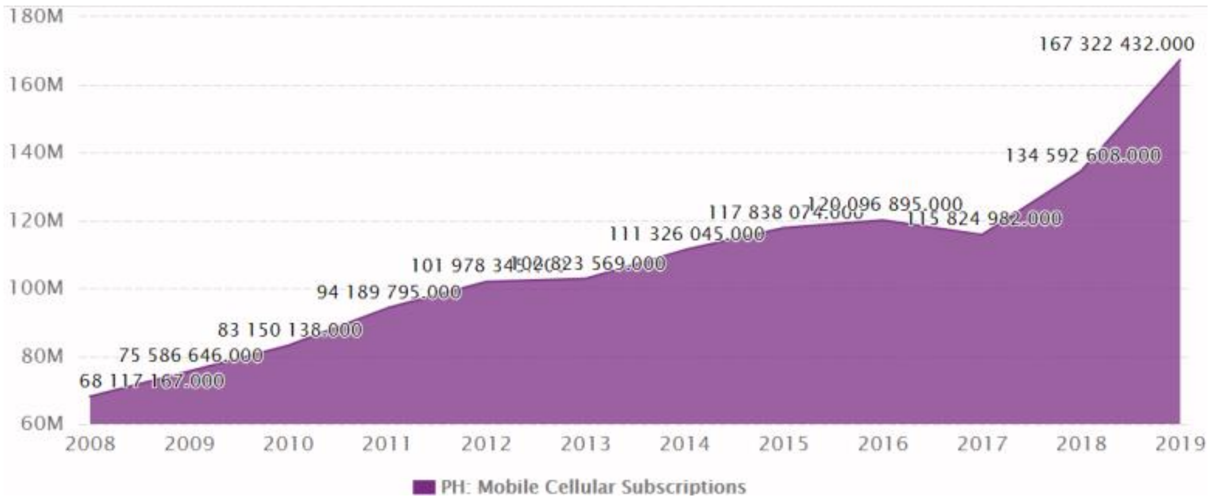
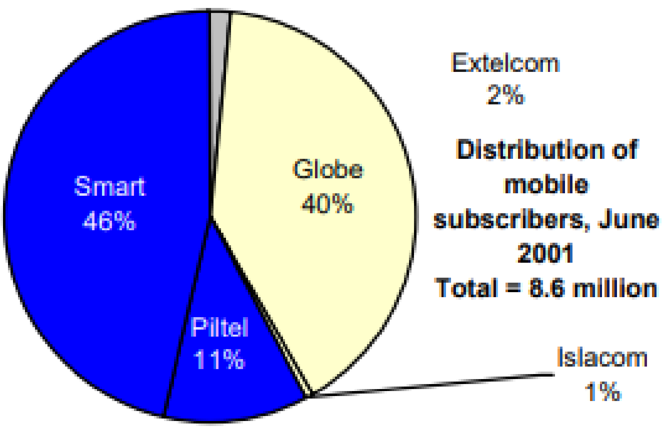


Figure 2. Number of Philippine mobile phone subscribers from 2008 to 2019 (in millions) (Ceic Data, 2020).



(a)

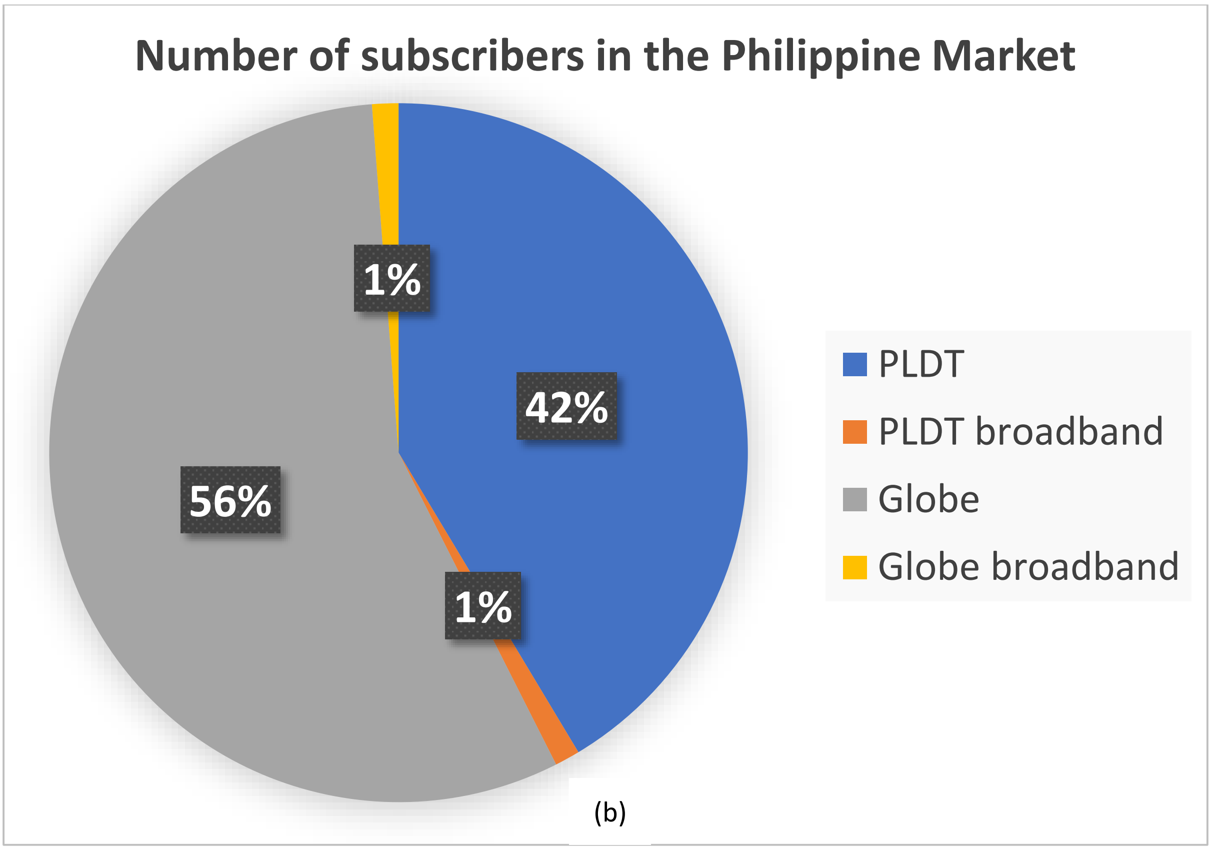


Figure 3. (a) Percentage of the number of mobile phone subscribers in private companies within the mobile phone market, 2001 (ITU, 2002) and (b) in 2020 (Trade.Gov, 2020)

Despite the many initiatives of the government in the early 2000s to boost internet connectivity through construction of additional infrastructure, problems still exist for the current connectivity. The number of internet subscribers only reaches, in case of the number of broadband subscriptions, around 11.9 percent, as shown in Table 1.

Table 1. Philippine ICT situation from 2010 to 2016 (individuals in millions), adopted from (Board of Investors, 2018)

Fixed Broadband Subscriptions per 100 Inhabitants	7.6	8.4	9.0	9.9	10.1	11.2	11.9
Percentage of Households with Computer	35.9	37.9	40.1	42.4	44.0	45.6	47.5
Percentage of Households with Internet Access at Home	30.0	33.4	37.9	41.8	45.1	49.0	52.3
Individuals Using the Internet	2,014	2,216	2,459	2,660	2,931	3,207	3,488
Individuals Using the Internet per 100 Inhabitants	29.2	31.7	34.8	37.2	40.5	43.8	47.1

In terms of market competition, additional private companies participated in the market as ISPs including Globe and Bayantel. However, PLDT still holds the largest market share as an internet service provider, holding over 60 percent of the total shares, as shown in Figure 4. This shows the dominance of the company in both the mobile and the internet sector, with around a 59 percent market share.

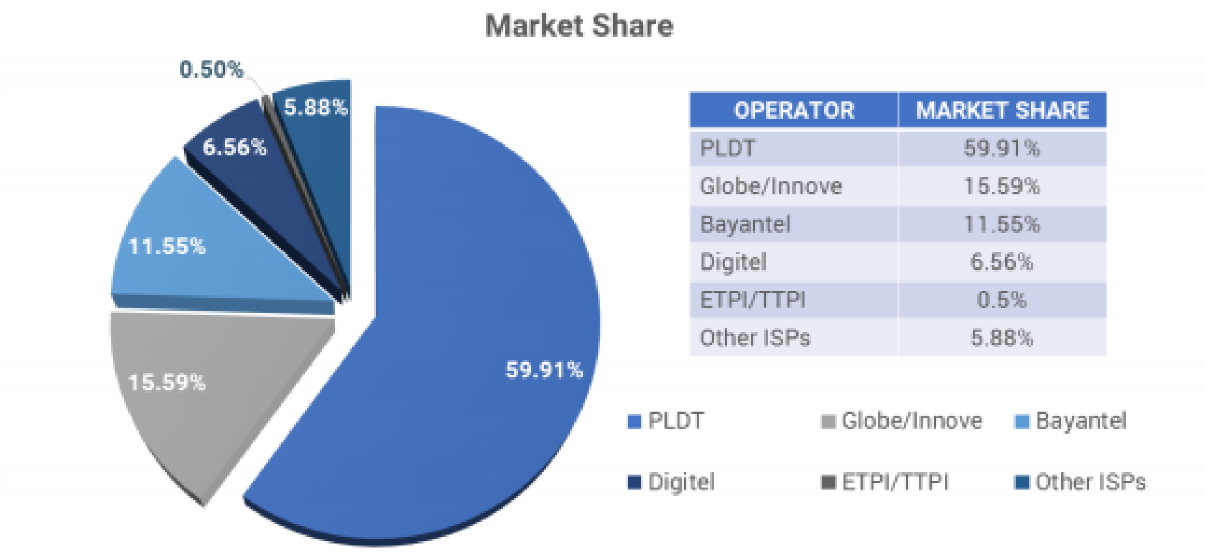


Figure 4. Market share 2013 (DICT, 2017)

As seen in Table 1, even though there is an increased number of options that cater to the increasing demand for internet connectivity, the number of connected individuals per household still does not exceed half. One of the reasons for the low percentage of subscribers per 100 people can be traced to the high prices of internet connection in the country. In 2013, the Philippines has the most expensive internet service in Southeast Asia, shown in Table 2. The country also has the highest landline and postpaid mobile broadband subscription prices. In 2015, for instance, the price of a mobile postpaid 1-gigabyte data plan is 19.67 US dollars, whereas for Indonesia the cost amounts to 4.11 US dollars for the same connection speed (ITI 2016).

Table 2. Price (in USD) of ICT services in South East Asia (ITI, 2016)

	Fixed Telephone	Mobile Cellular	Fixed Broadband	Mobile broadband, postpaid handset-based	Mobile broadband, prepaid handset-based	Mobile broadband, postpaid computer-based	Mobile broadband, prepaid computer-based
Brunei Darussalam	18.91	29.6	78.28	33.72	30.11	33.72	20.09
Cambodia	9.81	16.16	30.55	7	7	12.73	12.73
Indonesia	9.54	16.38	48.92	12.54	5.7	12.54	11.4
Lao PDR	12.01	17.84	41.65	12.82	0	16.02	0
Malaysia	17.99	14.2	41.52	23.91	23.91	30.2	30.2
Myanmar	-	-	-	-	-	-	-
Philippines	36.15	22.24	51.59	25.77	25.77	51.38	25.77
Singapore	9.1	9.04	20.58	32.97	12.4	20.58	0
Thailand	14.55	12.61	52.85	24.51	24.51	32.71	36.31
Viet Nam	4.44	8.81	7.15	-	-	-	-

The current minimum wage in the Philippines is reported to be 445 pesos daily (DOLE 2019). Assuming the least expensive monthly postpaid computer-based plan of 999 pesos (20 USD) (Smart 2020), the subscription alone contributes to 9.7 percent of the total monthly income. Compared with a KartuHalo promo from Telkomsel, an ISP in Indonesia, the plan costs 100 IDR, which is approximately 0.3 pesos per month (Telkomsel 2020), despite the Indonesian minimum wage being comparable to that of the Philippines (TradingEconomics 2020).

In addition to the relatively huge costs of the internet service, the Philippines also admits to having one of the slowest connection services in Southeast Asia (Roberts and Hernandez 2014), with a 1 megabit per second difference compared to India while ranking 100th in terms of internet speed. The primary cause for the slow internet speed in the country is the severe lack of infrastructure. As the demand for internet connectivity increases (with 73 million subscribers as of 2020), internet quality becomes a significant issue (Sanchez 2020). According to Albert et al. (2016), one of the other causes of increased costs for the same connection speed is the occurrence of Internet Exchange (IX), which involves the sharing of data between ISPs instead of establishing fewer connections through private transfer (Albert et al. 2016). Physical and social factors also contribute to the slow progress of connectivity improvement. According to the 2016 report by Salac and Kim (2016), the main reasons for the slow infrastructure improvement involve geographical difficulty, bureaucratic procurement, and connection monopolization (Salac and Kim 2016). Since the Philippines is an archipelago, the construction of cell towers for connectivity within the islands is more challenging than installation in a region within a wider land area. Moreover, Salac and Kim (2016) stated that the government at that time also hindered infrastructure development due to bureaucratic structures, or red-taping. This is exacerbated by the current duopoly of the entire communication service, in which potential entrants could be met with agreements benefiting the incumbent operators.

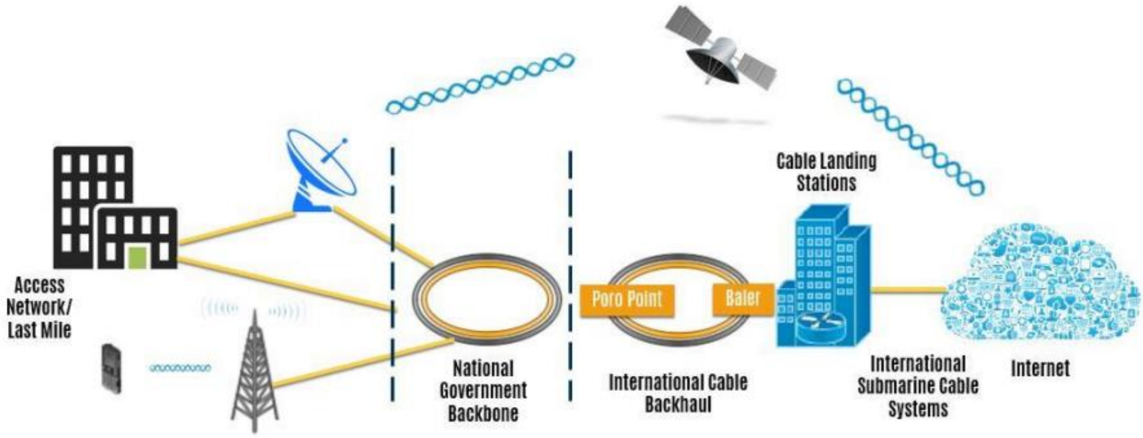


Figure 5. Philippine Network Architecture Adopted from
(Department of Information and Communications Technology, 2017)

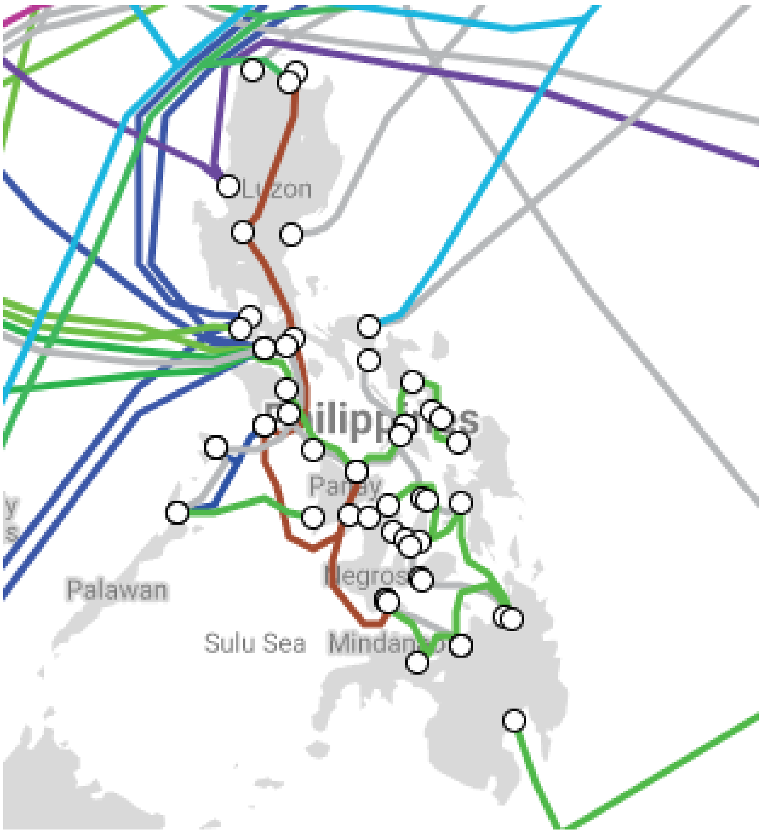


Figure 6. Submarine cable networks in the Philippines (SubmarineCableMap.com, 2020)

IV. Current Technologies in the Philippine Network

In the study of the Bureau of Information in 2016, current Philippine connectivity is reliant on three major telecommunications infrastructures: satellites, submarine cable systems, and radio masts and towers (Philippine Board of Investments (BOI) 2018). The overall network architecture is shown in Figure 5, where the main international cable backbone at Poro Point and Baler and its connection with the national government network backbone for internet access are shown. Communication systems with the use of satellites were employed by the Philippines mainly through the Philippine Communications Satellite Cooperation (Philcomsat 2020), a mostly privately owned subsidiary of the Philippine Overseas Telecommunications Corp. Satellites are utilized for long-range communications including maritime and television broadcast and are essential for linking between far-flung regions. In terms of satellite-based internet broadband, Philcomsat, together with a private Australian company Speedcast, is the main provider (Philcomsat 2020). Satellite-based communication through a Wi-Fi installation project Pipol Konek enabled the installation of 2,708 access points with the assistance of Republic Act 10929 (Liay 2019). SMART-PLDT has also utilized satellites for broadband transfer with its own control center (Smart Communications 2020) to enhance international communications. Submarine communication systems make use of long sealed fiber optic cables situated deep under the ocean in order to transmit data internationally, as shown in Figure 6. The Philippines has nine cable landing stations all over the archipelago, which is also dominated by the duopoly of PLDT and Globe (Submarine Cable Networks 2020). In 2017, the Bases Conversion and Development Authority (BCDA), a publicly owned firm, also established two major submarine cable landing stations in Luzon in collaboration with the social media company Facebook, which provides an additional connection of around 2 Tbps spectrum (Qiu 2017).

V. Foreign Attempts at Entry in the Philippine Communications Market

Due to the increasing demand for faster, more affordable internet, foreign investors also placed their interest in competing within the Philippine market. Telstra Corporation, an Australian network company, initially sought potential in the Philippine telecommunications market in 2016 (Marcelo 2018). Along with the conglomerate San Miguel Corporation (SMC), the potential installation of additional infrastructure utilizing the 700 MHz frequency band was negotiated under the present dominance of PLDT-Smart and Globe in the concurrent market (Albert 2016). Since the introduction of other competition would lead to lower profits for the present telco oligopoly, legal action was taken against Telstra, where the company eventually did not push through with the investment. First investment attempts of foreign-owned telecommunications companies that aim to improve these services faced hostile responses from the current conglomerates (Marasigan 2015). Other reasons include the legislation contained in Republic Act 7042, or the “Foreign Investments Act of 1991” in 2016, which states that only 40 percent of telco ownership is possible (BOI 1991). In addition, the requirements imposed by DICT including an initial investment amounting to at least 10 billion pesos, along with a five-year experience within the telecommunications service reinforce the decision to not invest in the country

(Marcelo 2018). Other telcos that have pulled out or been rejected from the market include Telenor from Norway, KT Corp from Korea, and Viettel from Vietnam (Lema and Morales 2018).

With the aim of addressing the increasing demand for better connectivity, a third telco, China Telecommunications Corporation, or China Telecom, consolidated its deal with the Department of Information and Communications Technology (DICT) in establishing its own submarine cable network (Valdez 2018). In terms of radio masts and cell towers, over 18,000 were installed within the country, as of 2020 (Barton 2020). Around 50,000 additional towers are to be built to enhance wireless broadband connection. As a result, DITO, under its owner Dennis Uy, an associate of the Philippine president Rodrigo Duterte, has succeeded in entering the market competition and establishing plans to increase connectivity in the country. The company is the first foreign-owned network in the country, under the consortium Mindanao Islamic Telecommunications Corporation (Mislatel) to which the firm Udenna Corporation of Dennis Uy also belongs. In 2018, Mislatel was declared the new major player alongside the concurrent duopoly (Cabuenas 2018). In 2019, Mislatel was renamed the DITO Telecommunity Corporation, which possesses the 700, 2,000, 2,100, 2,500, 3,300, and 3,500 MHz frequency bands, applicable to LTE and NR connectivity (Cabuenas 2018). The corporation plans to set forth its own submarine network with a budget of 5.4 billion United States dollars (USD), 500 million USD of which is provided by the Bank of China. The company was set to commence operation in March 2021.

According to DICT, DITO is already constructing 1,300 cell towers, and 1,502 towers are already approved, which equates to around a total of 6,000 constructed towers from 2019 to 2020 (DICT 2020). As of September 13, 2020, DITO has already constructed 859 cell sites (Camus 2020). However, unlike Telstra, DITO did not face numerous criticisms from the government during its entry. SMART and Globe even received threats from the president of shutting down the two companies due to their poor performance. With the aforementioned cases that turned to the favor of DITO, and also of the duopoly, there will be smaller obstacles they could encounter when developing their infrastructure.

VI. Entry of Chinese Telecommunications Companies: The Case of Zong in Pakistan

China Telecom initiated its expansion in the telecommunications industry in Pakistan under the directive of the One Belt and One Road initiative. In this initiative, the Chinese government aims to encourage merging and acquisition practices as a form of internationalization for the increase of its competitive advantage (Gnomblerou 2019, pp. 1-17). The bid for Paktel, the major telecommunications company of Pakistan at that time, was successful in 2006 where 89 percent of the holdings were obtained. In 2008, holdings increased to 100 percent and the company was renamed Zong. In 2017, approximately 20 percent of total subscriptions in the country belong to the company (PTA 2017, p. 50). In order to succeed in entry, legal requirements are posed by the Pakistan Telecommunication Authority, in which licenses to operate were the only requirements.

Contributing factors in the success in the acquisition by China Telecom of the Pakistani company leading to its entry involve those in which China and Pakistan have had successful agreements in trade and business in general, with around 911 million USD worth of investments in Pakistan (Gnomblerou 2019, p. 9). Moreover, Pakistan has been regarded the most favored nation (MFN) by the Chinese government, in which the country has been prioritized in respect of trading. With the history of trading between China and Pakistan, as well as this designation between the two nations, these could have fueled the approval for entry of Zong in the Pakistani telecommunications market.

Such historical strong trade relations between mainland China and the Philippines were also present, but not at the level of MFN in Pakistan. In terms of Chinese telecommunications, DITO, if accepted, would be the first foreign-owned company to enter the communications market. As for Philippines-China trade, China is the fourth-largest importer of goods from the Philippines, amounting to 8,699 million USD, or a 12.89 percent partner share. However, China is the top exporter amounting to 22,579 million USD (WITS 2021).

In terms of government intervention, the internationalization of China Mobile as a conglomerate was heavily influenced by the government in its Belt and Road initiative. The “Going Global” endeavor encouraged the company to increase the amount of its foreign holdings. On the side of the Pakistani government, its merge and acquisition policy regulation stated that foreign entry in the local market can be approved either (a) if the entry would not raise concerns over competition decrease among the concurrent businesses, or (b) if the entry would prove to be beneficial to the “efficiency or production of goods and services” (Competition Ordinance 2007, Sec. 11). Another reason for encouraging the merge is that the purchase by China Mobile of Paktel would include its USD 460 million debt (*Wall Street Journal* 2007). In comparison, the Philippine government also had legislations that encourage those aiming for foreign direct investment in the country, particularly DITO, as will be discussed in the next section.

VII. Legislation Changes for Foreign Companies

In response to the longstanding oligopoly, several branches of the government contributed to the hastening of procedures necessary for the application and approval of local and foreign-owned businesses as these attempt to enter the telecommunications market. For instance, DICT is responsible for the “primary policy, planning, coordinating, implementing, and [acting as the] administrative entity of the Executive Branch of the government that will plan, develop, and promote the national ICT development agenda” (DICT 2015). As the department concerned with the formation of regulations for the general improvement of communication, it headed the National Broadband Plan, wherein these regulations aim to “reduce the requirements and simplify the procedures required for the entry of market players who want to build and operate internet-based networks” (DICT 2015) and organize installation of free Wi-Fi in public places, as part of the AmBisyon Natin 2040 vision. DICT coordinates with the National Telecommunications Commission (NTC), which is responsible for the regulation and supervision of “public telecommunications services,” including broadband networks (NTC n.d.). Since both departments are under the management of the president, any direct orders coming from the executive would be heeded. Another recent reform of reducing the cell tower approval from 241 to 16 days was implemented by DICT alongside the Anti-Red Tape Authority under the Ease of Doing Business and Efficient Government Service Delivery Act of 2018, which further boosted the infrastructure development (Masigan 2020). Moreover, consumers would be benefited by the enacted Bayanihan 2 Law, which would grant a 60-day grace period for the payment of utility loans for consumers. The law also sped up the construction of cell towers since, for a three-year suspension period, the building permit alone can be used to secure legal establishment (Rojas 2020). The reformed law benefits the current conglomerates as well as DITO as they increase capital expenditure. With these reformed legislations set, the ease of doing business could increase due to the relaxation of imposed requirements to new local or international entrants in the market.

VIII. Discussion

a. Physical- vs social-based hindrance in development

The telecommunications infrastructure development of a country heavily relies on the cooperation of the government and the current private sector. Legislations are set forth by DICT and DOTC, as executed by the president, in order to manage the activities of private businesses. In the case of the Philippines, however, low service quality caused by poor infrastructure development is a longstanding issue. We see that, from the first use of mobile phones in the early 2000s until the transition towards LTE technology in the 2010s, the services provided by local private companies significantly lagged in comparison to those of neighboring countries. The reason for this can be classified as institution-based issues, since these merely involved lack of coordination within the governing bodies with those responsible for infrastructure construction, as compared with the challenge of construction due to archipelagic geographical separation. The effect of monopolizing the internet is shown in the for-profit exploitation of expensive data transfer schemes that compromise the quality of the connection the end consumers deserve. For example, a 100 Mbps plan in the Philippines would have an average cost of around 56 USD, which is the fourth-most-expensive plan with the highest at 87 USD in South Africa and approximately 21 USD in Thailand (Moneymax 2020). The problems of slow internet connectivity reported by Salac and Kim, institution-based issues of government bureaucracy, and private company duopoly are those that can be resolved with the proper initiative from either side. When the government reformed its legislation such as within the National Broadband Plan, which caters for foreign-owned network service providers, these problems were mitigated but the forthcoming investment was filled with controversy, which triggered the incumbent conglomerates to react.

b. Direct and indirect constructive responses of the duopoly

When a new entrant in the market arises, reactions coming from the incumbent institutions could be characterized into direct constructive and indirect constructive responses, defined in the following. For the former, goods and services (e.g., infrastructure) of the existing company visibly improve upon the entry of a new company by direct collaboration between the incumbent company and the foreign entrant. This signals a complementary reaction to the entrant, allowing for overall development. For the latter, however, the entrant is hindered by inciting opposition, in a way that the incumbent companies attempt to improve their own goods and services in order to increase competition, improving, however, the overall quality of the infrastructure.

An example of a constructive response to a foreign entrant is that of Huawei in the Egypt market. The Egyptian telecommunications system is similar to that of the Philippines, where the former also had a longstanding duopoly of Mobinil and Vodafone Egypt before Etisalat entered in 2006 (*China in Africa: A Strategic Overview* 2009). The Chinese telecommunications company Huawei entered Egypt in 2000 and undertook various projects alongside Telecom Egypt, the state-owned telephone company in the country (Ahram Online 2016). One of these projects involves telephony expansion towards Suez Canal regions, which are considered remote.

An example of an indirect constructive response is when DITO successfully penetrated the investment market, the conflict between network service improvement and the possible avoidance of a potential security breach became the main issue. The reactions of the duopoly commenced as DITO began aggressively investing in infrastructure reflected in their consequent service development, both in cell tower construction and cost reduction of network upgrades. These companies showed that they can respond to an incoming player through infrastructure improvements, and these investments themselves proved that these incumbent operators did not have a financial issue as their main concern. Instead, the motivation of the duopoly was to mitigate the threat of competition due to the speculated improvement in network connectivity. The projected internet speed claimed by DITO would be 27 megabits per second, which is 7.6 percent higher than the July 2020 fixed broadband speed (Amadora 2020). From the perspective of the consumers, these improvements from the incumbent companies result in an overall gain of the subscription quality.

c. Politicization of telecommunications development

From the rapid service improvements of SMART-PLDT and Globe in response to increased competition, it can be stated that the increase in government-led allowance of foreign direct investment directed these conglomerates towards the possibility of better service.

Having DITO as a pioneer of foreign direct investment in the Philippine telecommunications industry shows the ability of the government to significantly alter the market. One of the main factors for the success of DITO's entry in the competition is its allegiance with the president, which was not present in the Australian company Telstra. In the case of DITO, even the speculated data breach due to the planned construction of cell towers near military bases was defended by the president (Reed 2019). Thus, it can be stated that the Philippine telecommunications market is highly volatile due to political influence since the government can freely promote companies as long as they are in line with the agenda of the administration.

Poynter's (1982) paper about government interventions in less developed countries confirms these points. In his paper, the author was able to point out two arguments. The first is that the host government maltreats foreign companies when the government comes to making decisions to intervene. Where across-the-board intervention policies exist, the maltreatment takes the form of various degrees of enforcement. The second one is these interventions are not a fact of life beyond the control of the companies. Government behavior in this regard can be partially described in terms of particular corporate characteristics and policies that can mostly be manipulated to reduce intervention (Poynter 1982). However, in the case of DITO, the government adjusted the legislation not to hinder but to encourage the foreign investment to push through with the entry. Aside from enforcing ease-of-business-related legislation amendments with regards to foreign entry, the entry itself has to bring forth incentives once the foreign company finally undergoes full operations. The government can also initiate tax breaks for all private telecommunications companies, as well as those that would attempt to enter the market to encourage further competition, allowing for additional improvement in the infrastructure. Bureaucratic procedures could be hastened, such as that of cell tower construction, in order to expedite other investors to participate in the telecommunications field.

IX. Conclusions and Recommendations

This paper explores the factors affecting the dynamics of entry of the Chinese telecommunications company DITO in the Philippine market. It also discusses foreign attempts at market entry, as well as the reactions of the current conglomerates to these attempts. It investigates the case of Pakistan in the context of the state government facilitating the entry of China Telecom. And it classifies responses to such entry as either direct or indirect constructive,

Since DITO has not yet officially entered the consumer market, a challenge for the government is to establish coordination with the private sector, especially with SMART and Globe, in hastening the connectivity between far-flung areas, since these are the ones in dire need of connectivity, especially in the case of the COVID pandemic wherein classes have transitioned into online instruction. Coordination with other departments, such as the Department of Environment and Natural Resources (DENR) as well as the Department of Social Welfare and Development (DSWD), should also be conducted as local communities would be affected by the construction of large-scale infrastructure. The role of the current telco providers, on the other hand, may be furthering its consistency with their current investments. The main role of DITO as a service provider is to coordinate with the government in ensuring the public of its safety with its subscription. In gaining trust from the public, PLDT-SMART and Globe should consolidate their expansive goals as well as their promises of improving the current connectivity situation. As for DITO, prioritizing collaboration with locally recognized institutions should be achieved while maintaining similar quality of service. Aside from social factors, the geographical condition of the country such as its propensity to encounter typhoons should be considered. Failure to do so would greatly hinder the growth of the company despite its claims of significant network improvement.

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Hydrogen Sulfide Emission and Policy Barriers to the Sustainable Development of the Olkaria Geothermal Power Plant Facilities in Kenya

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Abstract

Kenya is ranked first in the world in the percentage of geothermal energy in the national share of energy production. This is an amazing feat of renewable energy adoption for a developing nation, something that is not expected to diminish, as the nation's Vision 2030 development plan outlines expanding the total geothermal energy capacity over the next decade. This development has positive implications for Kenya, particularly as its other most-used renewable energy source, hydroelectricity, is becoming increasingly unreliable as a result of climate change-induced drought. One of the centers of Kenyan geothermal development is the Olkaria region. This is a geologically active region in Hell's Gate National Park. To date, five of the facilities, aptly named Olkaria I through V, have been constructed in the park, with a further three under construction or in advanced stages of planning. Furthermore, the existing facilities continue to be upgraded and expanded. This has made Olkaria the largest supplier of geothermal energy in the region. Now, the Kenyan government has worked to facilitate foreign investments to enter the Kenyan geothermal sector, leading to significant outside investor interest. This foreign capital will help towards the Vision 2030 target.

However, although from a developmental perspective these events are positive, some concerns are warranted, particularly regarding the emission of hydrogen sulfide (H_2S) gas. This gas is toxic to human as well as plant and animal life in sufficiently high concentrations and a health concern as well as a general nuance in lower concentrations. Reviewing the available literature has shown a lack of independent and verifiable measurements of H_2S at the Olkaria facilities. Meanwhile, regulatory standards in Kenya as well as those maintained by the main developer of geothermal power, KenGen, short for the Kenya Electricity Generating Company, are based on WHO guidelines. These guidelines have been called into question by medical professionals. As such, other nations that are either active in geothermal development or have advanced industries that also release H_2S tend to maintain their own regulations below WHO standards.

Countries that have implemented such regulations have shown innovation to limit H_2S emissions by producing industries via the adoption of technological solutions.

This paper concludes that implementation of the currently available technologies is not too costly or infeasible. However, the fact that Kenya, unlike several other developed countries, follows WHO guidelines concerning H_2S emission control is the main obstacle in preventing the adverse impact on human health and on the environment.

Keywords: Geothermal power plants, H_2S emission, Olkaria, Geothermal regulations, Environmental safety standards

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I. Introduction

Today, the Republic of Kenya, a nation of nearly 50 million on the East Coast of Africa, is considered one of the fastest-growing economies not just in the region, but among all developing nations. This economic growth has awoken many foreign investors to this land of new opportunities. In as much as it is a universal economic constant, the more an economy develops, the more it hungers for energy resources. However, the national government as of yet lacks the capacity and resources to keep up with the growth in demand and has, therefore, not wishing to stilt economic growth, opened the energy sector to foreign investment. Without skipping a beat, many international companies and organizations have now started to invest in the Kenyan power generation sector thereby becoming one of the most successful nations in attracting renewable energy investments (Kazimierczuk 2018, p.434).

Among the myriad sources of clean and renewable energy available for the powering of its economy, Kenya is blessed by abundance. The capital city Nairobi receives significant solar radiation (Onyango & Ongoma 2015); the 1,420-kilometer coastline in the east and White Highlands in the west offer some of the highest potential wind energy in all of Africa (Kazimierczuk 2018, p.435; Food and Agriculture Organization of the United Nations (FAO) n.d.); and the Great Rift Valley, running from the White Highlands north to Lake Turkana, is one of the premier places to access the geothermal energy of the geophysical processes at our earth's interior, with Kenya possessing a greater energy potential than the demand of nearly any of the nations on the continent (Merem et al. 2019). In particular, the latter was adopted as an opportunity by the Kenyan government as one of their best bets for sustainable growth, leading to several projects aimed to set up geothermal power plants in the Olkaria region, a region located in the Rift Valley (Adaramola 2014).

As the aforementioned rapid growth needs to be sustainable, this paper focuses on the sustainability aspects of geothermal power plants. After providing an overview of the Kenyan energy sector and an outline of the Olkaria facilities, we will have a critical view of the recent developments regarding specifically their environmental impacts. Olkaria is located inside Hell's Gate National Park as it fittingly called, on land that has been used by the pastoralist Maasai community and various kinds of wildlife since ancient times. As such, there have been some tensions and conflict between the Maasai community and the developers of the Olkaria power plants in recent years. One particular issue worth further scrutiny is the environmental impacts of releasing H_2S into the atmosphere.

Neither Kenya's legislature nor its regulatory bodies have adopted any specific restrictions regarding H_2S emissions, opting instead to follow guidelines set out by the World Health Organization (WHO). This paper aims to investigate why following these guidelines alone cannot guarantee the negation of severe health and environmental impacts, particularly in cases involving the large-scale concentration of geothermal facilities such as those found in states with the wide adoption of geothermal power. As such, we will outline some of the specific environmental concerns of H_2S emissions by contrasting WHO guidelines with the regulatory standards of OECD members active in the geothermal industry, allowing us to formulate experience-based recommendations for the Kenyan geothermal sector.

II. Significance of Geothermal Power Generation in Kenya

The energy sector in Kenya comprises its energy and electricity production, consumption, and imports. As a result of Kenyan economic growth, so too is the energy sector rapidly expanding. Today, energy production is divided among several renewable and non-renewable resources. The largest share is made up of geothermal at 47.1%, followed by hydro at 38.9%, and diesel at 12.4%. Wind makes up a tiny 1.04% share while the remaining 0.63% is purchased from the Uganda Electricity Transmission Company (KPLC 2020). The combined total effective grid-connected capacity was 2712 MW in 2018. Although lower than initially projected, this number is expected to grow to 7200 MW by 2030 (Obulutsa & Fenton 2019). Not only to meet the demands of the future but also to diversify the nation's energy mix, the Vision 2030 Strategy outlines expanding the usage of various forms of energy. Unfortunately, the largest-growing segments in this plan are composed of non-renewable resources, particularly nuclear, set to make up 19%, and coal at 13%, of the energy mix in 2030 (see figure 1).

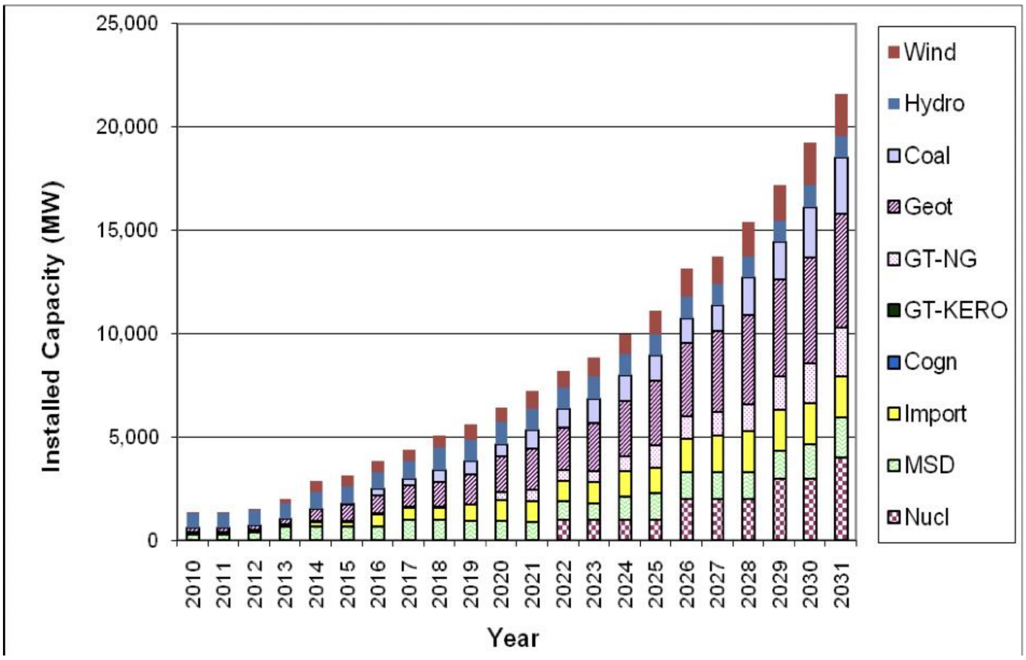

Figure 1. Projected energy mix by generation type as outlined in the Vision 2030 Strategy. (Source: Kianji 2012)

Although the expansion of non-renewable resources is part of Kenya's development plans, the nation is still aiming for climate-compatible economic development and as such has launched several initiatives to tackle issues of poverty, development, and climate simultaneously. This climate-compatible development (CCD) approach, developed by the Ministry of Environment and Mineral Resources (MEMR) in 2012, seeks to integrate CCD thinking within the frame of national development strategies. In particular, wind and geothermal are targeted to see significant growth in terms of installed capacity. By 2031, the expected geothermal capacity would exceed the entire nation's total 2020 capacity at 5530 MW. This is a planned growth of geothermal resource utilization of a massive 2,793% between the period 2012 to 2031, going from 198 MW to 5,520 MW (Kianji 2012). This would see geothermal energy maintaining its lead as the paramount source of Kenyan energy.

Geothermal power has many advantages over other forms of renewable energy. It is not affected by weather; resource depletion is not a major factor; and it is generally considered carbon neutral. Given such benefits and the abundance available to Kenya due to its geographic location, these developments make sense. Specifically, as the second-most-utilized renewable resource, hydroelectricity is becoming increasingly unstable as a result of climate change-induced drought (Micale et al. 2015, p.3). However, there are also some disadvantages such as the high barrier of entry in the form of high development costs, high maintenance costs, and the adverse impact on tourism resources. Most notably for the purposes of this article is the environmental damage as a result of H_2S emission into the atmosphere.

Before we investigate H_2S emissions at the Olkaria facilities, it is important to first understand the primary actors involved in developing Kenya's geothermal industries. KenGen, short for the Kenya Electricity Generating Company, is the largest power production company by market share at approximately 75%. Furthermore, KenGen is a majority state-owned enterprise with 70% of shares in the hands of the national treasury (KenGen 2020a, p.2). Meanwhile, the company managing customer relations for distribution to consumers, handling all billing and metering, is the Kenya Power and Lighting Company (KPLC). It is to KPLC that KenGen sells its power through power purchasing agreements (PPAs). Meanwhile, KPLC contracts the Kenya Electricity Transmission Company (KETRACO), which handles the distribution over its transmission network, allowing KPLC to reach its customers and Kenya to sell its renewable energy to neighboring states.

Facilitating geothermal developments is the Geothermal Development Company (GDC), wholly owned by the Kenyan state. It is this company that both develops and exploits geothermal resources, selling its services to KenGen and other independent power producers or IPPs (GDC 2017). This includes selling the geothermally heated steam for the geothermal power plants in the Olkaria region, the details of which will be outlined in the following section. GDC also promotes alternative sustainability measures related to geothermal power including agricultural processes such as greenhouse heating, the drying of grain, and milk pasteurization as well as general-purpose heating applications.

Another significant player is Ormat Technologies. While KenGen owns the majority of the Olkaria facilities, this US firm operates the Olkaria III facility through their subsidiary OrPower Inc., making it the largest private power generator in the country (Richter 2019b). In line with the nation's Vision 2030 Strategy, such private sector participation is deemed to be necessary to raise the required capital for economic development. Via its own 20-year PPAs, the power generated by OrPower is also sold to KPLC (US Securities & Exchange Commission 2007, p.2; Micale et al. 2015, p.8). Beyond the Olkaria III facility, which is alternatively known as OrPower 4, Ormat also partners in projects for other facilities such as the Menengai I Geothermal Power Station, also known as OrPower 22. Ormat Technologies is a significant player in the geothermal industry with facilities in places such as California, Turkey, and New Zealand.

Altogether, the above stakeholders have contributed positively to Kenyan development as the quality of the electricity supply, measured by the frequency of interruptions and the fluctuations in voltage, is among the best in the region (World Bank 2017). According to the International Energy Agency, Kenya is nearing total universal energy access for all citizens (IEA 2020) with the 2018 Kenya National Electrification Strategy (KNES) having set a universal electricity access target for 2022 (Obulutsa & Fenton 2019; World Bank 2018).

III. Development of the Olkaria Geothermal Field: International Investments

After an overview of the main players in power distribution, it is critical to understand the development process of the geothermal power plants in Kenya. As a result of the need for high initial investments, different international organizations and investors have played a significant role in developing the Olkaria power plants following their financial or political interests in the project. Furthermore, we should present a thorough site description: In the southern part of Kenya's Nakuru County, approximately 120 kilometers northwest of Nairobi, located directly south of the Naivasha Lake and Oloidien Bay lies Hell's Gate National Park with the villages of Kamere, Kongoni, and Watalii being the closest inhabited areas. Hell's Gate National Park roughly corresponds with the Olkaria volcanic complex that formed about 20.000 years ago (see figure 2). The last known eruption took place around 1770 CE (Smithsonian Institution 2013). The site is currently home to five geothermal power stations, aptly named Olkaria I through V, which each comprises several units.

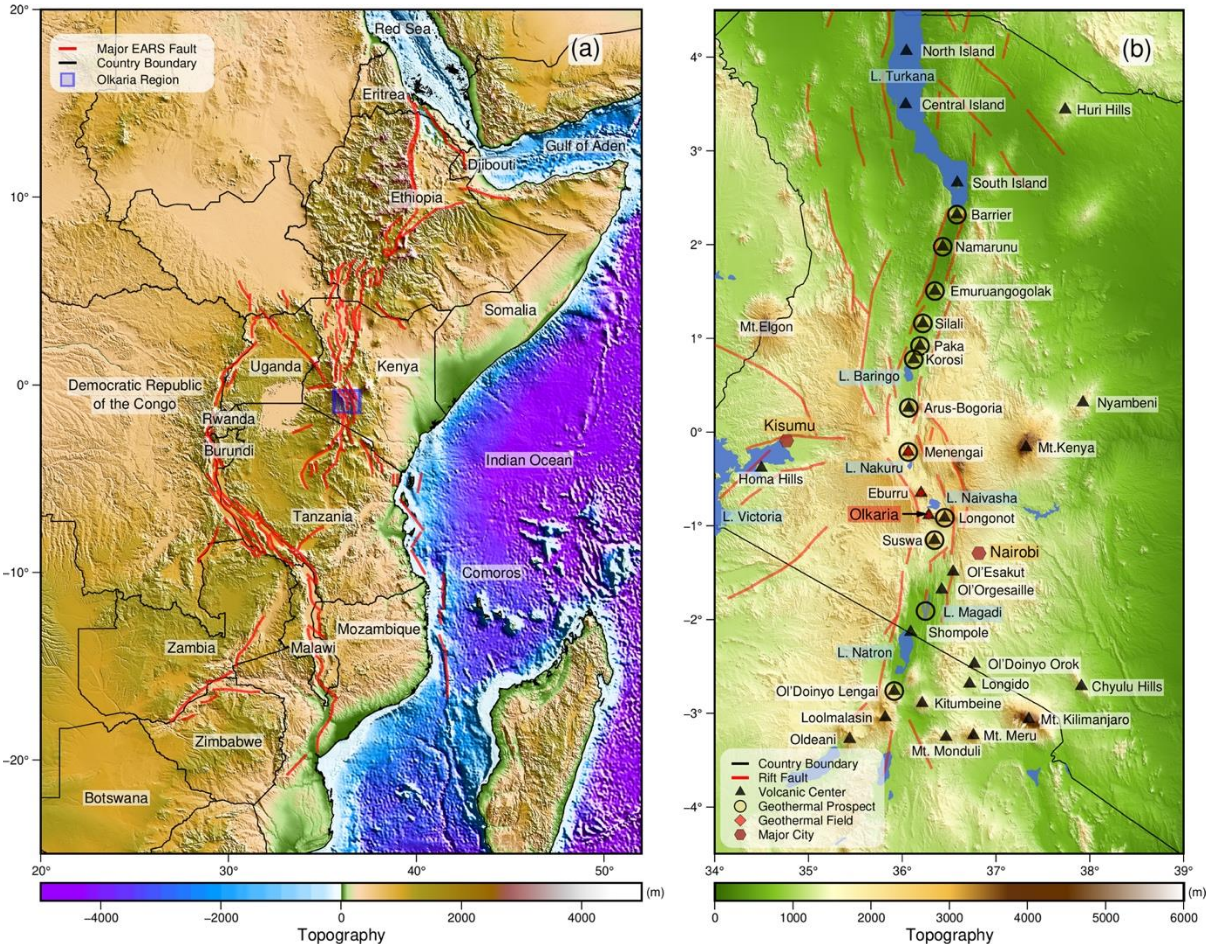

Figure 2. Location of the major fault lines (a) in Eastern Africa and the Great Rift Valley (b) in Kenya. The Olkaria site is highlighted just south of Naivasha Lake.
(Source: Fadel et al. 2021)

The exploitation of the geothermal resources at Kenya's oldest geothermal power plant started in 1981 with the 15 MW Olkaria I plant, which was later expanded to 45 MW. By 2015, an additional 140 MW capacity was added via two new units, bringing the total to five units for Olkaria I (GeoSteam Services 2015). In 2018, the Japan International Cooperation Agency (JICA) provided a loan of 95 million USD to allow for the refurbishment of Olkaria I's units 1, 2, and 3, upgrading their capacity to 50.7 MW, bringing the total capacity of Olkaria I to 190.7 MW (Otuki 2018; JICA 2018), thereby nearly exceeding 2012's installed capacity with just a single plant (Kianji 2012).

Olkaria II was conceived around the same period as Olkaria I. However, problems with accessing adequate funding resulted in significant delays. In 2000, the project was restarted following funding by the World Bank, European Investment Bank (EIB), and the German development bank KfW, eventually completing with a combined 70 MW capacity in 2003. The plant was expanded in 2010 with an additional 35 MW unit financed by the EIB, International Development Association (IDA), and French Development Agency as well as KenGen (Richter 2010).

Although generally referred to as Olkaria III, this plant actually started operation three years prior to Olkaria II in 2000. This plant is not owned by KenGen, but instead by OrPower Inc. It is made up of four units of varying capacity from one unit of 48 MW, one of 38 MW, to two units of 26 MW (Renewable Energy World 2016; Micale et al. 2015, 6; Ormat 2011). Being the first privately financed geothermal project in Kenya, the initial investment was shouldered entirely by Ormat Technologies. Once the viability of the project had been sufficiently proven, the project was refinanced and expanded, adding the two 26 MW generators, and undergoing a major upgrade of Unit 1, which was completed in January of 2009, bringing it to its current capacity from the 8 MW at its inauguration (UN 2018).

The development of Olkaria III was made possible through significant facilitation by the Kenyan government via its “Build, Own and Operate” scheme and risk-mitigating incentives. Also, KenGen supported the project via data sharing and the donation of the equivalent of 8 MW in geothermal wells to bootstrap the project. Experience gained from Olkaria III has contributed to the development of the aforementioned state-owned Geothermal Development Company, which now assumes the role that KenGen provided for Ormat for other potential IPPs (Micale et al. 2015). Although perhaps as of right now the exception in the Olkaria region, the project nevertheless indicates the potential of private investment in geothermal resources.

Olkaria IV is a 140 MW plant commissioned in 2014 that was financed by the World Bank, EIB, and KenGen. Consisting of two identical generator units with a nameplate capacity of 70 MW, the facility was designed as a more modern version of the Olkaria II plant (KenGen 2010).

Another JICA-financed project is the Olkaria V plant, the most recently completed plant that, according to a tweet by KenGen, started operation of its first unit in June of 2019 at 86.6 MW (KenGen 2019). This capacity was then roughly doubled with the activation of the second unit in October of the same year. Made possible by a JICA loan of 387 million USD, the largest loan ever granted by JICA in Japanese ODA history, the plant is currently the most modern active installation. This loan was provided on a concessional basis with a 0.2% annual interest rate and a 30-year repayment period (JICA 2018; Njini 2016).

At the time of writing, the next iteration, the 140 MW Olkaria VI, is under construction and is slated to be completed in 2022. This plant will be the first public-private partnership undertaken by KenGen. Starting with the PPP Act of 2013 and the promulgation of regulations in 2014, Kenya created the framework necessary for the next format to attract the necessary capital to develop its geothermal resources (KenGen 2019, pp.4-14). For the Olkaria VI project, similar agreements are outlined as in the case of Olkaria III: a 25-year steam supply agreement with KenGen and a 25-year PPA with KPLC. To facilitate this under a PPP, the project outlines a special-purpose vehicle (SPV), in which KenGen can have a maximum ownership stake of 25%. Furthermore, KenGen acquires the land lease agreement from the Kenyan Wildlife Service, which it then sub-leases to the SPV (KenGen 2019, pp.5-6). As of November of 2020, the interested parties to enter the PPP agreement and invest a majority of stake in the SPV are Ormat Technologies, Itochu Corporation, Sumitomo Corporation, and Enel Green Power (Richter 2020).

Beyond the facilities Olkaria I through VI, there are two more in the planning stages, Olkaria VII and VIII. Both are expected to be 140 MW facilities with two units each similar to Olkaria IV and V. VII is tentatively projected for 2022 with VIII to be completed at a later date. It is expected that developments will not halt as a projected 10,000 MW potential lies beneath the surface of the Great Rift Valley (Rotich 2016, p.6; Micale et al. 2015, p.3).

Table 1. Overview of the geothermal power plants in the Olkaria region

Power Plant	Owner	Unit	Date of Commissioning	Output	Notes
Olkaria I	KenGen	Unit 1	June 1981	50,7 MW	Initially, units 1, 2, and 3 were rated at 15 MW.
		Unit 2	November 1982	50,7 MW	
		Unit 3	March 1985	50,7 MW	
		Unit 4	December 2014	75 MW	
		Unit 5	February 2015	75 MW	
		Unit 6	Projected 2021	83.3 MW	
Olkaria II	KenGen	Unit 1	2003	35 MW	Construction of units 1 and 2 began in 1986 but was delayed due to a lack of funding.
		Unit 2	2003	35 MW	
		Unit 3	May 2010	35 MW	
Olkaria III, aka OrPower 4	Ormat Technologies	Unit 1	2000	48 MW	Olkaria III is the only plant on site not owned by KenGen. However, according to the power purchase agreement, KenGen is the buyer.
		Unit 2	2013	36 MW	
		Unit 3	2014	26 MW	
		Unit 4	February 2016	26 MW	Unit 1 originally had a generation capacity of 8 MW, before being upgraded in January 2009.
Olkaria IV	KenGen	Unit 1	October 2014	75 MW	In October of 2020, KenGen issued a procurement notice seeking a turbine upgrade to 85 MW at units 1 and 2.
		Unit 2	2014	75 MW	
Olkaria V	KenGen	Unit 1	June 2019	86.6 MW	

		Unit 2	October 2019	86.6 MW	
Olkaria VI	Public-Private Partnership		Projected 2022	140 MW	Potential PPP joint venture partners are Ormat Technologies, Itochu Corporation, Sumitomo Corporation, and Enel Green Power.
Olkaria VII			Projected 2023	140 MW	
Olkaria VIII			Planning stage	140 MW	

Compiled by the authors from the following sources: KenGen 2020 B; Richter 2020; Richter 2019 A; Richter 2018; Otuki 2018; Micale et al. 2015.

IV. Controversies Regarding H_2S Emission Impacts in the Olkaria Region

The Olkaria site has become one of the largest producers of geothermal power in the world, bringing Kenya as a developing nation to the forefront of renewable energy development. Compared with fossil and nuclear energy resources, geothermal power plants are considered to have only a minor environmental impact. The main environmental concern is the discharge of non-condensable gases into the atmosphere, most notably hydrogen sulfide (H_2S), carbon dioxide (CO_2), and methane (CH_4) (Ndetei 2010, p.442).

Of the geothermal byproducts, H_2S is considered to be the single most significant health concern related to geothermal energy development due to the risk of it causing several physiological responses (Reiffenstein et al. 1992; WHO 2000). H_2S is a colorless, flammable gas, with a distinctive smell of rotten eggs at low concentrations. It is toxic in higher concentrations when it becomes undetectable by humans (Irene 2009). Releasing this gas during the drilling process and later after steam utilization has been completed is one of the main sources of this type of air pollution and needs serious consideration both from the environmental protection perspective and its impact on the workplace of the personnel and the local communities living nearby.

The effects of H_2S are toxic to the human body, though the actual results are dependent on the dosage. As such, these effects can be grouped into three classifications, namely acute, subacute, and chronic. When a person is exposed to a large amount of H_2S, exceeding 1,000 ppm, the acute response is shown in the nervous system via the inhibition of cytochrome oxidase. The effect on this enzyme is similar to that of carbon monoxide; the enzyme fails to function as intended leading to cell death via cellular asphyxiation (Nicholls et al. 2013). The pace of breathing will increase, expelling carbon dioxide eventually leading to respiratory inertia, and without treatment to suffocation and potentially death. If the exposure dosage is not as severe, in the 100 to 600 ppm range, then a subacute response is noticeable in irritation of the eyes and respiratory tract. Although such irritation is less severe than the acute response, it can nevertheless lead to complications and death. The third classification, chronic, is in the 50 to 100 ppm range and can lead to individual cases of illness that might be similar to those found in the subacute classification (Sinclair Knight and Partners 1994). The table below shows the pathophysiological responses to different levels of H_2S in the air.

Table 2. Compilation of pathophysiological responses to hydrogen sulfide at various concentrations in air from various public institutions

Concentration (ppm)	**Expected Effects/Symptoms**
0.00011–0.00033	Normal range for background concentrations (OSHA)
0.0005	Lowest concentration by human olfactory senses (ATSDR)
0.01–1.5	Odor threshold (when a rotten egg smell is first noticeable to some). The odor becomes more offensive at 3–5 ppm. Above 30 ppm, odor described as sweet or sickeningly sweet (OSHA).
2–5	Prolonged exposure may cause nausea, tearing of the eyes, headache, or loss of sleep. Airway problems (bronchial constriction) in some asthma patients (OSHA).
20	Possible fatigue, loss of appetite, headache, irritability, poor memory, dizziness (OSHA).
50 – 100	Slight conjunctivitis (“gas eye”) and respiratory tract irritation. May cause digestive upset and loss of appetite after 1-hour exposure (ANSI and OSHA).
100	Coughing, eye irritation, loss of sense of smell after 2–15 minutes. Altered respiration, pain in the eyes, and drowsiness after 15–30 minutes followed by throat irritation after 1 hour. Several hours of exposure results in a gradual increase in severity of these symptoms and death may occur within the next 48 hours (ANSI and OSHA).
100 – 150	Loss of smell (olfactory fatigue or paralysis) (OSHA).
200 – 300	Marked conjunctivitis and respiratory tract irritation after 1 hour of exposure (ANSI and OSHA). Pulmonary edema may occur from prolonged exposure (OSHA).
500 – 700	Staggering, collapse in 5 minutes (OSHA). Serious damage to the eyes. Loss of consciousness and possibly death in 30 minutes - 1 hour (ANSI and OSHA).
700 – 1000	Rapid unconsciousness, “knocked down,” or immediate collapse within 1 to 2 breaths, cessation of respiration, and death within minutes (ANSI, ATSDR, and OSHA).
1000 – 2000	Unconsciousness at once, with early cessation of respiration and death in a few minutes. Death may occur even if an individual is removed to fresh air at once (ANSI and OSHA).

Abbreviations: ANSI, American National Standards Institute; ATSDR, Agency for Toxic Substances and Disease Registry; OSHA, Occupational Safety and Health Administration. *(1 ppm = 1.5 mg/m3)*
(1 g/m^3 = 1.5 ppm.)

(Source: Rubright et al. 2017; Selen et al. 2003)

In Kenya, environmental protection measures for the benefit of present and future generations are considered in Articles 69 and 70 of the Kenyan Constitution, according to which any release of noxious agents that may cause health or environmental problems are considered as a violation of constitutional rights

(Government of Kenya 2010). Protection of the environment was recently taken more seriously, with the promulgation of the Environmental Management Coordinating Act of 2015. In particular, Section 93 outlines the prohibition of discharging dangerous substances, either into water or otherwise into the environment. Administrative fines can be enforced on top of the cost of environmental restoration. For air quality standard, in particular, the Environmental Management and Coordination Regulations of 2009 outline the pollutants that are not allowed to exceed predefined ambient air limits in outside spaces.

Figure 3. Emissions (including H_2S) from the cooling towers at Olkaria IV.
(Source: Authors)

Figure 4. Emission (including H_2S) from the discharge and flow testing wells at East Olkaria.
(Source: Authors)

In line with WHO guidelines, these regulations set an acceptable H_2S concentration at 150 μg/m^3 averaged over 24 hours, without being exceeded for more than two days consecutively (EMCA 2015). These WHO guidelines are also the guidelines that KenGen adheres to independently (KenGen 2010). As such, their annual reports of the H_2S measurements at any of the Olkaria power plants all declare that the concentration of the gas is significantly below the WHO standards. However, there is a lack of third-party independent assessment of the H_2S emission in the region, with most of the reports concerning the issue being prepared either by KenGen itself or affiliated individuals. In the absence of employing an independent third party to keep track of emission levels at the different sites, across the region, and at different periods, there are only a few academics who were granted permission to measure the exposure amount independently, though for only for short periods.

Another example of reports prepared by the KenGen-affiliated scholars is provided by Ndetei (2010), a former student in the United Nations University's Geothermal Training Programme, while still affiliated with KenGen at the same time. His predictive modeling of the Olkaria I and II plants suggests H_2S concentrations equaling 118 μg/m^3 per 24 hours and 99 μg/m^3 respectively (Ndetei 2010, p.457). When attempting to predict the concentrations for the, at the time under construction, Olkaria IV plant, it too was estimated to be below the WHO guideline threshold (Ndetei 2010, p.458). As such, public acknowledgment of a potentially hazardous situation by Ndetei could be interpreted as having been problematic. Therefore, this study warrants both expansion to the now newly completed Olkaria facilities as well as independent verification. It is furthermore likely that for this reason the Olkaria III power plant (OrPower 4) was not included in the study, being outside KenGen control. This lack of independent verification challenges some of the data provided by KenGen due to the obvious conflict of interests.

In a study from the year 2000, conducted by Marani and his colleagues from the School of Environmental Studies at Moi University, Kenya, the concentrations of H_2S at different distances from the power station as well as a discharging well were monitored. Their measurements showed that the H_2S concentration exceeded 7.5 ppm over a half-hour period at least once in a two-week period, which is over the standards claimed by KenGen. The highest level of H_2S was observed when the winds were calm, the humidity was high, and the atmospheric temperature was low. While their measurement was conducted over an 11-day period, they concluded that, depending on the weather conditions, the concentration of H_2S may rise to an unsafe level for human health, plants, and wildlife. Therefore, their report calls for the need to maintain a constant monitoring program and early warning system (Marani et al. 2000).

Irungu (2017) conducted a study where he dealt with the impacts of ambient H_2S exposure to workers in Olkaria. His study focused on monitoring ambient H_2S concentrations in 37 sampling points distributed in the Olkaria I and II power plants. The measurement method used gas monitors such as the QRAEII 4 gas monitor type at a height of 1.5 meters for a maximum of one-minute concentration in each of the 37 selected points. His experiment demonstrated that the level of exposure to ambient H_2S level was below 10 ppm for a shift of eight hours during the measurement period on March 2012, which is in line with WHO standards. The average measured amount of H_2S for Olkaria I reported by KenGen for the period between 1997 to 2011 was 0.67 ppm per hour, while Irungu measured 0.97 ppm in March 2012 (Irungu 2017, pp.66-70). Such differences are also reported in the case of Olkaria II, where the reported hourly amount of H_2S was 0.23 ppm by KenGen while the measured amount in March 2012 illustrates emissions that were almost double at 0.41 ppm. While Irungu's measured amounts are still below WHO standards, such a big difference between KenGen's measured amount and his sample is difficult to ignore.

More importantly, Irungu (2017, pp.59-67) goes further to investigate the possible health issues of H_2S emission on the KenGen staff working in the region. The number of visits to the nearby Mvuke Clinic in the period of 2009 to 2011 with the clinical symptoms of H_2S exposure was 157, which comprise 37 individuals out of the sample of 40 (92.5%), working in the operation and maintenance sectors. They made 3.39 visits on average to the clinic compared to the 1.83 average visits by their co-workers in the other areas of the same department, which illustrates the need for serious consideration in revisiting the standards that KenGen follows (Irungu 2017, p.68). According to the clinical reports, some of the common symptoms were related to breathing problems, upper respiratory tract infections (URTI), bronchitis, coryza, mouth sores, pharyngitis, rhinitis, sinusitis, sore throat, and tonsillitis. Other symptoms reported by the clinic were reddening of the eyes, hypertension, and headache including chronic headaches that are related to strain.

Such an increase in health problems is also reported by some members of the Maasai community, the indigenous tribe residing in the Olkaria region. However, we could not find reliable data from the hospitals. It should also be considered that, as the Maasai tribal people have a traditional way of life, they barely visit the hospital for their health problems. But this should not be interpreted as H_2S emission having no impact on their health. While there have been several protests and riots against their land acquisition, the noise, and the environmental issues occurring in the region since the early stages of development of the Olkaria power plants (Koissaba 2014; Mwebe and Jika, 2018), the KenGen report does not mention such issues.

V. Problematic WHO Standards for Setting Tolerable H_2S Emission

The Kenyan situation is by no means historically unique, as all developed states have had to deal with the adoption of environmental regulations, including those dealing with H_2S emissions. In the initial phase, states tend to adopt the World Health Organization's guideline of 150 μg/m^3 averaged over 24 hours (WHO 2000, p.33). These standards have, however, been called into question for nearly three decades. In a 1992 study conducted by a group of medical doctors on the acute health effects of H_2S release at the South Karelia industrial site in Finland, it was revealed that, even with a 43 μg/m^3 hydrogen sulfide emission, which is more than three times below WHO standards, 63% of the respondents reported at least one symptom caused by exposure. They concluded that the WHO standard is too high and does not provide prevention of adverse health effects (Haahtela et al. 1992).

The fact that the H_2S norms in ambient air are not considered in large parts of the regions and countries in the world might be the reason behind the reluctance of the WHO in reconsidering its regulations. H_2S emissions have only become a major issue in the regions where heavy industry or geothermal power generation is utilized on a large scale. Therefore, many countries do not have ambient air quality standards for H_2S. For example, the European Union's Air Quality Standards do not outline H_2S (European Commission 2019). However, when looking at specific cases in Europe, such as in the Netherlands, a standard of 100 μg/m^3 averaged over 14 days is considered the health norm (Mooij 2011, p.54).

When narrowing our focus to other countries that have made remarkable strides in geothermal power adoption, we undoubtedly find Iceland. The OECD recognizes the achievements in renewable energy adoption that Iceland has made over the last decades. However, they warn that these developments are not without their own negative caveats, including the aforementioned H_2S emissions (OECD 2015). So too have the local population near Hellisheiði Power Plant indicated that they are suffering under H_2S emittance, which under certain weather conditions can reach settlements (Gunnarsson et al. 2011). In 2010, Iceland adopted Regulation No. 514/2010, aimed to set limits on the atmospheric H_2S concentrations. This limit is set at 50 μg/m^3 averaged for a runtime of 24 hours with only three incidental yearly allowed exceedances (EIB 2016; OECD 2014, p.9). This limit is significantly lower than the WHO guidelines. Hellisheiði has exceeded both WHO guidelines and Icelandic regulations on numerous occasions, leading to an EIB-funded upgrade program to install an H_2S capturing system, “SulFix,” allowing for subterranean injection (EIB 2016; Kristjánsdóttir 2014).

As is often the case in the development of new industries, such as Icelandic geothermal power, the technology and its implications tend to outpace legislation. Such reactive policy is often the result of civil unrest originating from disturbances caused by the novel technological implementation within new geographic spaces. For instance, the Icelandic environmental policy has been considered to have developed at a relatively late stage (OECD n.d., p.2). As such, we will briefly outline the development of Icelandic policy towards H_2S emissions and see what lessons Kenya can draw from these experiences.

During the planning phases of the Nesjavellir (2000) and aforementioned Hellisheiði (2005) geothermal power facilities, environmental impact assessments were carried out according to European regulations.[1] Originally outlined in European Council Directive 85/337/EEC, such assessments are designed to explain the direct and indirect project effects on, and interactions of, among others, soil, water, and air quality as well as human, plant, and animal life. This European directive was later expanded on in national legislation with Environmental Impact Assessment Act No. 106 (Iceland 2000). Both geothermal facilities were eventually completed and several studies on the effects of their H_2S emissions have since been conducted, challenging the earlier environmental assessments and WHO guidelines. These include a study on the increased mortality rate over the period from 2003 to 2009 (Finnbjornsdottir et al. 2015), and another on increased drug distribution associated with H_2S levels between 2006 and 2008 (Carlsen 2010). Since 2010, Iceland has strengthened its legislation to limit H_2S emissions, primarily due to complaints from residents near geothermal power stations about the aforementioned 50 $\mu g/m^3$ limit (EIB 2016; OECD 2014, p.9).

Much like Kenya, Iceland is dependent on a green image for its economic development (OECD n.d., p.2). Two of the largest Icelandic industries are fisheries and tourism, which greatly benefit from environmental protection regulations. And while fisheries are not as important for Kenya as they are for Iceland, Kenya’s world-renown safari tourism is equally dependent on the protection of the environment. In the case of the Olkaria geothermal developments, this is a particularly significant issue due to their location within Hell’s Gate National Park.

[1] Iceland is a member of the European Economic Area (EEA).

Beyond the Icelandic example, there are several other major adopters of geothermal power that have adopted regulatory standards stricter than WHO guidelines. For instance, the US Environmental Protection Agency (USEPA) of California, the US state that produces 71.2% of the nation's geothermal power, maintains an even more stringent H_2S emission standard of 43 μg/m^3 averaged over one hour (USEIA 2020; Nolasco 2010, p.188). Also, the US state of Wyoming maintains regulations lower than the WHO guideline at 70 μg/m^3 averaged over a half-hour period, not to be exceeded more than two times per year, or 40 μg/m^3 averaged over a half-hour period, not to be exceeded more than two times in any five consecutive days (Wyoming Department of Environmental Quality 2015, p.4).

In New Zealand, the guidelines are even more strict than those of the Californian USEPA at 7 μg/m^3 average over an hour period. The rationale behind such a low limit is based not on health concerns per se but rather odor nuisance in a more general sense. However, the actual ministerial guidelines question the suitability of this limit for geothermal areas (Nolasco 2010, p.188; New Zealand Ministry for the Environment 2002, pp.16-17).

Examples such as these show the seriousness with which H_2S emissions are treated among OECD member states. Given that the rationale in their adoption is not significantly divergent from the current situation in Kenya, it might be prudent to reconsider expanding environmental legislation beyond WHO guidelines.

VI. Possible Solutions and Suggestions

Noting the shortcomings of WHO standards at various sites around the world, coupled with significantly divergent environmental legislation from WHO guidelines among OECD member states, one may ask why WHO standards have not been changed so far? One possible answer is that the H_2S emission problem and concentration of geothermal power plants on large scales is not an issue among the majority of nations.

Here, we review some possible recommendations that the Kenyan government could consider mandating KenGen and other involved stakeholders to implement. Strict policies in the aforementioned countries to control the limit of H_2S emission has encouraged the operators to install some facilities for the reduction of H_2S released to the air by up to 99.9%, much like the previously outlined SulFix solution at the Hellisheiði Power Plant, some of which are presented in the table below.

Table 3. Compilation of different processes of H_2S emission abatement

Process Name	Condenser Design	NH_3/ H_2S ratio	Economics	Best Suitable For	Leading Region
Liquid redox methods	Surface contact	Low	High capital costs	Large plants	Geysers geothermal Field
SulFerox process	Surface condenser	Low	High capital costs	Large plants	California
LO-CAT II	Surface condenser	Low	High capital costs	Large plants	Coso Geothermal Field
BIOX	Surface condenser and direct contact condenser	High and low	Low capital costs and low operational costs	Small and large plants	Hudson Ranch II geothermal power plant California
Selectox	Direct contact condenser	Low	High capital costs and low operational costs	Medium and large plants	Yanaizu-Nishiyama Geothermal Power Plant
H_2O_2 process	Surface condenser and direct contact condenser	High	Low capital costs and high operational costs	Small units	Northwest Geysers Geothermal Resource Area

(Source: Rodríguez et al. 2014; Farison et al. 2010; Baldacci et al. 2005; Takahashi et al. 2000)

When considering the feasibility and the required initial investment costs in proposing a method to reduce the gas emission in the various Olkaria power stations, the options that could be implemented after completion of the power plant with lower cost are the most feasible options for the Olkaria power plant's context. For instance, in an instance similar to Olkaria, the BIOX (biocide-assisted oxidation) method is currently being used at the 49 MW Hudson Ranch Ⅱ geothermal power plant in California (Gallup, 1992). It is a downstream process, in which the off-gases are compressed and mixed with the condensate before entering the cooling tower, which reduces both primary and secondary emissions of hydrogen sulfide.

As we observed during a site visit to Olkaria, another serious source of environmental pollution and H_2S emission are the many discharging wells under construction. As we were told by a KenGen specialist, the duration of discharging for each well is about 60-90 days and its initial purpose is to test whether the pressure and other factors of the well would meet the standards for joining the system. Though the discharging period is not very long, the number of wells that are being tested regularly is considerably high, in line with the continued development of new Olkaria facilities, as well as the upgrading and expansion of units at the active facilities. Thus, implementing the already-existing low-cost solutions to reduce the H_2S emission during this process could be valuable in tackling H_2S emission as a whole across the entire Olkaria site (Nolasco 2010).

VII. Conclusion

Policy, regulatory, and geothermal innovations are occurring side by side as Kenya tries to balance developmental, economic, and environmental interests. New geothermal facilities are sprouting all over Hell's Gate National Park, using attractive new financing schemes to attract foreign capital, in line with the Vision 2030 development plan. As to be expected with the constitutionally enshrined environmental protection clauses, issues such as emissions have been given more consideration, especially from the Olkaria V facility onward with the introduction of the Environmental Management Coordinating Act (EMCA) in 2015.

One of the emissions of particular concern is hydrogen sulfite gas (H_2S). This gas can be lethal in high concentrations and has been shown to cause health problems in lower concentrations. Regardless of the EMCA, Kenya still holds to WHO guidelines on tolerable H_2S emission levels, which have been criticized by health professionals for decades. Other countries, which have developed geothermal industries of their own, have come to face similar issues regarding H_2S emissions. Major players in geothermal energy adoption such as Iceland and California have drastically cut allowed H_2S emission levels below WHO guidelines.

International investors involved in the geothermal sector such as the US-based Ormat Technologies are able to benefit from this as they are not required to keep to the same regulatory standards in Kenya as they are required at for instance their Californian facilities. Meanwhile, the Kenyan government is hard pressed to meet the Vision 2030 targets and is unlikely to be willing to promulgate new regulations that might make investors wary. This makes it seem like a dangerous situation where tough decisions between economic growth and environmental protection will need to be made.

However, there are cost-effective solutions available that would mitigate environmental and health impacts at a relatively low cost. Companies, however, cannot be expected to take the initiative in the implementation of these solutions. As with the case of the Hellisheiði facility in Iceland, only after legislative change mandating lower H_2S emissions were mitigating steps taken, steps that were seemingly necessary due to the mounting evidence of negative health effects. Kenya too is currently at a similar stage. However, uncertainty remains as long we are limited to KenGen data. We, therefore, recommend an independent inquiry into emission levels and health effects at the Olkaria site.

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III. Course Reports

- Group Work Practice III (Spring Semester 2020)

- Group Work Practice V (Fall Semester 2020)

Working Paper on Increasing Environmental Sustainability of Isolated Energy Systems:

A Case Study for the Implementation of a Co-Generation Binary Geothermal Power Project on Hachijō Island, Japan

Eco Hamersma

Introduction

The target of this report is to propose a method to increase the share of renewables on Hachijō Island, a remote island with an isolated energy system. The target we would like to achieve with this project is a 10% increase in renewable utilisation of total energy mix. In this paper we will propose augmenting the current geothermal energy output by utilising the waste heat generated by several Onsen, Japanese style hot springs, which dot the landscape of Hachijō Island. By taking advantage of existing geothermal resources and infrastructure on the island this project aims to increase the share of renewables in the islands energy mix without negatively affecting available geothermal resources, currently in use by both an industrial size geothermal powerplant and the aforementioned Onsen.

Tackling climate change while dealing with humanities seemingly near insatiable hunger for energy is one of the predominate issues of the 21st century. The island nation of Japan is no exception, as the world's third largest economy it demands massive amount of energy supplied according to stringent standards for its high-tech industries. Between 2010 and 2018 the approximate yearly average electrical consumption rate, though in a declining trend, was about 1050 TWh. This period of the nation's energy policy having been severely affected by the 2011 Great Tōhoku Earthquake and the subsequent meltdown at the Fukushima Daiichi Nuclear Power Plant (IEA, 2016).

Japan traditionally relied heavily on the utilisation of nuclear power due to the lack of natural resources, particularly fossil fuels, within the national territory. When as a result of safety concerns due to the Fukushima accident all of Japan's nuclear power plants were shut down pending checks, it caused the usage of fossil fuels, particularly natural gas and coal, to spiked. Not only has this resulting rise in CO2 emissions, but also a greater dependence on energy imports and unsustainable energy prices (Ibid).

To combat these effects the Japanese national government has outlined a series of goals for 2030 to increase that share of renewable energy within the nation's energy economy and cut greenhouse gas emissions by 26%. The most recent data from 2018 shows a 12,39% decrease over that period. While this is admirable, this is still 5,37% more CO2 emissions then 1990 (Ibid). Prefectural governments have set even more ambitious goals, such as Fukushima prefectures 100% renewable by 2040, a big step up from a mere 22% in 2014 (Yeo 2014). Clearly more work will need to be done to further reduce dependence on fossil fuels.

While Japan is resource poor when it comes to fossil fuels, when looking at geothermal resources Japan has one of the greatest potentials in the world. Located on the Pacific Ring of Fire making it one of the most geologically active regions in the world (Kubota et al 2013). These volcanos are formed by the subduction of the Pacific Plate and the Philippine Sea Plate under the Eurasian Plate. The main resulting volcanic belts run along Kyushu and Honshu's Chubu and Tōhoku regions on the Japanese mainland along with the Izu Islands Archipelago (also known as the De Vries Archipelago) and Ogasawara Archipelago (also known as the Bonin Islands) in the Pacific Ocean (Japan Meteorological Agency 2016).

Background of Hachijyo Island

Hachijō Island (Hachijō-jima/八丈島) is a small volcanic island roughly 77 km2 in size located in the Izu Islands Archipelago approximately 287 km from mainland Japan. Though quite remote, administratively the island belongs to the special wards of Tokyo. Furthermore, the islands are wholly inside the Fuji-Hakone-Izu National Park. The island itself is made up of only a single municipality of the same name, Hachijō, which according to the census of 2015 had a population of 7613 people (Favro & Brebbia 2010, p.189; Tokyo Government n.d A). Many of the demographic issues facing Hachijo Island are similar to the Japanese mainland, with a declining population which contains 3% more people over the age of 65 then the national average (Favro and Brebbia 2010, p.189).

Figure 1. location of the Fuji-Hakone-Izu National Park highlighted in dark green. Image source: BCT-Touristik, n.d.

The island, which has been inhabited since the Jomon period (14,000-300 BCE), has seen numerous uses. As early as the Heian period (794 to 1185) the island saw political refugees use it as a place of refuge. Later the island would serve as Japan's '*St. Helena*' for the exiling of dangerous political figures, starting with Ukita Hideie, one of the members of Toyotomi Hideyoshi's regent council upon his death, who fought against Tokugawa Ieyasu at the Battle of Sekigahara (1600). A practise which lasted until the Meiji Restoration in 1868 (Tokyo Government n.d. B). Through these historically periods agriculture and fisheries were dominant. Today, however, the tertiary industries dominate the island at 64%. This figure is made up almost entirely of tourism, while primary and secondary industries take up the remaining 19 and 17 percent respectively (Favro & Brebbia 2010, p.190). The relationship between tourism and the islands geological features is very apparent; According to Tokyo's official tourism area guide for the island the primary points of interest are the volcanos, Mt. Higashiyama (literally Eastern Mountain), and Mt. Nishiyama, (literally Western Mountain), the Nanbara Coast of Permian Rocks and Onsen hot springs (GoTokyo n.d.).

The effects of climate change can be expected to be felt most severely through increased storms including major typhoons, something Hachijō Island has had to deal with even under normal climate conditions (Soma 1977). During Typhoon Cora in the 1970's approximately 3700 of the 3800 homes on the island were damaged in some way (Wilson 1976, p.51). While in the past such strong weather occurrences were rare, climate change is driving increasingly severe storms which threaten vulnerable isolated areas like Hachijyō Island.

Energy on Hachijyō Island

Considering the importance of mitigating climate change, the island has been doing well to contributes its share within its limited capacities and relative isolation. Due to the remote location the island has an isolated grid from mainland Japan. Some minor wind utilisation, at 500 kW, takes place on the island. The main source of renewables derives from Japan's first geothermal power plant on a remote island. Developed by Tokyo Electric Power Company (TEPCO) this 3.3 MW powerplant also serves as a supplier for district heating in winter (GRSJ 2004).

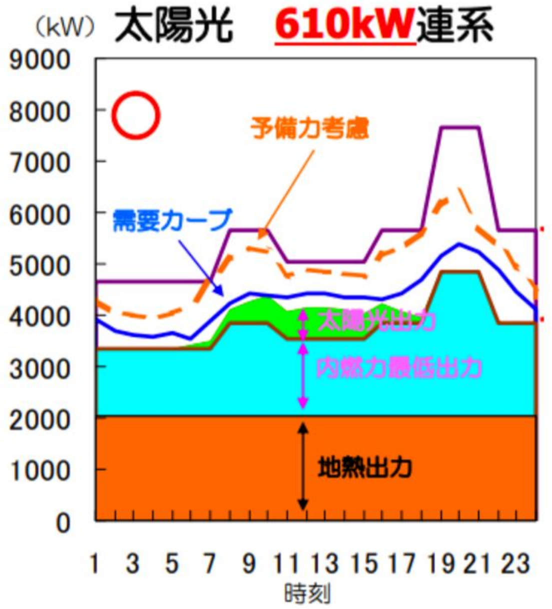

Figure 2. Graph showing the fluctuating demand on the island throughout the day and indicating baseload supply delivered by geothermal (orange) and diesel combustion (cyan). Source TEPCO 2014

Exploration of the site for this plant started in 1984 when between 1989 and 1991 the New Energy and Industrial Technology Organisation (NEDO), one of Japans Independent Administrative Institutions, identified a suitable geothermal source beneath the southern slope of Mt. Higashiyama (literally Eastern Mountain), the easterly located of Hachijyō's two volcanos (the other being Nishiyama, literally Western Mountain) (Matsuyama et al. 2011).

In 1995 TEPCO started drilling operations and eventually the powerplant opening in 1999. This powerplant acts as the island's primary baseload supplier, having saved the CO2 emissions which otherwise would have been generated by a diesel generator. Constituting an approximate reduction of 40%. Still, however, diesel makes up the remained of the island's energy needs, with an Internal Combustion Power Station also operated by TEPCO delivering 16.6 MW (TEPCO 2018). Figure 2 indicates the demand on the island, note how the baseload supply from geothermal does not exceed delivered minimum consumption during the spring, 6 o'clock in the morning. In 2017 ORIX Corporation started planning a replacement for the now aging TEPCO plant. This new plant will have a higher capacity at 4.4 MW and is expected to come online in 2022 (Nikkei 2017; ORIX 2019).

Current State of the Geothermal Industry in Japan

The Japanese geothermal industry has traditionally not matched the geothermal potential of the Japanese archipelago. Though new government initiatives are hoping to increase utilisation, decades of restrictive legislation and cultural factors have, up to this point, stifled developments. Although the first geothermal power station was constructed almost 100 years ago near Beppu city on the southwestern island of Kyushu, the economic downturn in the runup to, and subsequent global conflict, limited its expansion. After the war the Allied GHQ, the occupation government on Japan, instituted the 1948 Hot Spring Law. This law is still in effect and has been a limited factor in the application of projects seeking to generate electricity from geothermal resources.

Onsen in Japan should be seen as cultural institutions which embody a special place within the psyche of the average Japanese. As such any perceived threat, specifically by industries seen as industrial and pollutant is met with negativity. For this reason, the Japan Spa Association (JSA) actively lobbies against geothermal power. In a 2016 interview with Vice News the JSA chairman Masao Oyama stated:

「温泉と地熱発電は共存できません」

Which translates to *"hot springs and geothermal power generation cannot coexist"*. The argumentation he presents is that of a competition of resources. The development of geothermal power would detrimentally affect the Onsen industry due to resource competition (Yeung 2016).

Onsen proprietors are not the only people who pose a problem to geothermal adoption. Much like renewable developments across the developed world, a concept known as NIMBYism, which stands for Not In My BackYard-ism. This concept is characterised by a general positivity to renewables, but a strong feeling against such developments within the general living area. For instance, in the case of wind turbines in Europe this has led to increased developments of offshore installations, outside the range where people would feel personally affected by such developments. Geothermal power faces similar constrains. Particularly due to the perception of large installations with a factory-style appearance.

Geothermal Resources on Hachijyō Island

There are two main players active in the geothermal industry on Hachijyō Island. The geothermal power industry and recreational Onsen. The geothermal industry is outlined above, in the section on local energy usage. The recreational uses are predominantly Onsen baths on the southern tip of the island. Figure 3 shows the location of all the wells drawing geothermally heated water on the island. Not all of these are currently active and so the table below separates out the active and buried wells, with the numbers corresponding to those on the map.

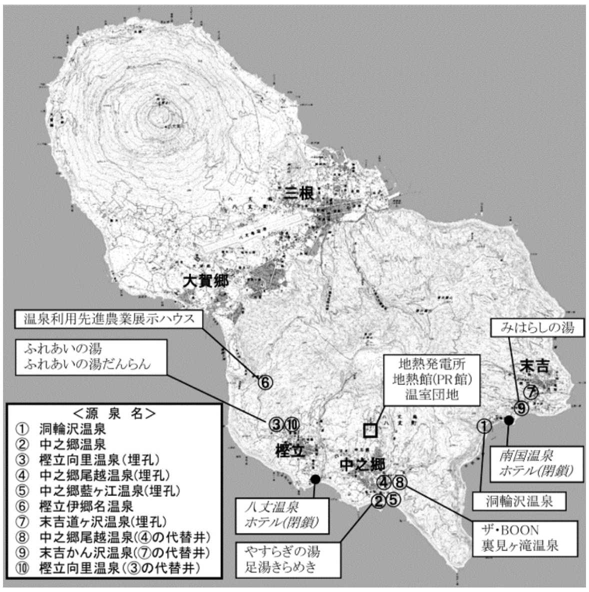

Figure 3. Map of Hachijyō Island indicating the location of all wells for geothermally heated water. Names of the Onsen utilising these wells are highlighted along with major settlements (Mitsune (三根); Okago (大賀郷); Sueyoshi (末吉); Kashitate (樫立); Nakano.

Active Wells

① Dowazawa Onsen (洞輪沢温泉)
② Nakanogo Onsen (中之郷温泉)
⑥ Kashidate-Igona Onsen (樫立伊郷名温泉)
⑧ Nakanogo Ogoshi Onsen [Alternative ④well] (中之郷尾越温泉)
⑨ Sueyoshi Dogasawa Onsen [Alternative ⑦wells] (末吉道ヶ沢温泉)
⑩ Kashitate Mukaizato Onsen [Alternative ③wells] (樫立向里温泉)

Buried Wells

③ Kashitate Mukaizato Onsen [Buried] (樫立向里温泉)
④ Nakanogo Ogoshi Onsen [Buried] (中之郷尾越温泉)
⑤ Nakanogo Aigae Onsen [Buried] (中之郷藍ヶ江温泉)
⑦ Sueyoshi Dogasawa Onsen [Buried] (末吉道ヶ沢温泉)

Co-generation Development Plan for Hachijyō Island

Considering the aforementioned issues of climate change, the shift to renewable energy is desirable. On small isolated energy systems these present both opportunities and challenges. Isolation creates difficulties in sourcing fuels for power generation and creates a reliance on outside support. Furthermore, isolation results in increased energy prices as the cost of transportation is significantly higher compared to mainland energy systems. Access to different types of energy has also historically been limited, with most isolated islands relying on diesel generators. While today renewable energy sources are available, they create difficulties when looking at grid stability. As a result, on many isolated islands the baseload supply is still relegated to diesel generators (Favro and Brebbia 2010, pp.197-200). Hachijyō Island presents, as a result of the above-mentioned geothermal resources, an opportunity to increase overall renewable adoption rate for a small isolated energy grid due to the characteristics of geothermal energy. Geothermal power is an exception among renewables in that it is not dependant on weather phenomenon and is therefore suitable as a baseload supplier. If we look at figure 2, we can see that there is still room to improve utilisation of renewable energy in both on-demand and baseload supply.
By focusing on specifically a co-generation geothermal power plant, also known as a binary geothermal power plant, over traditional implementations such as the current TEPCO installation and the planned ORIX facility we furthermore hope to sidestep the issues present within the Japanese geothermal industries. As figure 4 illustrates, by using a binary loop system the thermally heated well water is first cooled down via heat exchanger. This heat is then used to bring a secondary liquid, usually pressurized isobutane, to its boiling point. The secondary liquid drives the turbine allowing for power generation. Meanwhile, the primary liquid, well water, has been sufficiently cooled to allow for uses such as bathing.

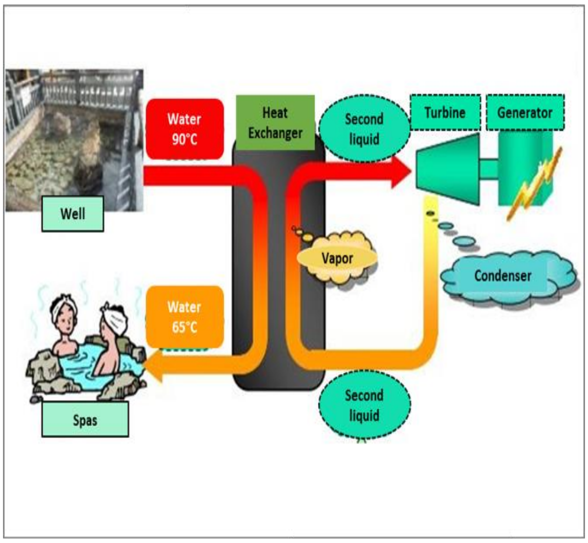

Figure4. Diagram of a binary geothermal power plant combining Onsen with power generation. Image source: Movellan 2015.

This process allows for the utilization of what would otherwise be waste heat. Primary concerns of the Onsen industry as outlined by the JSA would not be applicable to this type of geothermal power plant. The primary user of the well water remains the Onsen, only in the cooling process does power generation interact with the process. And even then, this is simply in the form of heat exchange. The actual spring water consistency is completely unchanged. Furthermore, when considering the construction phase of the powerplant no expensive drilling is necessary as only existing Onsen are targeted. Therefore, we can conceptualize this plan as one of resource use efficiency rather than the exploration of new resources. Through this method we avoid the majority of the high-risk elements as outlined by Gehringer and Loksha (2012). In their assessment the highest risks are found in the pre-survey, exploration and test drilling phases. With drilling itself considered a medium risk. By using existing wells and cooperating with local Onsen we can avoid the largest risks for a geothermal project.

According to Hernandez II (forthcoming 2021), when surveying numerous geothermal powerplants the resulting pattern in power generation efficiency can be presented using the following equations. Warm water before turbine conversion, assume efficiency of Hl=1:

Qi=rCl(THl-THe)

Qt=Qi*ηi*ηt

Wt=Qt-Qi

Wd=(Wt)*ηd

Colder water after turbine conversion:

Qo=Qi-Qt

To control Onsen temperature to a desired temperature Tons, the temperature in Wo should be controlled. One way can be to choose turbine such that (assuming no loss in water and no change in heat capacity flow rate):

Table 1: Labels	
Heat transfer liquid	*Hl*
Heat exchanger	*He*
Amount of input	*r* (unitless)
Specific heat capacity flow rate of heat transfer liquid	*C* [W/K]
Energy converted via heat transfer liquid and entering heat exchanger	*Qi* [W]
Energy of fluid after conversion from heat exchanger (cold fluid)	*Qcold*
Heat converted from heat exchanger going out of turbine as electricity	*Qt*
Energy output due to Qt	*Et*
Energy converted from heat exchanger going out of turbine as heat	*Qo*
Energy of Onsen water	*Qons*
Energy distributed to end user	*Wd*
Efficiency of Wi	*ηi*
Efficiency of Wt	*ηt*
Efficiency of Wd	*ηd*

Qons=rCl(Tons-Tt)

Alternatively, another method would be to use a cooling system, such as a secondary heat exchanger, which would use the cold water from the heat exchanger with the temperature Tcold which then:

Qons=rCl(Tons-Tcold)

This shows that energy is dependent on value r, allowing for independent control. Hernandez II then further stipulates that the estimated power output can be ascertained using the following equations. These calculations are based on a conceptual cooperation with 5 of the Onsen on the island, which would be seen as a reasonable goal within the scope of this proposal. The inlet temperature (deg C):

For an inlet temperature in ℃ of the primary fluid:

$$\eta_{act} = 6.9681 \ln(T_{in}) - 29.713 \qquad (16)$$

For an inlet average enthalpy in kJ/kg of the primary fluid:

$$\eta_{act} = 6.6869 \ln(h) - 37.929 \qquad (17)$$

Using the current TEPCO installation as a point of reference: h = 2582, m = 44, To = 20 deg C, h = 2582. Power generated (in kW) is:

$$W = 2.47\dot{m}\left(\frac{T_{in} - T_0}{T_{in} + T_0}\right)(T_{in} - T_{out})$$

If Tin = 50 deg C , Tout = T onsen = 40, W = 465 kWe Assuming 5 Onsen with similar properties, supplied power can reach around 1600 kW, which is around 10 percent of 16.6 MWe total energy. Using the above estimations and considering the cooperation of five Onsen to partner with we can structure the economics of this project accordingly.

Cash Flow and Financial Aspects

As mentioned in the previous section, the riskiest elements of developing a geothermal power plant according to Gehringer and Loksha (2012) are in the exploration and drilling phase of the project. Since we are working together with local Onsen this stage has already been achieved at no risk to our own project. What this means for economics of our binary power station, however, is that we do not have ownership of the well. This means we become a client of the hot water provider and as such our cash flow is modelled on input costs, throughput costs and output income. As seen in figure 5, the cashflow for this project requires a financial incentive for the participating Onsen which takes place in the form of input (hot water) purchases.

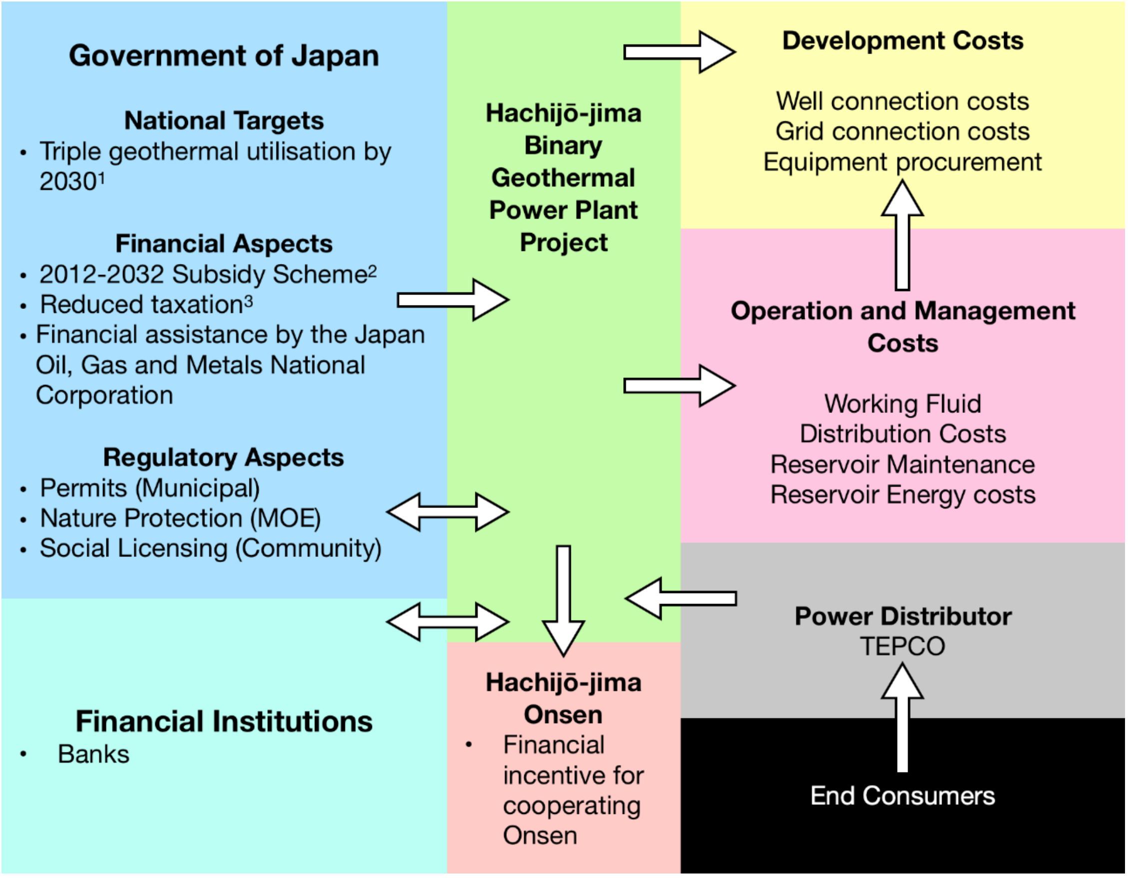

Figure 5. Project cash flow combining development and operational phases.

Japanese public perception to geothermal power is slowly changing. The Ministry of Economy, Trade and Industry promulgated its 'Long-term Energy Supply and Demand Outlook' as part of a series of policies from its 'Strategic Energy Plan'. This plan outlines increasing the use of geothermal to between 1% and 1.1% of total primary energy by 2030. This plan can be seen in increased governmental support for geothermal projects, such as for example reduced taxation on geothermal power. Japan Oil, Gas and Metals National Corporation (JOGMEC), one of Japan's independent administrative organisations, is a major provider of geothermal support in the form of direct investments, equity and generous liability guarantees of up to 80% on loans provided by financial institutions (JOGMEC 2016). Having a strong liability backing it should be easier to persuade financial institutions to invest in geothermal projects like we one presented in this paper.

Development costs are highly situational and dependent on the realities of on the ground. As explained in the previous section, to meet our target we need to work with 5 Onsen. However, the simple geography and space utilisation within and near the land of those Onsen will determine the exact developmental process. We can furthermore expect that the procurement procedure will be more expensive then the Japanese national average due to the remote nature of the project site. Likewise, maintenance costs are expected to be higher than national average, as will the attracting skilled engineers.

Project Timeline

We estimate a 5-year duration for the development of binary geothermal power on Hachijō Island. Table 2 shown below gives a rough sketch of this plan starting in 2020. This plan is based on a larger scale geothermal development project in Iceland, specifically for a flash steam geothermal system. Such a system does include exploration and drilling phases. Therefore, we believe our assessment, excluding those phases, but taking into account the more remote nature of the island is realistic. The assessment does not take into account the novel coronavirus pandemic and assumes productive capacities similar to pre-pandemic levels.

	2020	2021	2022	2023	2024	2025
Beginning of research	→					
Reaching out to stakeholders	→					
Setting up agreements with Onsen		→				
Prepare powerplant permits		→				
Environmental impact assessment		→				
Beginning of construction (prep-phase)				→		
Onsen 1					→	
Onsen 2					→	
Onsen 3					→	
Onsen 4					→	
Onsen 5					→	

Table 2, This timeline is based on an Icelandic geothermal development plan (Gunnlaugsson 2012)

Environmental Assessment and Regulatory Aspects
Development of geothermal resources in Japan is hindered by the fact that many of these resources are located in national parks. The case of Hachijō Island is no different as it is located in the previously mentioned Fuji-Hakone-Izu National Park. This brings with it specific challenges found with the development of other renewable sources of energy. Change is in the air, however, as after the accident at nuclear power plants in Fukushima, the Ministry of Environment (MOE) issued the guideline which lifted restrictions on drilling at national parks (JOGMEC 2016).

The MOE set regulations on the 'conditions on the environment of the hot spring resort area'. These are to ensure that the area has environment, landscape, history, climate and culture making it suitable for a heath resort. This is then achieved by requiring that appropriate action is taken for construction of hot springs, management of sanitation, promoting public use of hot springs and ensuring a universal design. Furthermore, there should be a measure of safety against disasters ensured within a project (National Hot Spring Health Resorts, n.d.).

In 2004 the national Landscape Law was enacted in response to growing interest in preserving natural and cultural landscapes. This law stipulates that local governments set up criteria for matters such as building heights and exterior appearances in order to create and maintain beautiful landscapes. Beautiful in this context refers to the aforementioned suitability for the environment within national parks and hot spring areas.

Social Licensing & Survey Results
By considering binary geothermal power we sidestep some of the primary issues currently constraining the adoption of geothermal, particularly those promulgated by JSA. One issues which remains, and is relevant no matter the project, is the issue of social licensing. In other words, the willingness of local communities to accept developments by a third party. In the case of this project specifically this means the acceptance of the people of Hachijō to allow for the development of further geothermal power on the island. In order to ascertain the level of social acceptance for a project such as this one we conducted a research among the local population.

Sadly, this research was severely hampered by the outbreak of the novel coronavirus as we were unable to conduct fieldwork on the island. Therefore, we utilised a third-party survey company, Macromill Inc. (株式会社マクロミル), to conduct an online survey via a questionnaire we provided. We had set a target of 200 respondents in order to gain statistically significant data set. However, Macromill was only able to attain 26 respondents within the timeframe of this research. Without a statistically significant our analytical ability is limited. Nevertheless, some interesting results were gathered.

Respondents were about evenly split between male (46,2%) and female (53,8%), with the average age being overwhelmingly between 40 and 49. All respondents are Hachijō residents, with half living in Mitsune (50%). As seen in figure 3, Mitsune is relatively distant from any current form of geothermal exploitation. This might colour perceptions, particularly regarding the issue of NIMBYism. Although all respondents are currently residents, only one fourth was born on the island (26,9%). It is unknown if this the result of inadequate medical facilities on the island or whether these are new residents who have opted to move to Hachijō Island.

We approached the issue of further development of geothermal resources by gauging residents understanding of current usage. When asked what geothermal means to them, the overwhelming majority acknowledges recreational uses (92,3%), with limited acknowledgement for specifically health related uses (19,2%) and for power generation (7,7%). Applications such as cooking, and agriculture are unknown to the respondents. When asked specifically about their awareness of geothermal resource use for power generation a more even distribution indicated awareness (53,8%). We then asked via a multiple-choice question if they know the source of power on Hachijō Island, and again an 53,8% knew that geothermal is part of the island's energy mix. The correlation (Spearman's Rho) between the awareness of geothermal resources for power generation and geothermal power utilisation on Hachijō Island was counter to expectations not statistically significant at rs = -0,071 and p(2-tailed)=0.74 .

Shifting to the developmental side, we first wanted to know how important the adoption of renewables is for the local population. More than half (53,8%) and over one fourth (34,6%) indicated that they consider it to be important or a little important respectively. Considering such a mandate, further implementation of renewable projects, including the increase of geothermal utilisation, might be met favourably. Expanding on this by specifically asking about general public perception of geothermal power again perceptions were positive (50%) and slightly positive (38,5%) respectively. The correlation (Spearman's Rho) between these two factors is again significant at rs = 0,5 with p(2-tailed)=0,0088.

Understanding of the technical aspects of geothermal power was also perceived to be quite high, at 42,3% stating they understand a little bit and 19,2% stating they understand. It would be expected that understanding and positive perception would have a mutual positive correlation. However, with an outcome of rs = 0,027 and p(2-tailed)=0,9 this does not appear to be the case. It would be worthwhile to further subdivide the question of technical understanding to account for this discrepancy in future research.

Worries about geothermal power are still present, with 26,9% being slightly worried. A majority at 50% and 15,4% are not worried so much and not worried respectively. When asked about their impressions regarding potentially expanding geothermal use on Hachijō Island and overwhelming majority was ether positive (46,2%) or slightly positive (50%). Regarding specifically geothermal power results were similar at both 42,3% positive and slightly positive. Overall this could indicate that the community on Hachijō Island has accepted geothermal power within the community, thereby negating a major risk for the project outlined in this report.

Looking at the actual concerns of inhabitants regarding geothermal power the largest groups consist of 'don't know' at 30,8%, 'no concern' at 26,9% and the 'emission of pollutants' also at 26,9%. Considering that the proposed binary geothermal plant does not generate its own pollutants, instead cooperating with existing extraction from Onsen, this entire concern in of limited applicability for the proposed project. Both at 19,2% the issues of 'well degradation' and 'environmental destruction around the facility' are also of limited applicability. Again, since binary in this case is in cooperation with Onsen the actual extraction damage, if any, would already be caused by the Onsen. As for environmental destruction around the facility this would be strictly regulated due to the plants location within the Fuji-Hakone-Izu National Park.

Conclusion

This working paper outlines a plan for the development of a binary geothermal powerplant on Hachijō Island. After conducting a survey on the opinions of local residents we have found that they are generally speaking positive about geothermal developments on the island. Although the survey was limited in scope due to the outbreak of the Novel Coronavirus (COVID-19), nevertheless this represents a worthwhile jumping of point to increase the renewable energy utilisation as percentage of the isolated grids total energy mix by an additional 10% or 16.6 MWe. Figure 6 summarises the positive and negative aspects of the project in a SWOT diagram.

	Helpful to achieve the objective	**Harmful** to achieving the objective
Internal origin	• Plan would increase environmental sustainability • Utilising existing geothermal infrastructure circumvents major risks in geothermal development	• Limited respondents to survey limits accuracy of perceived perceptions of geothermal developments among local residents.
External origin	• Geothermal power already established on the island. • Government support is showing an increasing trend. • The population is generally pro-geothermal power	• Vested interests such as - Onsen - TEPCO & ORIX • Located on an isolated island increases costs • National park increases regulations • Novel Coronavirus pandemic (COVID-19)

Figure 6, Project SWOT Diagram

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Assessing the establishment of additional renewable energy source in Hachijojima Island, Tokyo

James Edward A. Hernandez II

I. Introduction

With the increase of demand in energy sources in Japan, additional energy generation stations are being planned in various rural areas. In provincial regions located away from the main grid, one of the main sources of energy is that of combustion-type run by diesel generators. This source serves as the base load of the overall energy source and is essential for stable power output. However, it is desired that the percentage of the total power consumption would be alleviated as possible. One of the ways for this reduction would be the increase in contribution of renewable energy to the mix. This indicates the consideration for the applicability of renewable energy sources to specific regions, noting also the suitability of each type of renewable energy source to a geographical location. Especially in the construction of an entirely novel or the incrementation of an existing power generation resource, investigation of the viability of the geographical location in renewable energy generation is critical.

In order to accomplish this, a location in which a stable renewable energy resource proven to be ably harnessed is preferable. These locations can be near water sources (for hydro or micro-hydro construction), heat sources (for geothermal applications), or those which will not cause any interference with the normal operations of the region. In terms of the power output, the addition of power output via renewables should be stable, as excess power generated from the grid without proper control could cause severe power interruptions. Also, the location is preferred to lie outside the main grid, for the impact of the establishment of the renewable source will be maximized.

Given these considerations, the island of Hachijojima is chosen for the improvement of geothermal energy. Hachijojima is one of the Tokyo Islands which consists of multiple geothermal plants, as well as solar and wind farms. As a tourist location, the island boasts of multiple onsen facilities whose heat source arises from the natural geothermal reservoir. The total amount of power generated in the island, according to TEPCO, the Tokyo Electrical company, is around 16 MW. In terms of geothermal energy, the island consists of around 3.3 MW. For solar energy, the total power output is 2 MW. All renewable energy sources are backed by the combustion source. The energy demand in the island as of 2014 is shown in Figure 1. It can be observed that during 'peak' hours (from 0900 – 1800) the energy demand reaches around 8 to 8.5 MW. During rainy times (blue line), the demand is higher by around 1 MW during the peak hours. It is noted that the graph excludes the contribution of energy due to solar power generation. This goes to show that the demand for energy is independent of weather conditions. With solar

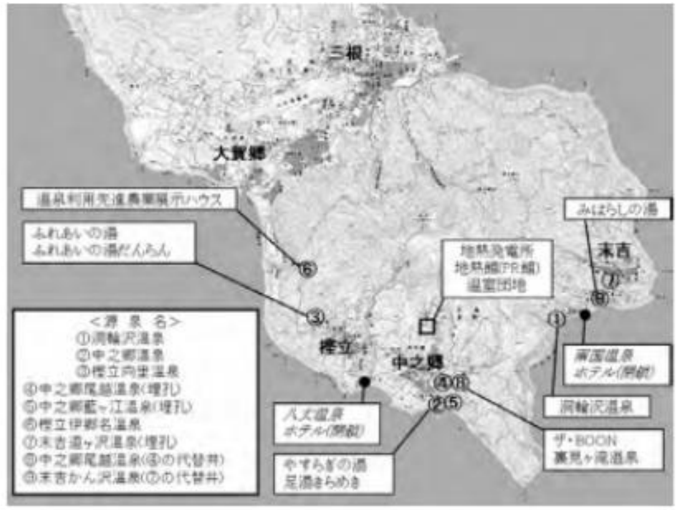

Figure 1. Geothermal facilities in Hachijojima island as of 2009. Adopted from Ref [1]

power generation, the energy supply would be expected to cover some of the energy demand originally covered by combustion type sources, especially during periods of high solar intensity. However, additional solar generation facilities were not recommended due to the low number of available connections within the main grid. Furthermore, the addition of solar facilities in the island could result to electrical instabilities as these energy sources are highly climate dependent and covering up the energy due to the combustion systems would pose risks. Thus, in aiming to increase renewable energy contribution in Hachijojima, the improvement of other forms of renewable sources should be focused. In this report, the feasibility of constructing a geothermal resource in Hachijojima is investigated and assessed.

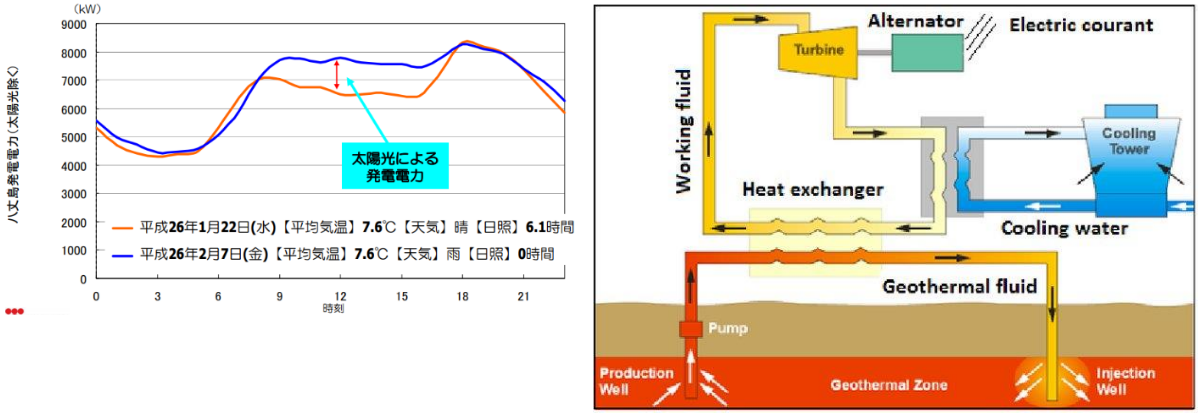

Figure 2. (Left) Energy demand (solar power excluded) in Hachijojima at various hours of the day. Adopted from [cite]
(Right) Schematic of a binary geothermal power plant

II. Geothermal Energy status in Hachijojima

One of the feasible renewable energy sources that could be incremented is geothermal energy due to its stability, as well as its geographical applicability in Hachijojima. The island generates around 2000 MW of geothermal energy as base load, which is coupled by internal combustion engine source as a variable load. [2] Geothermal power plants can be classified in either (a) condensing type or (b) binary type. [3] Condensing types, or flashed types operates in high temperature steam (around $200-300°C$) which directly runs the turbines. In Hachijojima, single flash-operated power plants exist in Nakanogo town and supplies around 3 MW, which are operated by JOGMEC. [4]. On the other hand, binary type power plants operate with the use of secondary fluid, coupled with heat exchangers. When heat from the geothermal source is transferred to the heat transfer fluid, the heat from the fluid is responsible to the operation of the turbines. Residual heat can be utilized for other purposes such as reheating. Like the electrical co-generation, the binary type geothermal power source outputs stable electrical and thermal energy that could be controlled depending on the properties of the required components needed for operation.

Hachijojima has already adopted the use of geothermal energy output apart from electrification. Apart from the established geothermal power plants, a geothermal energy museum also exists in Nakanogo region. Geothermal energy also enforces agricultural output in the island. [5] Greenhouse facilities within Hachijojima benefit from the excess warm water after its utilization in running the turbines. Seeing this as a potential source of income, the facility is currently being promoted to advocate the agricultural benefits of geothermal energy, one of these methods is via the term ‘eco-agri’, or the cultivation and

Table 1. List of Onsen sites in Hachijojima Island

Excavation Period	Onsen Name	Excavation depth	Onsen water Temperature ($°C$)	Water capacity (L/m)	Utilizing Facility	Starting period
1978	Dowazawa	60	40.5	150		Jan 1979
1986	Nakanogo	60	61	90		Apr 1995
1992	Kashitate Mukaizato	450	57.8	386		Mar 2006
1992	Nakanogo Ogoshi	300	64.2	440		
1993	Nakanogo Aigae	300	32.4	423		
1994	Kashidate-Igona	700	57.7	208		Mar 1997
1995	Sueyoshi Dogasawa	1000	49.9	370		Aug 1998
2001	Nakanogo Ogoshi	270	53.1	500		
2007	Sueyoshi Dogasawa	1300	49.8	500		

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purchase of crops under the influence of geothermal byproducts. [6] These benefits might have motivated other private companies in furthering renewable energy development in the island. In a recent announcement, the leasing firm ORIX has established plans to construct a 4.4 MW geothermal power plant, which is expected to finish around 2022. [7] The company aim is to replace the existing TEPCO installation. Overall, the prospects of geothermal development in the island would pose significant progress in its surrounding areas.

III. Construction plan of a geothermal power plant in Hachijojima

a. Preliminary considerations

In assessing the feasibility of constructing additional geothermal energy source, it is essential to consider various political, economic, and geographical background of the intended site. The Natural Parks Law of 1957 states that activities which require construction of buildings near a natural resource are subject to permission from the Ministry of Environment and the local prefectural government. [8] Since Hachijojima consists of a wide variety of scenic spots, more stringent criteria coming from the region would need to be fulfilled. Similarly, the problem of satisfying economic and geographical requirements, especially with the limited availability of buildable land, would pose high level of difficulty towards independent investors. Thus, in this assessment, collaboration with existing institutions is assumed. In order to provide a significant benefit of the proposed development, an energy output ‘threshold’ is imposed wherein the aimed contribution of the energy source is at least 5 percent of the current total.

b. ‘Onsen energy’ as maximization of geothermal byproduct

In further emphasizing the positive effects of geothermal construction on the island, the development of geothermal power plants is seen in accordance with that of onsen. In a paper by Matsuyama et al. the geographic situation of Hachijojima in terms of regions with onsen wells is discussed. [1] As of the date, there are nine onsen sites in the island, mainly in the Nakanogo region. The onsen wells consist of various temperatures which imply the diverse conditions of geothermal source. The temperature from onsens cannot operate electrical turbines due to their relatively low temperature. Thus, wells with appropriately high temperature ($\sim 100^\circ C$) would contribute to the power generation of nearby facilities. This is also called ‘onsen energy’ and is widely utilized all over Japan. [8] With increased utilization of deep wells containing high temperature source for electrification, the contributed energy towards onsen facilities, as well as nearby households can be directly benefitted, while decreasing the amount of energy consumed due to internal combustion system.

In Hachijojima, the Tokyo prefectural government establishes the program of ‘Hachijojima Clean Air Island Concept’. [9] In this Concept, the integration of renewable energy towards the main activities of the island are stressed. For example, solar, wind, geothermal, and other clean energy sources are encouraged to be utilized for events within the island. Moreover, smart systems such as EV are utilized as main transportation media. The project aims to generate energy entirely via renewable resources. In terms of activities, pollution-free activities are encouraged to realize the objectives of this mission.

c. Feasibility calculation

In estimating the amount of energy that can be harnessed from the active wells, energy calculation is performed. The active wells from Table 1 are Kashitate Mukaizato Onsen, Nakanogo Ogoshi Onsen), Nakanogo Aigae Onsen, Kashidate-Igona Onsen, and Sueyoshi Dogasawa Onsen. The basis for the calculation is found in Ref. [10] The formulae used in the reference involved the analysis from the compilation of geothermal power plant parameters globally. The calculations are based on the binary type power plant. However, since the currently available data, to the best of the author's knowledge, is of the single flash type, then the parameters for the single flash is employed. The amount of power generated is calculated by

$$W = \frac{2.47m(T_{in} - T_o)}{T_{in} + T_o}(T_{in} - T_{out}),$$

Wherein m is the amount of flux of brine (used in this calculation), T_{in} is the input temperature, T_o is the room temperature, and T_{out} is the output temperature. In the calculation, T_{out} is the temperature of the onsen, and T_{in} represents the temperature of the well.
Using Hachijojima geothermal power plant with parameters m = 44, To = 20 deg C, h = 2582. Power generated (in kW) is approximately 1600 kW which is around 10% of the intended energy increase via geothermal power plant, which is 16.6 MW. Although the efficiencies of the turbines, the working fluid, and other distribution systems were not considered, this calculation serves to be a rough estimate as to whether the output of the active onsens would be sufficient to the intended value.

d. Proposed Timeline of construction

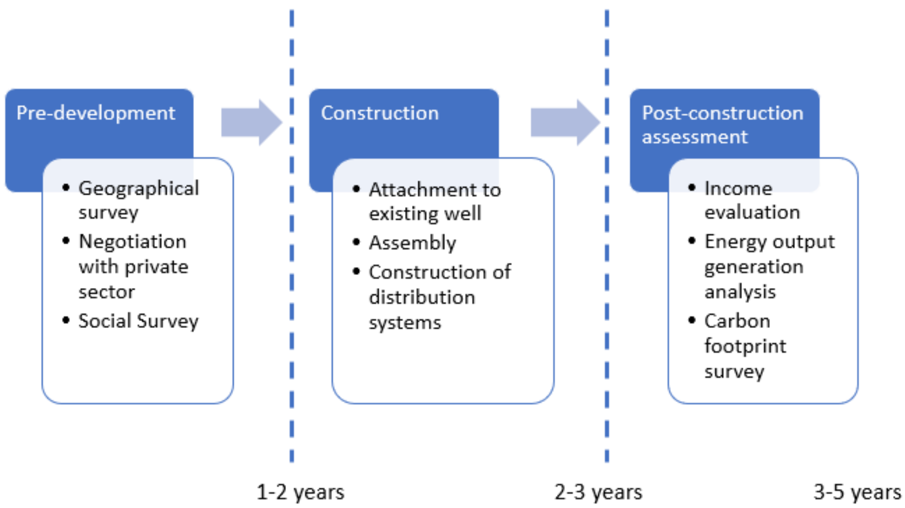

Figure 2. Proposed timeline for construction of binary geothermal plant for existing wells.

Figure 2 shows the proposed timeline for the construction of the geothermal power plant. The timeline is divided into three sections: pre-development, construction, and post-construction assessment. For the pre-development stages, mainly preliminary surveys are conducted which involve geographic assessment, social acceptance surveys, energy distribution analyses, and potential income analyses. Geographic analyses mainly involve blueprinting of well connection design and distribution systems. Private negotiations involve those under the onsen operators, leasing companies, and other companies which could be affected by the construction. It is assumed that these negotiations would include plan creation for the local government. This involve policy creation, and public relations-related announcement preparation. Social surveys involve the investigation of the perception of the locals towards the construction of the geothermal power plant. The general aim of these surveys is to identify whether conflicts would emerge in the construction that could serve as potential intervention in the normal operations involving the local population.

With regards to the construction stage, the main components of the power plant serve to fulfill the aims of (a) power generation (b) power distribution (c) co-generation. For power generation, the construction would mainly involve well drilling and the establishment of additional power generation systems connected to the existing wells, considering the schematic of a binary power plant design. Power distribution involves the construction of transmission lines from the grid to individual households and facilities near the wells. Co-generation involves establishment of electrical connections from the wells to the onsens, generators, and other connectors such as agricultural greenhouses. Co-generation is not limited to the examples; it is described as the establishment of additional connections other than those related to the onsen business. Operations and management are included after construction has been completed.

For post-construction assessment, evaluation after around 5 years of operation will be conducted. The focus in this stage is the economic situation of the established power plant after initial operations have been performed. Economic situation involves (a) cashflow analysis, (b) additional revenue gained, and (c) carbon footprint analysis. For cashflow analysis, the economy of the power plant itself coming from all the direct consumers is assessed. This also includes any cashflow to and from companies involved in collaborating with the power plant construction. Moreover, businesses which are influenced by the additional energy supply will be noted.

Carbon footprint analysis also operates in a similar manner, as carbon output is determined. By the integration of renewable energy toward local activities, the results of these assessments would have a significant impact towards the Hachijojima agenda of clean energy usage. Cash flow analysis is focused in this report.

e. Cash flow analysis

Cash flow analysis mainly involves estimation of construction as well as operation and management costs. In the context of constructing a geothermal power plant in Hachijojima, the main concern involves the economic interplay between public and private stakeholders. Starting with the public sector, the Japanese government offers subsidies for the renewable projects. For example, the government has the 2012-2032 subsidy scheme, as well as the reduced taxation for renewable energy source construction. Included in the cash flow are miscellaneous fees involving licensing, initial evaluation, environmental assessment. On the other hand, cashflow towards private stakeholders like ORIX includes connection costs. Since the company is mainly involved in the direct excavation of wells, the additional construction merely involves the annexing from the main wells. Nevertheless, potential commission costs are considered. Development, operation, and management costs are the usual, dimension-specific and perpetual (typically yearly) costs involved in constructing and maintaining the facility.

In terms of financing bodies, banks and power distributors (in the case of energy surplus distribution) contribute to the initial financing and input cashflow.

Obtaining permission and subsidies from the local government is possible through the feed-in tariff (FITs) system. Depending on the type of energy source and power output, procurement can be applied for every kWh of output. [14] For geothermal power in this case, amount of 43.2 yen (Tax inclusive) per kWh is applied for electricity output less than 15 MW. The Japanese Ministry of Environment (MoE) provides guidelines in establishing large scale power plants near Natural Parks. Also known as 'Natural Parks Law' of 2004, excavation near the sites would be under stringent conditions, but will still be possible. [11]

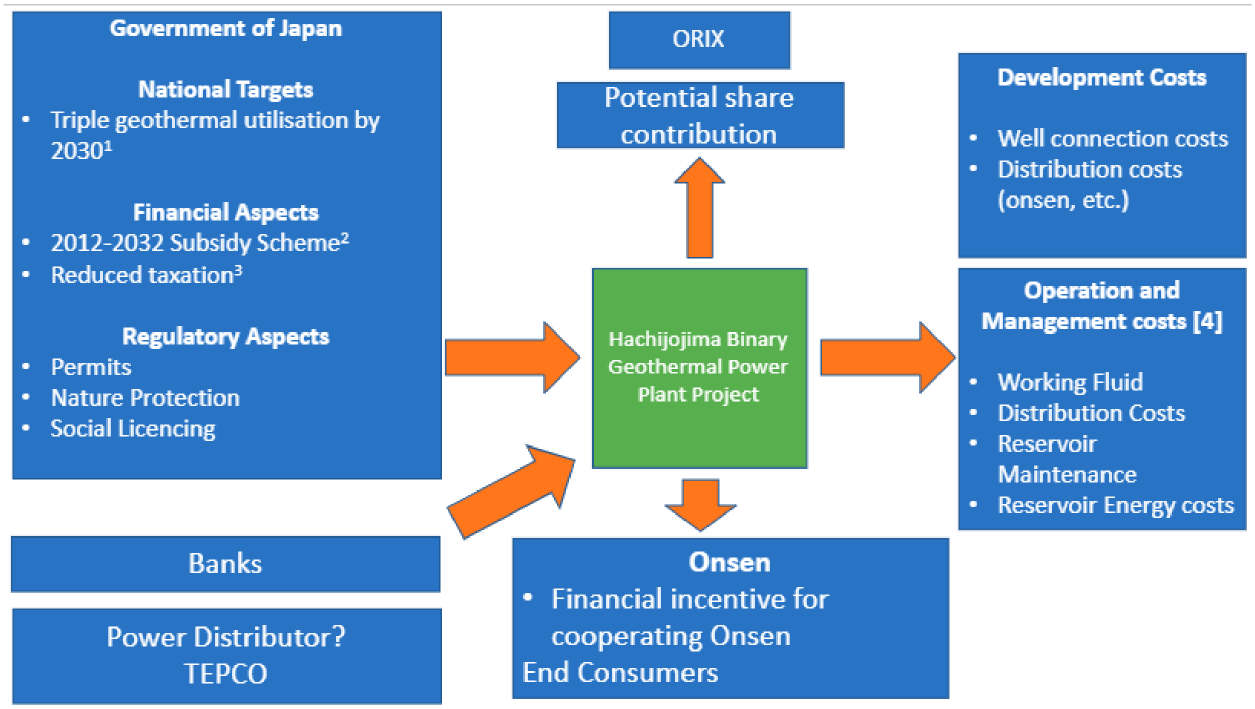

Figure 2. Cashflow direction in Hachijojima geothermal power plant construction

IV. Assessing the situation of locals within Hachijojima regarding geothermal energy

A segment of pre-development of renewable energy sources is the evaluation of local perceptions towards the additional establishment of clean energy within the region. In order to assess this, A computerized survey is sent via a company to the Hachijojima station, which is to be filled out by the locals. The questions is of multiple choice type, some of which containing free input. The questions tackle the awareness of the locals towards the installation of a geothermal power plant near the existing wells. The survey involves 26 respondents, most of which were residents of Hachijojima. One respondent had an association with the island, but the address was transferred. Fourteen out of the total respondents were female, which shows even gender distribution. The youngest respondents were from 25 – 29 years old range, where almost half of the respondent population were aged 40 – 49 years old (54 %). All respondents have Tokyo city prefecture, and Tohoku region as their origin. Ten respondents were not married. In terms of whether the respondents have children, sixteen respondents answered having children. The household income distribution of the respondents is shown in Figure 3a, while the individual income is shown in Figure 3b.

Figure 4 shows the distribution of the respondent occupation. Most (27%) of the respondents were either full time housewife or house husbands. This could explain the idea of the difference between the household income and the individual income. Around 20 percent of the respondents belong to those which work part-time or civil servant. Moreover, the total amount of freelance and self-employed respondents is approximately equal to that of those who work in company (others). Even then, the total amount of company employees is lesser than that of the civil servant. From the responses regarding region of residence, half of the respondents reside in Mine region. Only 3.8 % of the respondents came from Nakanogo, where the Hachijojima power plant is situated. Despite this, the number of respondents born in Hachijojima were just approximately 28 percent of the number of respondents. This could mean that most of the surveyed population could have acquired a residential property within the island.

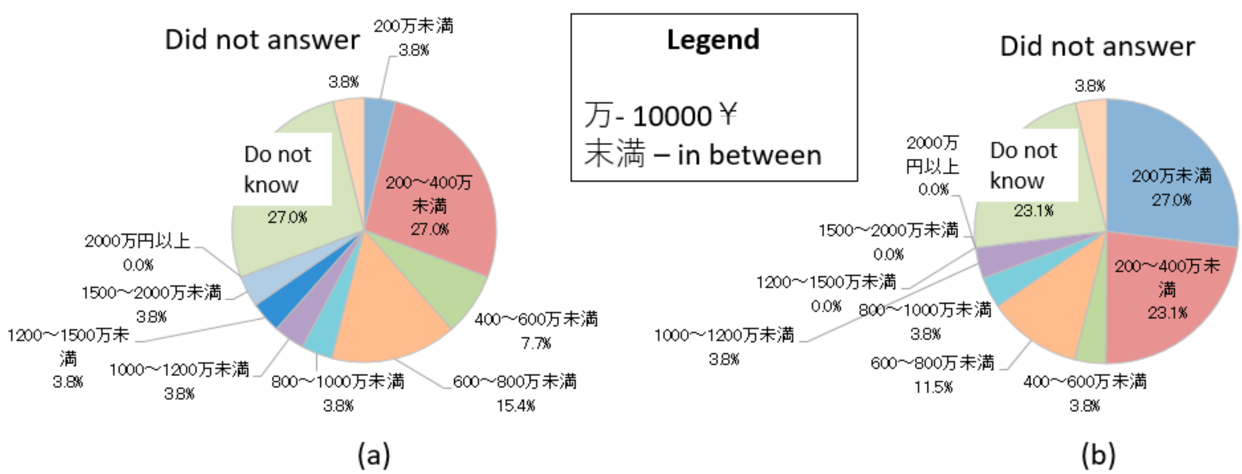

Figure 3. (a) Household annual income distribution, and (b) Individual income distribution (in Japanese Yen)

The income distribution of the respondents leans towards the 2 million to 4 million yen. However, an equivalent number of respondents do not know their income. For the individual income, almost half of the respondents fall under the below 2 million to 4 million income range, which is approximately the average Japanese monthly income. [12] This could be interpreted that some respondents rely on the other member of the family for financial support.

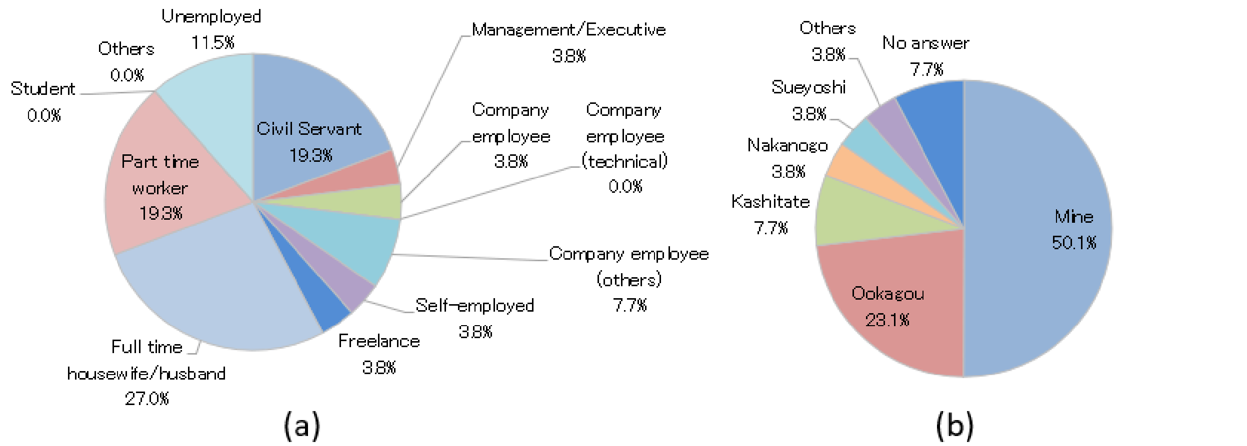

Figure 4. (a) Occupation distribution, and (b) region of residence in Hachijojima of survey respondents

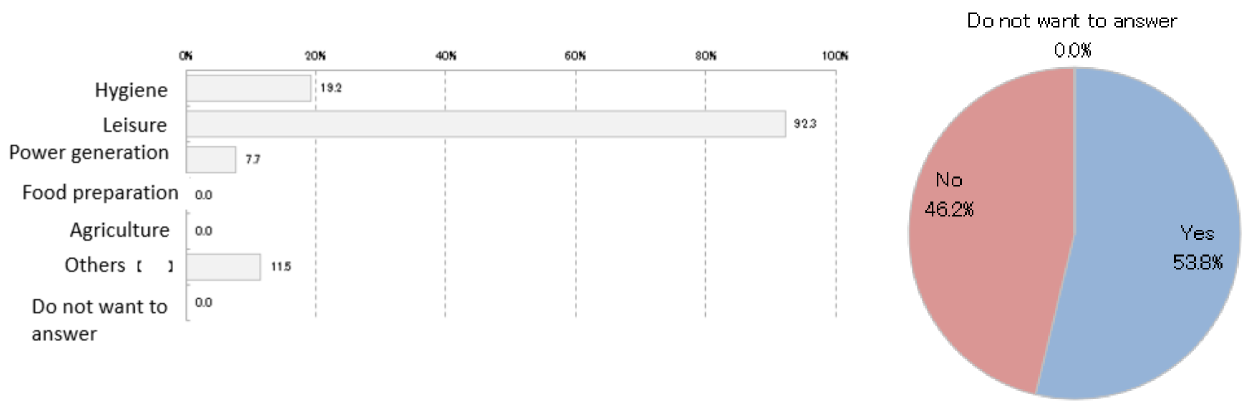

Figure 5 (Left) Distribution of the perceived function of onsen as power generation resource (Right) Perceptio on whether onsen can be utilized as a power generation resource

In terms of the perceived use of onsen, most of the participants perceive the onsen as for hygiene and leisure. However, 7 percent of the population perceive the onsen as source of power generation. Looking at the educational attainment of the respondents, around half of the population has at least attained at leaast a university level degree. The responses, however, for whether the onsen is considered to be a power generation resource is almost half of all respondents. This result could show that although the onsen is generally perceived to be serving its primary function as a business, the awareness for its additional use as a geothermal power source is present.

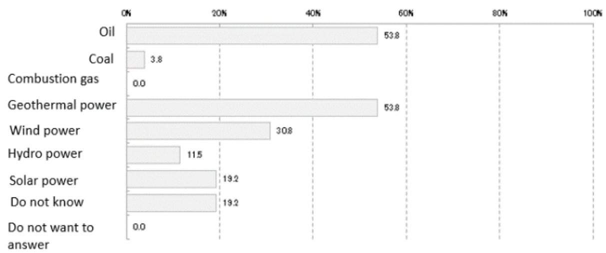

Figure 6 Perceived sources of energy in Hachijojima

The previous argument is supported by the respondents' perceived types of energy sources in Hachijojima, shown in Figure 6. Responses which fall under the geothermal power are almost half, whose percentage equates to that of the oil fuel source. Mainly, both these sources act as the main generators of energy, as discussed. Around a third of respondents also recognize that wind power is also utilized as a source of energy. On the other hand, around 19 percent of the respondents recognize solar power as one of the island's energy source. The results confirm the prominence of geothermal power as the main energy source geothermal energy mechanism, as well as its perceived utility towards the island and the perception of its positive impact as an energy source. The awareness can be deepened further by investigating awareness of the respondents of the current investment of ORIX towards the development of an additional renewable energy resource, for which the majority were not aware. However, since the Hachijojima power plant is situated in the Nakanogo region, and the leasing company aims to renovate this power station, and reviewing the places of origin of the respondents, it could be interpreted that awareness on the project is significant, despite the majority not expressing awareness.

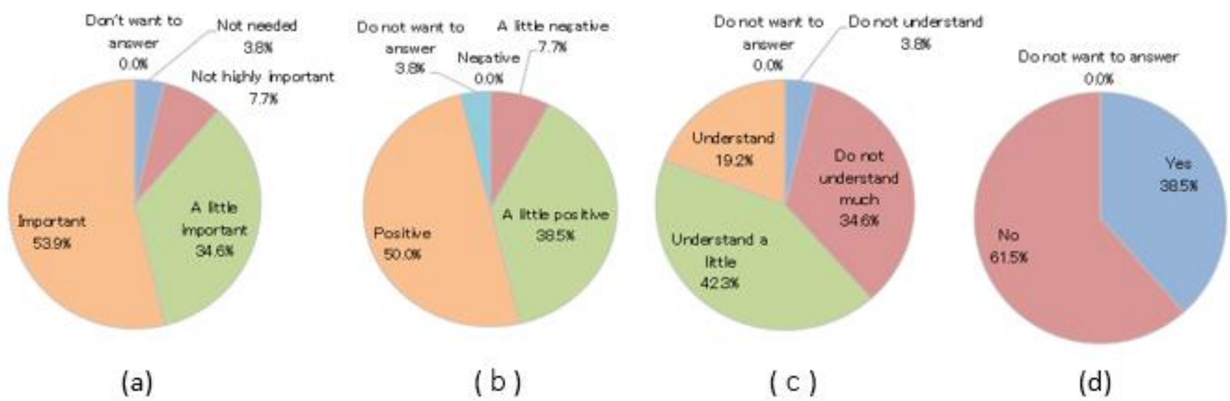

Figure 7 (a) Perceived importance of renewable energy in Hachijojima (b) perception on the current geothermal power plant (c) Perceived understanding on the mechanism of geothermal energy sources (d) Awareness on the current endeavor of ORIX in establishing a geothermal energy resource

Investigating the perception of the respondents on renewable energy in Hachijojima, importance is highly placed on the establishment of these sources. Looking at their perception on the Hachijojima geothermal power plant, the impression was shown to be mostly positive, meaning that there seems to be a consensus between the establishment of the power plant and the lifestyle of the residents of the island. On another note, in investigating the understanding of the respondents towards geothermal energy, the result showed that majority of the respondents (96% in total) have at least an understanding on how the energy source operates. It could be hypothesized that there could be a relation between the understanding of

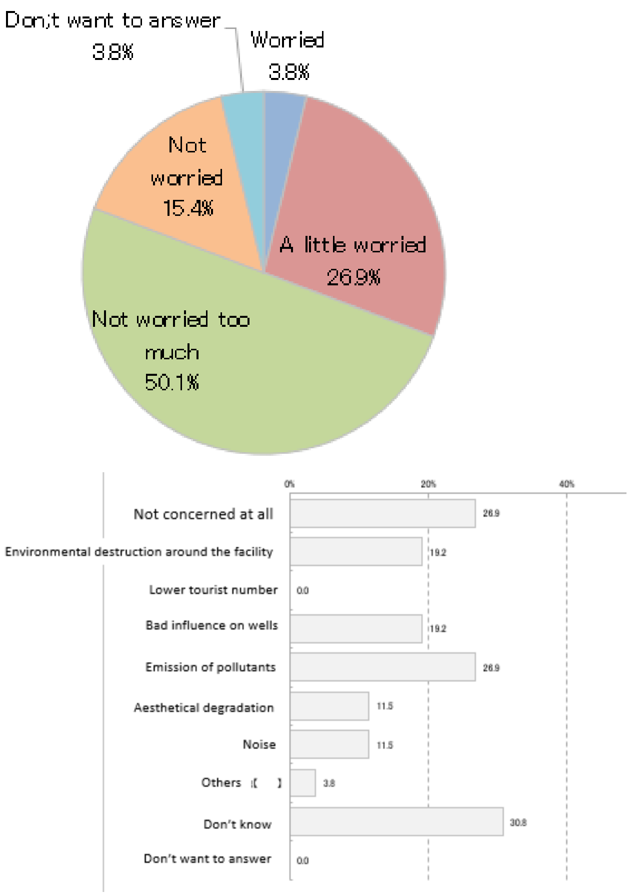

Figure 7 (Upper figure) Perception on the potential hazards of geothermal power generation in Hachijojima (Lower figure) Details on potential worries on Hachijojima power generation

On another note, reservations of the respondents were also investigated to identify concerns towards construction of geothermal power plant in Hachijojima. Shown on Figure 7 on the left, the majority felt little worry about the establishment of geothermal energy source in the region, whose results agree with the previous result where there were mostly positive responses towards the construction of geothermal power sources. However, looking at the details in which the respondents worry about regarding the establishment of this source, the majority (30%) of the respondents responded they do not know particular factors that could induce negative effect to themselves or to the region. Around 29 percent have cited pollution as the second highest concern of the construction. Concern towards the wells is also shown, since excavation is expected in establishing additional connections of water sources. Tourism status is not an immediate concern. Majority of the identified concerns lie on the environmental degradation. Thus, while there is a general consensus within the population on the establishment or operation of geothermal power facilities, there are environmental concerns which prevail despite the overall positive perception of geothermal energy as a renewable resource.

Observing the perception on the installation of additional geothermal power plant in Hachijojima, the consensus showed mostly positive responses towards its development. Shown in Figure 8 is the distribution of responses regarding the perception on the possibility of construction of the additional geothermal resource, where 84 percent of respondents showed at least a positive outlook. This is an important result, since this could reflect the tentative image towards the expansion of the current energy source.

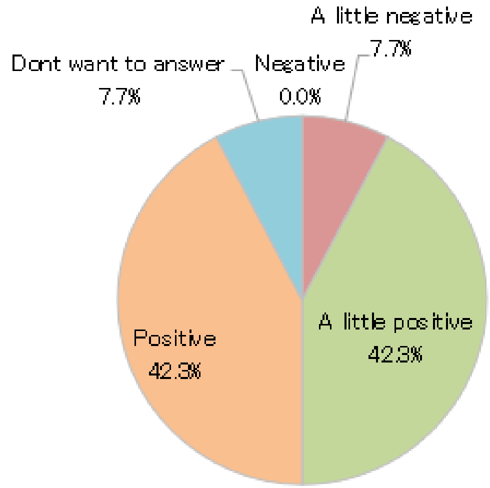

Figure 8 Perceptions on the possibility of construction of additional geothermal energy source in Hachijojima

V. Summary

In this report, the feasibility of constructing an additional geothermal power plant in Hachijojima island is discussed. Geography and current initiatives towards the use of geothermal energy, as well as other renewable energy sources are investigated. The proposed project involved construction of additional connection to the already excavated main well, which aims to generate around 1.6 MW electrical power. The feasibility of the project is determined by estimating energy output of five selected active onsens within the region and investigating the cashflow of the project. A survey was also conducted to the residents of the island to provide input regarding their perceptions on the further installation of a geothermal power plant. The results showed positive responses for the construction of an additional geothermal energy source. However, some reservations are observed among the surveyed respondetnts, which mainly included environmental-related degradation concerns.

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Working Paper on Development in Areas of Economic Water Scarcity: Increasing Water Supply Access in the Rural Himalayan Town of Rongli, Sikkim

Eco Hamersma

Introduction

As part of the course GRM Joint Seminar II we were tasked with finding a solution to an issue of economic water scarcity. After an extensive region and site selection process we opted to focus our attention on a region suffering from economic water scarcity in North-Eastern India. India is one of Asia's rising economic and geopolitical powers. Nevertheless, as a developing nation there are still serious issues of poverty and inequality which have contributed to unequal access to water resources. Using an Eigenvector analysis our target area became Sikkim in the Eastern Himalaya, eventually settling on the rural municipality of Rongli.

As part of this project, we set up a hypothetical organization under the name of Doshisha Utilities Co., Ltd. which would be working with the local authorities to establish a public private partnership (PPP) for the development of a rainwater harvesting system. Such a legal PPP legal construction was necessary due to the specific legal circumstances which give Sikkim a special status within India.

After weighing the different option, we decided on utilizing a type of rainwater harvesting known as a Jalkund. This is a type of dugout pit structure which is able to collect and store runoff rainwater which has typically been employed in an agricultural setting; One of the largest water conception sectors in Sikkim. This technique has a proven track record as a viable low maintenance water conservation technology which fits well within the frame of local development. In this project plan we are combining rainwater harvesting with a UV filtration system to provide an increase in drinking water supply availability as well.

I. Region and Site Selection Process

The process to select the target region for this project was done in two stages. Firstly, the primary concern for this project was dealing with issues of economic water scarcity. When we typically think of water scarcity, we imagine physical water scarcity. This is when the natural water supply is not enough to satisfy the demand. Such scarcity is generally associated with arid regions, although environmental degradation can also play a part in this type of scarcity. Meanwhile, economic water scarcity occurs when, although ample natural water resources are available at a given locale, economic factors such as a lack of investment or human capacity significantly hamper one or more links in the water supply chain. As a result, people in such a region are unable to access water resources due to economic reasons (FAO 2009).

One of the major areas suffering from this type of water scarcity is Northeast India, also referred to as the North Eastern Region (NER), a large area of 262.179 km^2 with a population of 45 million people (Ibid.; North Eastern Council Secretariat 2015, p.3). The NER receives a large portion of its water supply from glacial runoff coming down from the Himalayan mountains. As well as ample rainfall during the June to August monsoon season (Pradhan et al. 2019, p.1). Nevertheless, the area is economically disadvantaged. Some of the primary factors which have been noted as contributing to poverty are the inaccessibility of certain areas. With a generally higher poverty rate seen in those areas in or near forests or in areas with snow cover. Other geographic factors make agriculture, the NER's primary industry, a difficult sector to work on. Issues such as steep or rocky slopes limit useable agricultural land. Such terrain is also a limiting factor on infrastructure as road construction is difficult and landslides cause frequently damage (Bhandari & Chakraborty 2015).

Setting our sights on the NER, we still had to narrow down the specific state. The NER consists of eight states Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura. Each of these states poses their own challenges in development. As such it was important to select the right area for the purposes of our project. To achieve this, we utilized an Analytic Hierarchy Process (AHP) wherein factors ten factors for each possible regions of interests were assigned a quantitative value which is evaluated by calculating the eigenvector. The ten factors were:

1. Ease of access
2. Language
3. Availability of surrounding water
4. Affordability
5. Ease of legislation procedure
6. Impact population
7. Current development (Communication, Health, Environment, Technology)
8. Political stability (Security)
9. Willingness
10. Natural resources

Due to a lack statewide data for many of the NER states, we opted to use the data from each state's capital city and assume that rest of the state's situation would be comparable or worse. The results of this analysis indicated that Guwahati, Assam, was the most suitable location for our project. However, one of our red lines for site selection was the availability of the English language. As Assam is the only NER state where English is nether the official or secondary language, we had to exclude it from the results. Therefor the second place Gangtok, Sikkim, became our primary target location (See figure 1). Because the project focus was to be on rural households we then searched for the optimal municipality, eventually selecting Rongli, the municipality directly south-east of Gangtok due to perceived infrastructure advantages close to the capital.

#	City	State
1	Agartala	Tripura
2	Aizawl	Mizoram
3	Gangtok	Sikkim
4	Guwahati	Assam
5	Imphal	Manipur
6	Itanagar	Arunachal Pradesh
7	Kohima	Nagaland
8	Shillong	Meghalaya

Places	Criteria												Eigenvectors	Eigenvector (normalized)
	1	2	3	4	5	6	7	8	9	10	11	12		
1	0.148905	0.10895486	0.119664	0.123468	0.157835	0.142832	0.133079	0.055328	0.116384	0.12584	0.313578	0.142832	0.12473052	0.484149103
2	0.119131	0.03558928	0.122496	0.131034	0.099078	0.207884	0.124724	0.012091	0.132294	0.046922	0.037356	0.207884	0.11069815	0.429681605
3	0.040719	0.0527245	0.316974	0.133078	0.148617	0.148176	0.13911	0.004928	0.180435	0.216612	0.156274	0.148176	0.12864663	0.499349722
4	0.45322	0.57997007	0.07271	0.11412	0.049539	0.148176	0.107249	0.788804	0.06725	0.020247	0.062261	0.148176	0.25762832	1
5	0.108911	0.06063297	0.061976	0.129361	0.099078	0.052205	0.152885	0.087068	0.120535	0.079382	0.09806	0.052205	0.09916152	0.384901474
6	0.024154	0.04481603	0.123709	0.120811	0.148617	0.100347	0.115352	0.008214	0.160223	0.256463	0.047941	0.100347	0.09121759	0.354066626
7	0.046806	0.05008854	0.103576	0.126201	0.148617	0.148176	0.125488	0.027928	0.047222	0.091915	0.225072	0.148176	0.1005298	0.390212536
8	0.058153	0.06722375	0.078895	0.121926	0.148617	0.052205	0.102112	0.01564	0.175657	0.162619	0.059459	0.052205	0.08738748	0.339199821

Table 1, Eigenvector results. The numbers 1 through 8 correspond to the numbers in the top table indicating the target regions and capital cities.
(Source: GRM Joint Seminar II interim working paper, Hamersma & Hernandez II 2021)

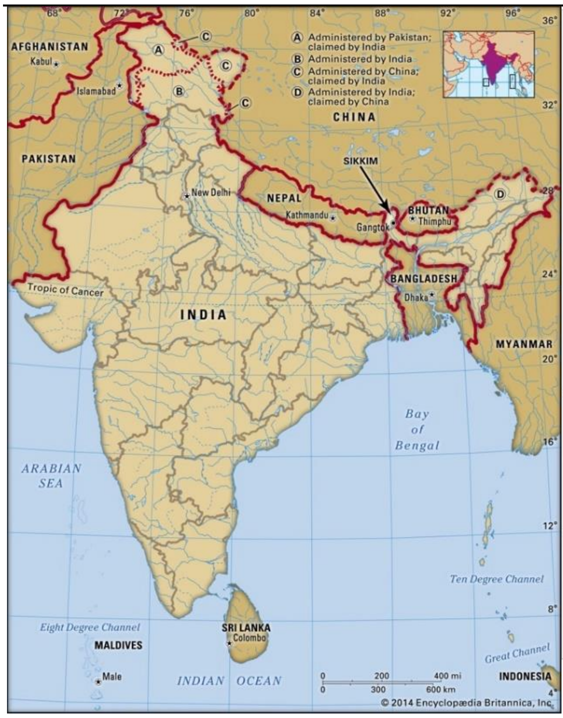
II. Historical and Geographic Background on Sikkim

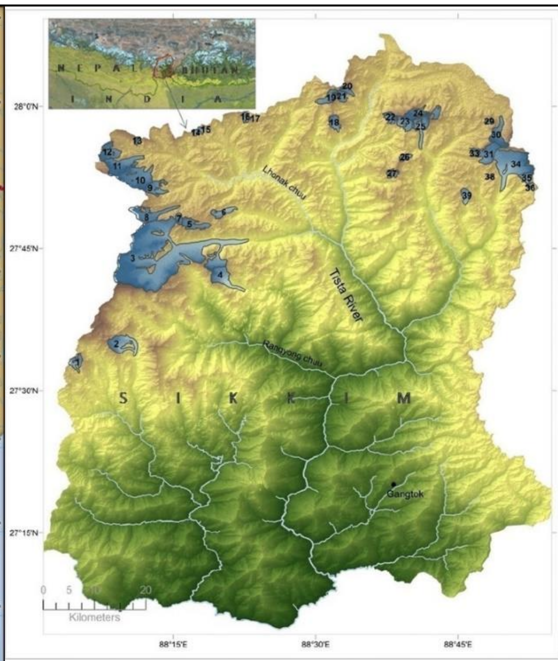
The small Indian state of Sikkim is located in the Eastern Himalayan, nestled between two independent states: The Kingdom of Bhutan to the east and Federal Democratic Republic of Nepal to the west. To the south is the Indian state of West Bengal and to the north is the Tibet Autonomous Region of the People's Republic of China (PRC). This makes Sikkim one of the three Indian border areas with the PRC, one of India's major geopolitical rivals.

There has been a nominally independent Sikkimese polity since the 17th century, though at various times under the suzerainty of Nepal, Tibet, the East India Company, the British Empire and eventually India. Within British India, Sikkim had been considered a dependent territory and so upon Indian independence in 1947 the Indian government felt that it was the inheritor of this protector status over the fledgling Himalayan state. One argumentation for the continuation of Indian interests in Sikkim was its geographic location, one which was highly strategic, acting as a potential buffer against China and it's at the time increasing interests in Tibet.

Although de jure independent, increasingly Indian pressure was put on the Sikkimese government to conform to Indian demands. This Kingdom of Sikkim had been ruled by a dynasty of Chogyal's, the Sikkimese title for absolute monarch, of the Namgyal dynasty. In the late 1960's to early 1970's, the final Chogyal, Palden Thondup Namgyal, attempted to steer his country towards greater international recognition and independence from India. As a result, on the 10th of April 1975 the Indian army invaded and called for a referendum on annexation to India to be held on the 14th of April. The results were 97,55% of the votes being in favor of abolishing the monarchy and integrating with India. The ruling Chogyal, famous Indian intellectuals such as Morarji Desai, as well as Sikkim's neighbors decried the referendum as a forgery. Considering Sikkim's geography and the difficulty in accessing large swaths of the population, this assessment is not without merit.

The geography of Sikkim is very mountainous, containing 28 mountain peaks, including India's highest. The total area of the state is 7906 km^2, making it a bit smaller than a combined Kyoto and Shiga prefectures. This small area is nevertheless densely packed with more than 80 glacial formations, resulting is ample available water in for form of rivers from glacial melt. One of these is the Rangpo which runs through Rongli. Regardless of these ample resources, issues of poverty and discrimination based on ethnicity have led societal inequalities and as a result to unequal access to these resources.





Figures 1 & 2, On the left is a map of the administrative divisions of India, highlighting Sikkim in the North East via an arrow. On the right is a topographical map of Sikkim.
(Source: Lodrick & Chib 2020; Basnett et al. 2013)

III. Land and Legal Issues

Sikkimese law does not make it possible for foreigners to purchase land. Representing a foreign development organization for the purposes of this report we have to navigate these legal complexities. Understanding the issues relating to land access have a long and turbulent history. At its core the issues stem from Article 371F, also known as the 36th Amendment, of the Constitution of India. This article outlines the special provisions provided to the State of Sikkim within the Union of India in spite of the provision applicable for the Republic of India. One of the important paragraphs of Article 371F is paragraph (k) which maintains in force all laws promulgated by the Royal Sikkim Government prior to the Indian annexation (Constitution of India 2020, pp.167-169). As such, for the actual origins of the legal restrictions foreign persons or organizations face we should look back to a 1663 peace treaty.

With the rise of nationalism and the introduction of the concept of citizenships the importance of defined nationalities grew. The Sikkimese king perceived the ongoing Nepali immigration, a trend with at least a century of precedent, a threat to the nation’s stability. This process was also stimulated by the increasing Indian threat after that nation’s declaration of a protectorate over Sikkim in 1950. As such, much like the development of national identities in other emerging states, the ethnic characteristics of the nation played a key role in the development of national citizenship. In the first draft of the subject regulation, two ethnic groups, the Bhutia and Lepcha, were outlined as being natural citizens of the Kingdom of Sikkim. Joined in the actual promulgation of the Sikkim Subject Regulation of 1961 (SSR1961) by the Tsong (Sikkimese Limbu). Together, these three ethnic groups were historically significant in the foundational process of the Sikkimese kingdom via a 1663 tripartite treaty at the conclusion of the Mön Pa War (Vandenhelsken 2020 pp.6-9; Vandenhelsken & Khamdhak 2020, p.5; Chakraborty & Sarkar 2013).

Those residents of the Bhutia, Lepcha and Tsong ethnicity who have their permanent abode within the territory of Sikkim were considered to be citizens with the implementation of SSR1961. Additionally, those people who have made Sikkim their permanent place of residence to the exclusion of all other territories can be considered citizens. Such persons must break all connection with their country of origin. This regulation was revised a year later in 1962 when significant public outcry led to the removal of the ethnic criteria. Notification No.S/227/61 substituted the ethnic criteria with a ancestry criteria where a person can be registered as a citizen if they can prove their ancestors were Sikkimese subjects going back to at least 1850. This date happens to precede the settlement of significant numbers of Nepalis. Therefore, although the wording changed the actual results had little effects on the situation of foreigners who wished to acquire Sikkimese nationality (Vandenhelsken 2020, p.8)

Those residents not of Bhutia, Lepcha and Tsong origins who have immovable property prior to 1961 were often already discriminated against and barred from acquire such property. As such the actual effect of this legislation did not change the result that citizenship was in majority limited to those of the aforementioned accepted ethnicities. When Sikkim was annexed as a state of India, Article 371F of the constitution was implemented and as such the Sikkim Subject Regulation of 1961 with the 1962 revision was maintained even when contradicting the contradicting the other provisions in the constitution. Particularly article 19, paragraph 1, subsection (e) guaranteeing the right to reside in any part of the territory of India (Constitution of India 2020, p.27). As such even citizens or residents of India from other states are not allowed to take up permanent residency in Sikkim without fulfilling the criteria of the SSR1961.

IV. Rongli

Rongli is a subdivision of the East Sikkim district (see figures 3 & 4). This area consists of 22 towns, villages or hamlets (Gazeis 2017). The largest town is also called Rongli and is located in the southern part of the subdistrict. It is specifically this town, not the entire subdistrict, which we will be targeting for this project. The town of Rongli has an estimated population of 30.000 people in the 2011 census. East Sikkim, and by extension Rongli, is has a cool and humid climate with temperatures ranging between a minimum of 1.5 to a maximum of 27.5ºC. Annual rainfall is approximately 3800mm, however, this is not evenly distributed as there is a monsoon season from May to September and a dry season in the winter (NICRA 2013).

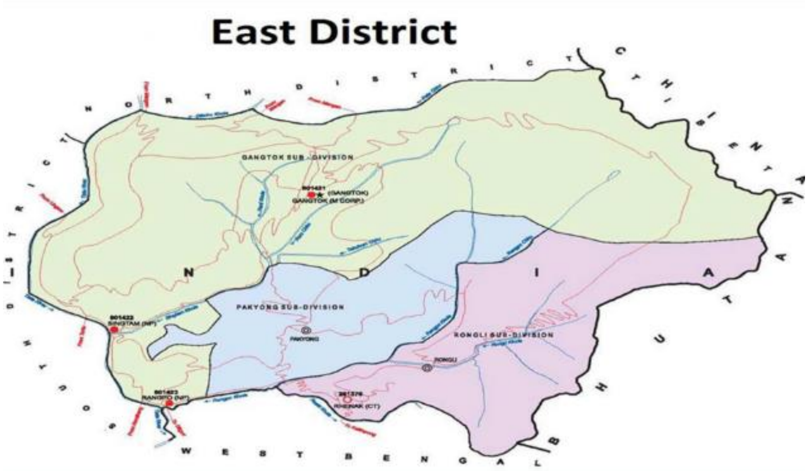


Figure 3 & 4, The left map outlines the districts of Sikkim, with East Sikkim shown in green. The right map shows the subdivision of East Sikkim, with the Rongli municipality shown in purple. The town of Rongli is highlighted with a red arrow. (Source: Maps of India 2019 & Gazais 2017)

This project is a design to increase the Rongli water supply by 10%. Household water demand is roughly 150 liters per capita per day according to WHO standards. Therefore, the total demand is around 510,000 liters per day for this fraction of the population.

V. Project Selection Process

The water supply infrastructure is Sikkim is outdated, with large parts such as the only sand filtration plant in the capital Gangtok predating Sikkim's annexation into India. Similarly, the pipe network is severely outdated, suffering from leakages and illegal piping connections. Lack of available means and sufficient care by the Indian government has led to a gradual decline in the quality of the water supply. This combined with strong population growth and growing popularity of Sikkim among tourists (pre-COVID-19 pandemic) has increased water demand not in line with available capacity. As such three different projects were proposed in the initial phase of this study. These included (a) development of a water purification system through rapid or slow sand filtration, (b) increasing the pipeline network of the current river harvesting method through polypiping, and (c) development of a rainwater harvesting system.

After careful consideration we decided on a rainwater harvesting system would be the best fit considering Rongli's geography and developmental level. For this project we are looking for a solution which has low operating overhead, due to the economic state of the region, small in relative size due to the lack of available build space. While it's possible to build a small rapid sand filtration plant, the operating overhead would affect the project detrimentally. Conversely, a slow sand filtration plant would take up too much space in the difficult Himalayan terrain. Considering the pH value of the available water supply, presence of unwanted micro-organisms the necessity of treatment is obvious. However, the other factors give a negative indication of project viability. As such, rainwater harvesting is perhaps a better solution. The type of rainwater collection method we opted for in the design of this project is a Jalkund.

VI. Jalkund

A Jalkund is a rainwater harvesting method utilizing a dugout pit used to collect runoff (see figure 6). Jalkunds come in various shapes and sizes, with varying water storage capacities. However, certain factors are standardized. Jalkunds are usually found near hills in order to utilize the gravitational water flows. By design a barrier is placed between the Jalkund and the soil pit to prevent collected water from seeping into the ground. This barrier is usually a simple LDPE agri-film lining. As such precautions are taken to minimize the damage to this otherwise delicate material. These precautions include plastering the sides of the Jalkund and using cushioning material. In hilly terrain this method rainwater collection carries many benefits. Not only does it protect against erosion and provide agricultural irrigation water, it also offers other water use possibilities such as wish rearing or drinking water after treatment (Singh et al. n.d.).

According to the Central Coastal Agriculture Research Institute in Goa, the general the Jalkund construction steps involve (ICAR CCARI 2019):

1. Dig a bit to the desired specifications
2. Remove debris and sharp material
3. Smooth the walls of the Jalkund (clay, plaster or concreate)
4. The usage of insecticides between the walls and agri-film is recommended
5. Dig drainage trenches to guide water flows
6. Line the Jalkund with LDPE agri-film lining
7. Weigh down the sheet to maintain stability

Figure 5, the various stages of Jalkund construction (Source: ICAR CCARI 2019)

VII. Rongli Rainwater Harvesting Project Design

Sikkim gains a significant amount of its revenue from tourism (Jamal 2020). One of the reasons these tourists come to Sikkim for its clean air and water (Ministry of Tourism & Culture 2002, p.64). Yet the population of Sikkim is still dealing with issues of economic water scarcity and polluted water resources. This project hopes to deal with this issue through the application of the aforementioned Jalkund system.

The use of Jalkunds rainwater harvesting is not new to Sikkim. In the region of South Sikkim, the Dhara Vikas project seeks to implement a climate adaptation strategy which utilizes Jalkund rainwater harvesting to combat rural water scarcity (NITI 2015). The seemingly successful project use collected rainwater for the purposes of environmental restoration, including aquafer and lake replenishment. Also in the East Sikkim region, the same region as Rongli, a recent project constructed 25 Jalkunds (NICRA 2013). This successful project expanded local farmers agricultural activities. Taking these two examples of Jalkunds we believe that the expansion to other regions in Sikkim has merit.

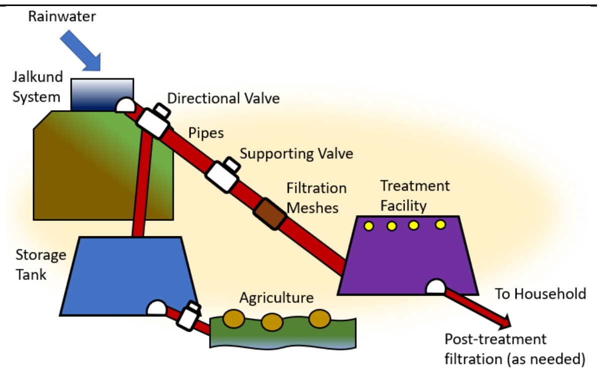


Figure 6, Jalkund and water treatment system design for this project. (Source: Hernandez II 2021)

Hernandez II (2021) calculated the number of Jalkunds needed for this project based on a sizeable 10% increase in water supply. The format used by NICRA 2013 consisted of 30.000 liters capacity Jalkunds with dimensions of 5,0 x 4,0 x 1,5 meters. Meanwhile, ICAR CCARI 2019 outline specifications for Jalkund at dimensions of 8,0 x 6,0 x 1,5 meters for a capacity of 72.000 liters. We decided to opt for several of the smaller Jalkund version, spread over a larger area to maximize the catchment area. The formula for calculating the number of Jalkunds needed was:

Number of Jalkunds needed = Yearly intake/Number of total liters

Assume a fixed amount of rainfall and using the surface area of the smaller Jalkund type, we can calculate the total amount of evaporation loss. We have the following table:

Months	Total rainfall (L/sqm)	Total Water Loss WL (L/sqm)	Jalkund Surface Area JSA (sqm)	Total Rainwater in Jalkund TR (Litres)	Percentage of Jalkund filled PJ = (TR)/30000	Daily intake (DI)	Yearly Intake YI (DI x 365)
4,10	200	60	20	2800	0.1	9000	3285000
5,9	400	60	20	6800	0.2		
6,8	800	60	20	14800	0.5		
7	600	30	20	11400	0.4		
		Total Litres TL		**35800**			
		Number of Jalkunds = (YI/TL)		**92**			

Table 2: Number of Jalkund units based on the monthly amount of rainfall. (Source: Hernandez II 2021)

As seen in the above table 92 Jalkund units are necessary to meet our targeted water supply increase. In terms of total added water supply, the following formula is used:

(92 units) * (4m x 5m x (1.5m - 0.001m)) * (1000 L/m^3)
= **2758160 L of rainwater supplied for the Jalkunds, per year.**
*Note that this result does not necessarily mean that the Jalkunds are filled. (see column PJ in the above Table)

In the next step, calculate the monthly available water supply delivered by the Jalkund units. We use the formula:

$$AW_j = TR_m \times N_j,$$

Where AW_j is the available water via Jalkund per month, TR_m is the amount of rainfall per month $N_j = 92$ is the number of Jalkund units.

Month	TR_m	AW_j **(L)**
January	0	0
February	0	0
March	0	0
April	2800	257600
May	6800	625600
June	14800	1361600
July	11400	1048800
August	14800	1361600
September	6800	625600
October	2800	257600
November	0	0
December	0	0

Table 3, Available water in Jalkund per month based on monthly rainfall.
(Source: Hernandez II 2021)

Note that this result is assuming that the water the supply per month is independent of one other, meaning that the Jalkunds are emptied each month. This is something should not happen. We now look at the monthly overall demand in Sikkim, to see where we can best utilize this water collected. Monthly water supply, demand, and allocation to agriculture in Sikkim was collected in the below table.

Month	Available Water (1000 L)	Estimated Agricultural Demand (1000 L)	Estimated Household Demand (1000 L)	Total Demand (1000 L)	%Agri (=Agri/Total)	%Household (=Household /Total)	Surplus = Available water - Total Demand (1000 L)	Allocation to Agriculture (1000 L)
January	300000	75000	25000	100000	0.75	0.25	200000	150000
February	200000	70000	30000	100000	0.7	0.3	100000	50000
March	200000	165000	35000	200000	0.83	0.18	0	**-50000**
April	250000	215000	35000	250000	0.86	0.14	0	**-50000**
May	500000	515000	35000	550000	0.94	0.06	-50000	**-100000**
June	550000	215000	35000	250000	0.86	0.14	300000	250000
July	1500000	565000	35000	600000	0.94	0.06	900000	850000
August	3000000	615000	35000	650000	0.95	0.05	2350000	2300000
September	3250000	365000	35000	400000	0.91	0.09	2850000	2800000
October	1200000	465000	35000	500000	0.93	0.07	700000	650000
November	600000	265000	35000	300000	0.88	0.12	300000	250000
December	500000	315000	35000	350000	0.9	0.1	150000	100000
Total		3845000	405000					
Estimated Supplied water		**2480000**			**0.87**			

Table 4, Monthly water supply, demand, and allocation to agriculture in Sikkim. Red regions indicate a shortage in water, in which we can allocate the Jalkund water. Green regions indicate those months where surplus is observed. (Source: Hernandez II 2021)

The above table shows that, in line with the dry season, there are periods of water deficit. To overcome this shortcoming water will need to be stored to maintain an equal supply the whole year round. The below schematic outlines the strategy by indicating output as a measure of intake.

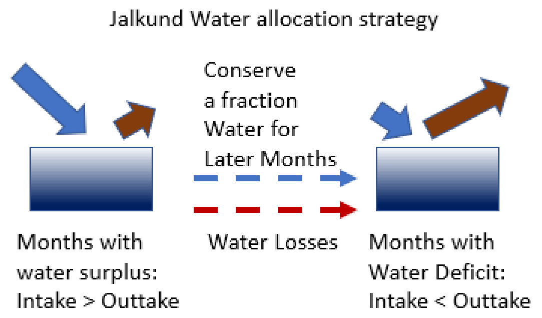


Figure 7, outline of the water supply strategy across the wet and dry seasons.
(Source: Hernadez II 2021)

Conserving Jakund water means limiting distribution. To achieve this we estimate fractional amounts of water C ($C < 1$) that are not distributed to households or agriculture during months of surplus. When C = 1 it means no Jalkund water is used while C = 0 means that no water is conserved. If we assume this system starts operation in January, we can estimate that the total initial supply from only the Jalkund is equal to AW_j, with the allocation for households and agriculture to be utilized correspond to:

$$Uhj = (1-C) \times AW_j, \times P_h,$$
$$Uaj = (1-C) \times AW_j, \times P_a$$

From there we can calculate the sum of the available water for the following month (Awj_original_this_month) and conserved water of the current month:

$$Awj\ (next\ month) = Awj\_original\_next\_month + Awj\ (this\ month) - (Uhj + Uaj)$$
$$= Awj\_original\_next\_month + Conserved\_water\_this\_month$$

For household and agriculture respectively. Applying this conservation strategy, assuming C = 0.2, we have the monthly allocation:

Month	Water Deficit (Litres)	Awj (Litres, no conservation)	Awj (Litres, with conservation)	C	Pa	Ph	Conserved water in Jalkund (Litres)	Uaj (Litres)	Uhj (Litres)
January	-200000	0	0	0	0.75	0.25	0	0	0
February	-100000	0	0	0	0.7	0.3	0	0	0
March	0	0	0	0	0.83	0.18	0	0	0
April	0	257600	257600	0.2	0.86	0.14	51520	177229	28851
May	50000000	625600	677120	**0**	0.94	0.06	0	636493	40627
June	-300000	1361600	1361600	0.2	0.86	0.14	272320	936781	152499
July	-900000	1048800	1321120	0.2	0.94	0.06	264224	993482	63414
August	-2350000	1361600	1625824	0.2	0.95	0.05	325165	1235626	65033
September	-2850000	625600	950765	0.2	0.91	0.09	190153	692157	68455
October	-700000	257600	447753	0.2	0.93	0.07	89551	333128	25074
November	-300000	0	89551	0.2	0.88	0.12	17910	63044	8597
December	-150000	0	17910	0.2	0.9	0.1	**3582**	12895	1433

Table 5, Monthly Allocation of Jalkund water supply. (Source: Hernandez II 2021)

As we can see in table 5, when C = 0 in the month of May due to the water deficit all water utilisation is required. Therefore, we can project that after one yearly cycle has been completed, we can start the following year with a 3582 Litre surplus.

VIII. Filtration system

Considering the difficulty and cost associated with developing complex facility such as a rapid sand filtration plant in the remote Himalayan location, and the space limitations making a slow sand filtration plant difficult, we decided to look for other options. Ultimately, we decided on UV filtration due to the simplicity of the system. As a sterilization method UV light is effective by disrupting cellular function in bacteria and fungi (see table 6). Although requiring slightly more frequent maintenance then a sand filtration system, the maintenance consists primarily of replacing the lamps at their end of life. For the UV treatment system, the average lifetime of a UV lamp is estimated at 5000 hours.

Inactivate Microorganisms at a Dosage of 30mM/cm² of UV 253.7nm

Name	100% lethal Dosage (Second)	Name	100% lethal Dosage (Second)
Bacteria			
Dysentery Bacilli	0.15	Micrococcus Candidus	0.4~1.53
Leptospira SPP	0.20	Salmonella Paratyphi	0.41
Legionella Pneumophila	0.20	Mycobacterium Tuberculosis	0.41
Corynebacterium Diphtheriae	0.25	Streptococcus Haemolyticus	0.45
Shigella Dysenteriae	0.28	Salmonella Enteritidis	0.51
Bacillus Anthracis	0.30	Salmonella Typhimurium	0.53
Clostridium Tetani	0.33	Vibrio Cholerae	0.64
Escherichia Coli	0.36	Clostridium Tetani	0.80
Pseudomonas Aeruginosa	0.37	Staphylococcus Albus	1.23

Table 6, Example of the sterilisation effect of UV light. In this case outlining the time in seconds to administer a lethal dose of UV radiation to kill the above bacteria. (Source: Shenzhen Sinos Technology Co., Ltd 2021)

IX. Budgeting Estimates & Lifecycle

Budgeting is broken up into several stages. These include among others the construction of the Jalkunds and filtration system, installation of the necessary equipment and piping, permitting. An outline is given in table 6. All prices are given in US dollars. If no current dollar price is available, then the dollar price is calculated based on the 14th of December 2020 exchange rate.

Category	Content	Estimated Cost	Example Procurement Option or Source
Labour (Construction Phase)	Skilled labour category by Sikkim government	4,56 USD per person per day	https://www.labourlawreporter.com/wp-content/uploads/2017/12/Sikkim-Minimum-Wages-Notification-1st-July-2017.pdf
Permitting (All)	No Objection Certificate New Connection Fee Cost of application Form	0,82 USD 8,16 USD 0,34 USD	Water Security & P.H.E. Department Gangtok (14/11/2014)
FILTRATION SYSTEM			
Settling tank	Per unit	40.000 USD	https://www.alibaba.com/product-detail/Cheap-price-Column-supported-settling-tank_60550891763.html?spm=a2700.7724857.0.0.4a13bc13RnT4DU
Aeration tank	Per unit	30.000 USD	https://www.alibaba.com/product-detail/Aeration-Tank-DaZhang-Wastewater-Treatment-Aeration_60686380726.html?spm=a2700.7724857.0.0.50353b38l7Wx6P
UV filtration	Per lamp	300 USD	https://www.alibaba.com/trade/search?IndexArea=product_en&CatId=1101&fsb=y&viewtype=&tab=&SearchScene=&SearchText=uv+filtration
Labour (Plant Management)	Unskilled and Semiskilled workers category by Sikkim government	4,08 & 4,35 USD per person per day	
Main building	Administrative building (50 sqm) & Interior/Furnishings	10.000 USD 2.000 USD	
PIPING NETWORK			
Pipes	HDPE (Transfer from Jalkund) PVC (Drinking)	0.27/meter 1.365 USD/meter	https://dir.indiamart.com/
Water meters	Measuring the water flow	Approximately 10 USD per unit	http://www.cnwatermeter.cn/product/Mechanical-water-meter-115
Mesh	One mesh is 600cm2	3 USD per mesh	
Labour	Unskilled and Semiskilled workers category by Sikkim government (pipe fitter & pipe fitter grade I/II)	4,08 & 4,35 USD per person per day	https://www.labourlawreporter.com/wp-content/uploads/2017/12/Sikkim-Minimum-Wages-Notification-1st-July-2017.pdf
RAINWATER COLLECTION			
Capture & Storage System	Per $40m^3$	16 USD	Sharma & Behera 2011. 'Resource Conserving Techniques in Crop Production', Scientific Publishers, Jodhpur
Digging	Per $5m^2$	2 USD	Ibid
Plastering surface of collection pond	For Jalkund baseline	3.26 USD/bag	https://www.justdial.com/Gangtok/Cement-Dealers/

Water supply projects such as these typically include a slew of required permits. These can include: Wastewater System and Potable Water Supply Permit, Source Permit, Construction Permit and Operating Permit. Much of this can be provided by our partner organisation, the public health engineering department, as they are often the issuing authority as well. In the case of Sikkim some of these can be found here: Certificate of ownership of premises for water supply and sewerage connection[1], request for a water supply line from state main[2] and request for a sewerage connection[3].

X. Maintenance & Training

Maintenance costs for a Jalkund have been described as negligible or low cost (ICAR CCARI Goa 2019; Saha et al. 2007). A typical clay/soil Jalkund has a lifespan of 3 years and costs approximately 7400 rupees in 2012 (ICAR (RC) NEH, n.d.). To mitigate the necessary maintenance, we have opted for the use of a concrete base. The lifespan of the concrete lining of the Jalkund can be estimated at 30 years before needing maintenance (PCA 2019). Considering for instance a project duration of 5 years until handover, it would be up until 2050 before we could expect a single round of heavy maintenance to the Jalkunds to be necessary. Based on the previously calculated 122.111 rupees (1.675 USD) per Jalkund excluding labor we can expect a single Jalkund's lifetime cost to be 339 rupees (4 USD) per month for 30 years.

The lifespan of the LDPE Agri-film is shorter. Degradation of LDPE Agri-film is generally prevented via what is referred to as 'Buried Membrane Lining'. This means that a layer of clay is placed between the Jalkund structure and the water to prevent wear, erosion and deterioration to the thin Agri-film caused by flowing water. As well as damage by the use of operation and maintenance equipment. The alternative to buried membrane lining is 'Exposed and Hard Surface Lining' constructed of cement concrete (Kumar and Singh 2010, p.8). LDPE Agri-film has been cited as a potential source for microplastic pollution (Norwegian Environment Agency 2014; Ohtake and Kobayashi). This is caused by the degradation of the agri-film and as such we

[1] http://sikkim-wsphed.gov.in/wp-content/uploads/2017/05/CERTIFICATE-OF-OWNERSHIP-OF-PREMISES.pdf
[2] http://sikkim-wsphed.gov.in/wp-content/uploads/2017/05/PDF-10-Water-Supply-Application-Form.pdf
[3] http://sikkim-wsphed.gov.in/wp-content/uploads/2017/05/PDF-11-Sewerage-Application-Form.pdf

recommend regular maintenance. When replacing the agri-film every 10 years then this would mean an expenditure of 16,66 Indian rupees per month to maintain the agri-film.

Long term viability of this project is to be guaranteed via the training of local professionals who will take over the task of infrastructure maintenance. Most of the solutions provided are not high tech in nature, so a modest training in the workings of the various aspects should suffice. At other Jalkund projects, these skills are developed via a combine regime of meetings, trainings and exposure visits (NICRA 2013). Training can be assisted via already set up training programs and publications such as the ‘Village Water Safety Planning: Sikkim Rural Drinking Water’ by the World Bank’s Water and Sanitation Program (WSP 2010). Similarly, the Sikkim Rural Management and Development Department conducts information campaigns, including on issues of water management, which would be useful for the functioning of this project. Once a skilled worker has been trained the estimated wage would be approximately 4,56 USD per person per day. This is based on the ‘skilled labor category’ of the Sikkim government (Department of Labour 2017).

XI. Limitations & Constrains

Having already covered the land property issue and necessity for training, there are still other limitations to this project. One of the primary concerns is the large scale of this project. As outlined in table 2, a total of at least 92 are needed for this project. That is a major infrastructure development for an otherwise remote Himalayan town. As such further a detailed feasibility study is highly recommended. Another issue related to the scope of the project at hand is related to the economics of Sikkim. As stated in section VII, tourism is an important industry for Sikkim and Rongli. One of the main pull factors attracting foreign and domestic tourists is the beautiful Sikkimese nature. If this project significantly disrupts the scenic landscape, it could negatively impact tourism. As a result, this project would end up having the opposite effect, worsting the economic situation in Rongli.

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Abstract

Rongli is a town located in the Eastern Himalayan state of Sikkim. Sikkim, a state of India since 1975, is dealing with the negative effects of economic water scarcity. This implies that while water as a natural resource is available in sufficient quantity to meet the needs of the population, the economic circumstance of population is such that the citizens are unable to utilize the available resources effectively, leading to poor distribution and sanitation. As such our project aims to provide a cheap source of drinking water through an innovative rainwater collection project. The Sikkim region was chosen via Analytic Hierarchy Process (AHP) wherein factors of each possible regions of interests were assigned a quantitative value which is evaluated by calculating the eigenvector. Here, the city with largest value of eigenvector is selected to be the region under study. Although our target was smaller rural communities, due to data limitations the eigenvector analysis was based on data available from the regional capitals.

Despite the ample physical availability of water via the yearly monsoon season and the river Rangpo, access is hindered due to high infrastructure costs in the state's difficult Himalayan terrain. As a resort to accessing water, (illegal) polypipes are being connected to the government water infrastructure to connect to individual households, such illegal connections are prone to leakages and other hazards. Moreover, the Sikkim region experiences a recurring dry season during the months of March to May, which greatly affect the livelihood of the citizens. With regard to the region's water supply for agriculture purposes, Sikkim relies on precipitation which peaks during the months of June and July. For household purposes, the Sikkimese capital of Gangtok, the state's largest urban area, is limited to only one old water treatment facility. Current methods of water purification that could be implemented in the region involve slow and rapid sand filtration, as well as rainwater harvesting.

Considering the features and disadvantages of each process, our project settled on rainwater harvesting. Since some of the main problems of rainwater harvesting, however, include issues of scale. Particularly the number of required collection units to supply each residence, traditional rooftop harvesting is said to be a costly process. Currently, the region implements the construction and use of a Jalkund trench consisting of polymer film as a basin for rainwater collection. However, the use of rainwater from the Jalkund is traditionally implemented for agricultural purposes, which accounts for approximately 70 percent of the entire Sikkimese water demand. From the precipitation data of Sikkim, the region experiences a surplus of rainwater in the months of June and July. Since there is a projected increasing demand for both agricultural and household water supply, the feasibility for the development of a water collection, distribution, and purification system based on the Jalkund system in Rongli province is investigated. The distribution consists of a series of pipes directed to systems for both agricultural and domestic usage. For domestic usage, an ultraviolet light treatment system has been proposed.

The project goal is to provide ample water supply to 10 percent of the Rongli population of approximately 30.000 people. The household water demand is roughly 150 liters per capita per day, as per WHO standard. Thus, the total demand is around 510,000 liters per day for this fraction of the population. We considered the current available water supply in the region to identify how many Jalkund systems are required. Land acquisition for the construction of these Jalkunds is not possible due to special exceptions in the Indian constitution for the state of Sikkim legislation, the project therefore assumed to directly cooperate with the local government. Possible social participation in terms of task delegation in the construction of these systems, as well as the utilization of water towards are enumerated. From the system maintenance and construction materials, the project is expected to last for thirty years.

Feasibility Study in the Development of a Water Purification and Distribution System in Rongli, Sikkim, North Eastern India

James Edward Hernandez II

I. Background

A. Economic Water Scarcity

Among all the water content in the planet, only three percent is freshwater, with one-third of which is contained within glaciers which are unable to be used [1]. Thus, water scarcity is considered to be a major global problem. As it is perennial, there are regions affected by this phenomenon the greatest. According to the Food and Agriculture Organization of the United Nations, there are two major classifications of water scarcity: physical and economic; the former is described as the lack of proper access of a nation to ample water sources due to geographical situation, the latter is described as the inability to access sufficient water supply due to the inability of the population to establish systems in usable water harvesting [2]. Thus, despite the availability of usable water within the nation, economic issues become the main hindrance in meeting the water demands of the population. In this project, the objective is to establish a method in increasing the water supply of a region undergoing economic water scarcity.

B. Rongli, Northeastern India

In choosing the region of interest, the regions which economic water scarcity, shown in Fig. 1 is first investigated. The proponents of the project selected northeastern (NER) India as the region of interest. The NER consists of eight states Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura. An eigenvector method is then adopted, where factors including data availability, language used, and GDP of the region were considered. After the eigenvector calculation, particularly Sikkim, a town in Northeastern India.

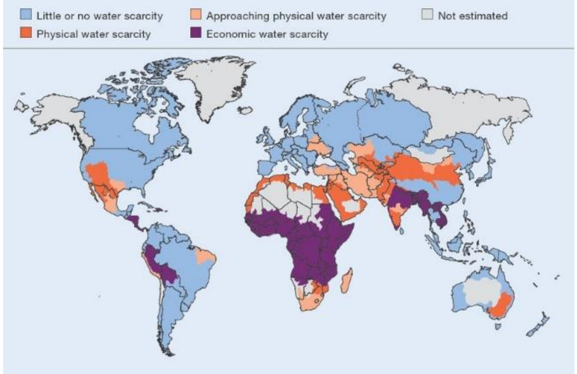


Figure 1. Physical and economic water scarcity map

Within Sikkim, the region with the lesser population is sought. Using the factors in the eigenvector calculation such as geography, data availability, project implementation viability, affordability, cultural diversity, political openness, and religious diversity, the province Gangtok, in east Sikkim is chosen as region of interest. Within Gangtok, the town Rongli was further narrowed down as the region where the feasibility of constructing a water purification is considered.

Rongli is a small town in northeastern India in Sikkim region with a population of 27741 as of 2011. Rongli is a mountainous area situated around 3300 feet above sea level. Agriculture is one of the main livelihoods within the region. Historically, the kingdom of Sikkim reigned from 1642 to 1975. Sikkim consists of several ethnicities including Bhutia, Nepali, Lepcha, and Tsong. Due to Indian annexation of Sikkim, within the Indian Constitution (Article 19, par.1, subsection e), Sikkim is considered to be part of India, while having its own regulations. One of which is land ownership, where only citizens of Sikkim are able to acquire land for private purposes. Consequently, initiatives originating from the private sector involving land purchasing must involve residents of Sikkim. In terms of water utility, Rongli currently has a dam from which a hydroelectric Brahmaputra power plant is constructed [3]. In terms of the water quality in Gangtok, the pH values of the water samples are around 8.4 [4]. Moreover, microbial activity was present in the Gangtok freshwater samples. This indicates that the quality of the existing freshwater supply is not sufficient for consumption.

II. Water Distribution and Purification Systems in Sikkim

A. Water Distribution

In terms of water distribution, freshwater is transported across localities by means of illegal piping. Polypipes, or branched out metal pipes are connected throughout freshwater reserves such as rivers through private households. Figure 2 shows the installation of polypipes within Singtam. One possible disadvantage of utilizing polypipes is the difficulty in monitoring the quality of water from the source region when water leaks ensue, since the identification of the leak would mean traversing through the complicated piping connections. As weathering frequently occurs within these pipes, maintenance costs would be significant.

Figure 2. Polypipe installation in Singtam, adopted from Ref [5]

B. Water Purification

In terms of water purification, current water filtration systems fall into two categories: slow and rapid sand filtration. Slow sand filtration is typically employed for regions with a relatively large area of freshwater, which requires relatively little maintenance to its rapid counterpart. Moreover, the skill required for the operation of slow sand filter is lower than that of the rapid sand filter. However, rapid sand filtration supplies more water at a faster interval than the slow sand filter, which deems it to be the main method in supplying water to large cities. This leads to the comparison between the two systems. Shown in Fig. 2 is the comparison between slow and rapid sand filtration methods. Since the target population is under 10000 people, it may seem that the slow sand filter would be optimal for the Rongli town. However, a major concern is the lack of space within the region, as the town mostly consists of mountainous area. Thus, in order to establish purification systems applicable to the region, other means of harvesting freshwater are sought. Another type of freshwater accumulation and purification system is through rainwater harvesting, described in the following section.

Item	Slow Sand Filter	Rapid Sand Filter
Pre treatment	Not required except plain sedimentation	Coagulation, Flocculation and Sedimentation
Base materials	Gravel base of 30 to 75 cm depth with 3 to 65mm size graded gravel.	Gravel base of 45 to 50 cm depth with gravel size varies from 3 to 50 mm in 4 or 5 layers
Filter sand ▪ Effective size ▪ Uniformity coefficient ▪ Thickness of sand bed	 ▪ 0.25 to 0.35 mm ▪ 3 to 5.0 ▪ 80 to 100 cm	 ▪ 0.45 to 0.70 mm ▪ 1.2 to 1.7 ▪ 60 to 75 cm
Under drainage system	Open jointed pipes or drains covered with perforated blocks	Perforated pipe laterals discharging into main header
Size of each unit	50 to 200 sq.m	10 to 100 sq.m
Rate of filtration	100 to 200 Lph/sq.m	4800 to 7200 Lph/sq.m
Cost ▪ Installation ▪ O&M	 ▪ High ▪ Low	 ▪ Low ▪ High
Efficiency ▪ Turbidity of feed water ▪ Removal of bacteria	 Low; < 30 NTU 98 to 99%	 Any level of turbidity of feed water; (with pre-treatment) 80 to 90%
Suitability	For water supply to rural areas and small town	For public water supply to towns and cities
Post treatment	Slight disinfection	Complete disinfection is a must
Ease of construction	Simple	Complicated;
Skilled supervision	Not essential	Essential
Loss of head ▪ Initial ▪ Final	 ▪ 10c m ▪ 80 to 120 cm	 ▪ 30 cm ▪ 250 to 350 cm
Method of cleaning	▪ Scrapping and removing *Schmutzedecke* and 1.5 to 3 cm thick sand layer ▪ Laborious	▪ Back washing with or without compressed air agitation ▪ Simple and easy
Quantity of wash water required	0.2 to 0.5% of total water filtered	1 to 5% of the total water filtered
Cleaning Interval	Three to four months	One to two days

Fig. 2. Comparison between slow and rapid sand filtration. Adopted from Ref. [6]

C. Rainwater Harvesting

Another method of freshwater accumulation and transport is through rainwater harvesting. Rainwater harvesting is commonly utilized in regions with little available flatland to employ large scale water filtration systems. Due to smaller area requirements, rainwater harvesting systems can be localized in residential levels. However, due to the same reason, increasing water supply via rainwater harvesting poses some disadvantages including size and location-dependent output. As the rainwater system consists mainly of a collection and transport region, the amount of specification of the size of the collector region. Moreover, the precipitation distribution may differ across regions, which also affect the output of the collector. Although rainwater is considered to be freshwater, its quality may also depend on that of the evaporated water. As per the project objectives of providing water supply to around 3000 people, this method of water supply system is selected. In this work, due to available resources, the assumption that data obtained from different areas of Sikkim are sufficient to be applicable to the entire region.

In South Sikkim, the precipitation pattern is shown in Fig. 3. From the months of June to September (as shown from the labels 6 to 9), the rainfall is shown to be highest, while January, February, November, and December were shown to have little to no rainfall. This is indicative of the wet and dry seasons in Sikkim, where periods after summer have the most amount of precipitation, while summer and winter seasons have the least amount of rainfall.

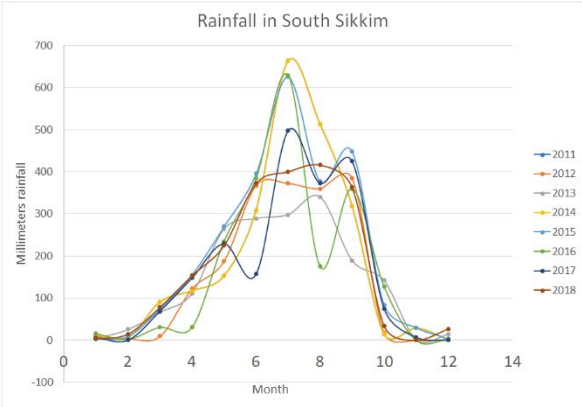


Fig. 3. Rainfall in South Sikkim in millimeters versus months

Following the rainfall distribution in Sikkim, the current water supply and demand pattern is investigated. Fig. 4 shows the monthly water availability and demand in East Sikkim. Surplus in available water is observed from the months of June to October. Since the highest precipitation values in the distribution fall under these months, the excess available water (shown in blue bars) are classified as rainwater. On another note, the pink bars indicate the total demand which is shown to be higher in the months ranging from March to May, most probably due to the summer season at which evaporation losses reach the highest. Household (HH) and livestock (LS) demand is shown to have a constant pattern throughout the year. The graph shows the time periods where water scarcity is observed. A possible strategy is to utilize the surplus rainwater from July to October for those periods where water shortage is expected.

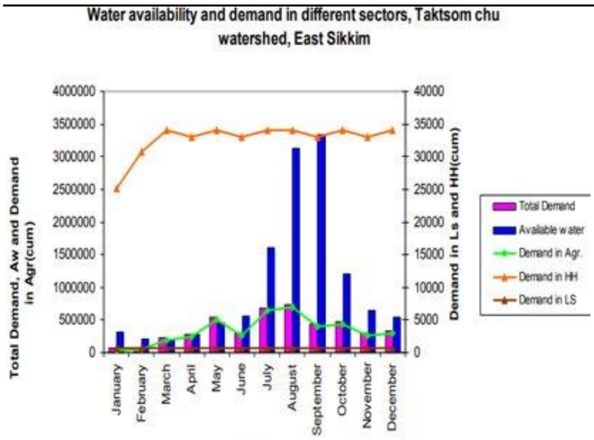


Fig. 4 Monthly water availability and demand in East Sikkim. Ref [7]

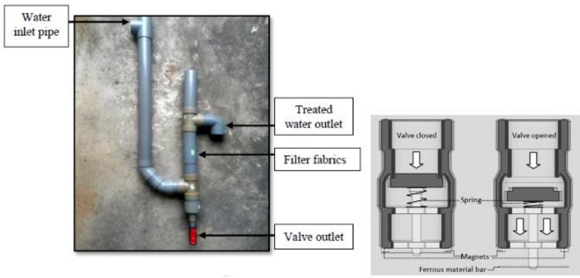


Fig. 5. Schematic of a rainwater filtration system Left figure adopted from Ref. [8] Right figure adopted from Ref [9]

D. Cost-effective Water purification system

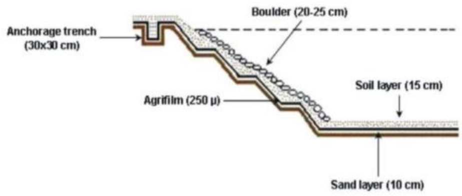
Since the collected rainwater can be a source of contaminants, filtration is required for household consumption. Moreover, the material cost for filtration also requires to be inexpensive. A self-cleaning filtration mechanism was reported based on filter fabrics, shown in Fig. 5 [9]. The mechanism design consists of water inlet, outlet, and filter components. The water is first directed downward toward the filter fabrics. Increased water pressure pushes the water upward through the fabrics and toward the outlet component. The valve outlet consists of a spring attached to the water sealant and a magnet attached near the valve exit. As the water pressure between the water outlet and the valve outlet is further increased, the pressure applied on the spring results to its contraction and the opening of the valve, releasing the water. As a result, the filter fabrics is 'cleaned' by the filtered water located between the outlet region and the filter fabric region. This mechanism is proposed to reduce maintenance as well as labor costs, while increasing the quality of water output. The proponents claimed the apparatus conformed to the water quality standards such as that imposed by the WHO. In this project, the use of this mechanism is adopted due to its cost-effectiveness and simplicity.

III. Jalkund-based Water Harvesting System

A. Structure of the Jalkund

A Jalkund is a lined trench dug in mountainous regions and is utilized for rainwater storage. The steps in the construction of the Jalkund is shown in Fig. 6. The typical Jalkund trench has a size of 5 m x 4 m x 1.5 m, which holds around 30,000 liters. Concrete is poured on the trench as a foundation, although clay can also be used. The Jalkund is lined with a waterproof agrifilm made from low density polyethylene (LDPE) where rainwater is settled. Boulders are placed on the agrifilm to keep the film intact. Once rainwater is stored, the Jalkund is covered by grass and fenced to keep animals from contacting with the Jalkund. In Sikkim, the Jalkund is utilized for agricultural purposes, where the region mainly grows corn and ginger as a main crop.

(a)



(b)

(c)

Fig. 6 (a) Steps in Jalkund construction a. excavation, b. plastering with clay, cushioning with pine leaf, d. lining with LDPE agrifilm, e. rainwater collected in Jalkund, f. thatch covers Adopted from Ref [10] (b) Cross section of a Jalkund. Adopted from Ref. [11] (c) Rejuvenation of lakes via Jalkund system, Adopted from Ref. [12]

The Jalkund can be utilized as means for replenishing water on dried lakes. In South Sikkim, runoff from surface rainwater flows to the Dolling lake via piping

[12]. This is currently performed by the Dhara Vikas project, where locals participate in the water transport in rejuvenating springs and other freshwater bodies.

B. Schematic of Water Harvesting and Purification system

Through the use of various components of currently implemented apparatuses and systems for the increase in water supply, a schematic for incorporating these components is proposed, as shown in Fig. 7.

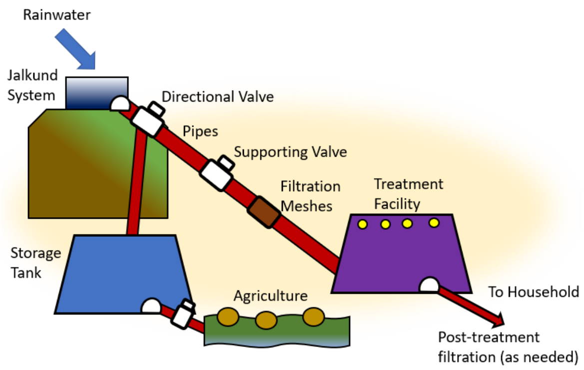


Fig. 7 Schematic of the Jalkund-based water collection, distribution, and purification system

The proposed schematic can be separated into three regions: collection, distribution, and treatment. In the collection region, rainwater first poured into the Jalkund which fills the volume of the trench. The water then flows as runoff through pipes similar to that of the Dhara Vikas system. Directional valves steer the water flow to storage tanks designated either for agriculture or household purpose. The distribution region consists of polyvinylchloride pipes, which are typically used for water transport. These pipes connect the Jalkund systems to the storage tanks and from the storage tanks to the crops and the treatment facilities. Within the pipes, supporting valves are attached so that removal and maintenance of the pipes becomes easier. Filtration meshes are installed within the pipes to remove large sediments, which could be a cause of clogging. For water transported to storage tanks for agriculture, no additional treatment is required. For the treatment region, an ultraviolet (UV) light water treatment system is adopted. In Sikkim, small-scale UV filtration systems are already available, where output water is approximately 50 liters per hour [13]. The output water is claimed to be suitable for drinking. Output water coming from this setup acts as the final stage, after transporting water coming from the storage tanks for household purpose. Advantages of the system include the possibility of rerouting the water towards either agriculture or household, which increases the versatility in catering for the demand. Another advantage, compared to the slow sand filtration process, is that the systems can be expanded, given adequate connection. Two or more Jalkund systems can be linked via piping, to increase overall supply.

IV. Supply and Demand analysis

A. Available water and Water Allocation

In order to identify the quantity of Jalkund systems required, the demand is investigated. From Fig. 4, the monthly demand is tabulated, as shown in Table 1. The data corresponds to that of Taktsom chu, which has a population of 5000, which is well above the 3400 target population.

Table 1. Tabulated data for available water and total demand in Taktsom Chu

Month	**Available Water (1000 L)**	**Estimated Agricultural Demand (1000 L)**	**Estimated Household Demand (1000 L)**	**Total Demand (1000 L)**	**%Agri (= Agri/Total) Pa**	**%Household (= Household/Total) Ph**	**Surplus = Available water - Total Demand (1000 L)**	**Allocation to Agriculture (1000 L)**
January	300000	75000	25000	100000	0.75	0.25	200000	150000
February	200000	70000	30000	100000	0.7	0.3	100000	50000
March	200000	165000	35000	200000	0.83	0.18	0	-50000
April	250000	215000	35000	250000	0.86	0.14	0	-50000
May	500000	515000	35000	550000	0.94	0.06	-50000	-100000
June	550000	215000	35000	250000	0.86	0.14	300000	250000
July	1500000	565000	35000	600000	0.94	0.06	900000	850000
August	3000000	615000	35000	650000	0.95	0.05	2350000	2300000
September	3250000	365000	35000	400000	0.91	0.09	2850000	2800000
October	1200000	465000	35000	500000	0.93	0.07	700000	650000
November	600000	265000	35000	300000	0.88	0.12	300000	250000
December	500000	315000	35000	350000	0.9	0.1	150000	100000
Total		3845000	405000					
Estimated Supplied water		**2480000**			**0.87**			

The table also shows the percent allocated to household and agriculture, wherein the mean allocation for agriculture is shown to be approximately 87% of the total demand. Surplus above 900,000,000 liters of water is observed from the months of July to September, indicative of the rainy season. On the other hand, water shortage is observed from march to May, where the surplus is greater than or equal to zero. This indicates a yearly water scarcity problem within this area of Sikkim. The household water demand in areas in Sikkim across various socioeconomic classes is shown in Fig. 8. In this graph, the lowest and highest socioeconomic group based on income is labelled as 'Category I' (monthly income below 10000 Rs.) and 'Category V' (monthly income from 41000-50000 Rs.) respectively [14]. Gangtok does not show major variation in water consumption across the socioeconomic groups. Daily household water consumption in Gangtok is 9907 liters, from 28 households, resulting to around 90 liters consumed daily per capita, assuming a household of four members. According to the WHO standard, daily consumption of water should be approximately 150 liters. This indicates a shortage of 60 liters per capita among the residents. Given this assumption, the number of Jalkund systems, assuming a 30,000 liter capacity of the Jalkund is calculated, as shown in Table 2. However, it is only assumed that 150 liters is the minimum supply for the resident. Depending on the daily activities of the citizen, the water usage varies. Thus, this measurement of minimum daily water consumption only serves as a baseline for calculation of the water supply.

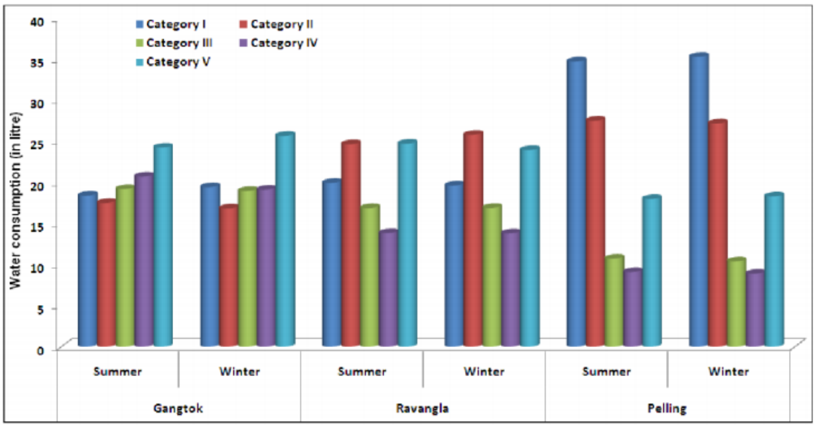


Fig. 8 Household water consumption in Gangtok, Ravangla, and Pelling across various economic groups

B. Calculation of Number of Jalkund units

As shown in Table 2, a simplified precipitation distribution is adopted where the highest rainfall is in July with a total amount of rainfall (TRa) of 600 mm (600 L/sqm) of precipitation, followed by June and August (400 L/sqm), May and September (200 L/sqm), and April and October (100 L/sqm). All other months were assumed to have zero precipitation. The Jalkund surface area (JSA) is 20 sqm. Water loss (WL) is also considered to be 1 mm per day in Sikkim [15]. The total amount of water in liters from the daily (DI) and yearly (YI) intakes is obtained from

Equation 1:

$$DI=60\times TRP+60\times 10\times TRP/5 \qquad (1)$$

where TRP=3400 is the target population. The factor 60 represents the WHO requirement minus the currently consumed water (150 – 90 liters per day). The second term represents the water allocation for agriculture, which is approximately 10 times that of the household consumption. The divisor 5 assumes that a household of five members share the same part of water for agricultural use. The result of 6240 units considers the yearly water intake. Although one threat to this number of units would be the construction, this number satisfies the demand of the target population under the assumption that the amount of water utilized for agriculture is always fixed (around 9 times the household consumption amount). From the previous discussion, the amount of additional household demand of 60 liters per day depends on the average individual water consumption of the residents. Thus, DI can be lower.

Table 2. Calculation of required number of Jalkunds based on yearly intake

Months	TRa (L/sqm)	WL (L/sqm)	JSA (sqm)	TOj (Liters)	%TRj (TR)/30000	DI, L	YI (DI x 365, L)
4,10	200	60	20	2800	0.1	612000	223380000
5,9	400	60	20	6800	0.2		
6,8	800	60	20	14800	0.5		
7	600	30	20	11400	0.4		
		Total Liters TL		**35800**			
		Number of Jalkunds = (YI/TL)		**6240**			

C. Water Conservation

In order to increase the utilization efficiency of water in the Jalkund system, a conservation strategy is adopted. In this strategy, the amount of water collected in the present month is conserved for use in those months which experience water shortage. Assuming that sufficient storage units are available for use for the excess water and the amount of water can be monitored, the strategy, when adopted, can accumulate for use even for the succeeding years. In order to integrate the strategy in the calculation of water supply, a factor C<1 is introduced in the Jalkund total output water. The total amount of water utilized for household and agriculture $〖U_h〗_j$ and $〖U_a〗_j$ are then

$$〖U_h〗_j=(1-C)\times AW_j\times P_h \qquad (2)$$
$$〖U_a〗_j=(1-C)\times AW_j\times P_a \qquad (3)$$

where AW_j is the available water in the Jalkund equal to the total monthly amount of rainfall times the number of Jalkund units, P_h and P_a is the percentage of water allocated to household and agriculture. When the factor C is equal to 0 or 1, total water utilization or storage, respectively, is expected. For C=0 from January to May and C=0.2 elsewhere, we have the calculation shown in Table 3. Assuming the construction finishes in January, the conserved water in the Jalkund in December the same year amounts to around 200000 liters, following this scheme.

Table 3. Calculation of Jalkund water supply with C=0 from January to May, and C=0.2 elsewhere

Month	Water Deficit (Liters)	Awj (Liters, no conservation)	Awj (Liters, with conservation)	C	Pa	Ph	Conserved water in Jalkund (Liters)	Ua (Liters)	Uh (Liters)
January	-200000	0	0	0	0.75	0.25	0	0	0
February	-100000	0	0	0	0.7	0.3	0	0	0
March	0	0	0	0	0.83	0.18	0	0	0
April	0	17472000	257600	0	0.86	0.14	0	221536	36064
May	5E+07	42432000	625600	0	0.94	0.06	0	588064	37536
June	-300000	92352000	1361600	0.2	0.86	0.14	272320	936781	152499
July	-900000	71136000	71408320	0.2	0.94	0.06	14281664	53699057	3427599
August	-2350000	92352000	106633664	0.2	0.95	0.05	21326733	81041585	4265347
September	-2850000	42432000	63758733	0.2	0.91	0.09	12751747	46416357	4590629
October	-700000	17472000	30223747	0.2	0.93	0.07	6044749	22486467	1692530
November	-300000	0	6044749	0.2	0.88	0.12	1208950	4255504	580296
December	-150000	0	1208950	0.2	0.9	0.1	241790	870444	96716

V. Lifecycle assessment

Lifecycle assessment of the project mainly focuses on the operation costs of the proposed system. One reason for considering the Jalkund-type rainwater harvesting system is its affordability and relative ease of construction. Moreover, the current availability and utility of the Jalkund system would imply that construction of such units would not be an entirely new experience for the Sikkim residents. However, the construction of the units has to be investigated. Cost estimation is separated into the following components: the Jalkund system, piping and distribution, storage, and treatment facilities. An estimate for the Jalkund is shown in Table 4.

Table 4. (Upper) Estimated costs involved in the Construction of Jalkund (30,000 liter capacity), Adopted from Ref. [14] (Lower) Estimate legal, distribution, and treatment expenses for the Jalkund system.

Particulars	Unit price (Rs)	Total price (Rs)
Digging expenses	30/m^3	900
Plastering with clay	2.50/m^2	120
Cushioning with pine leaf	2.50/m^2	120
Lining with LDPE black agri film (250 μm)	40/m^2	2880
Thatching	2/m^2	60
Fencing	2/m	75
Insecticide, etc.	–	50
Total	–	4205
First year cost/l stored water	–	0.14
Second year cost/l stored water	–	Nil
Third year cost/l stored water	–	Nil
Average cost/l stored water	–	0.046

• Permitting • Certificates (Connection, No objection, Application)	approx. 10 USD
• Water Distribution Pipes	approx. 70.000 USD
• Water Treatment • UV Filtration	11.200 USD 600 USD per unit (approx. 333L per unit for 70L/h)
• Water Storage • Storage Tank	7000 USD for 30000L water

It can be observed that the total cost of construction of Jalkund is around 4000 rupees which is approximately 60 USD. For comparison, the cost of each Jalkund unit is, one-tenth of a Category V resident. However, the cost of other components of the system could add to the difficulty of construction, such as the pipelines. Thus, it is recommended that all the components would not be established simultaneously. For instance, 10 Jalkund units, when full, will supply 400 households of five people in a day, or the household needs of 60 people in a month. However, assuming that the consumption of Jalkund water is around 20 percent, then approximately 300 people, or 10% of the target population will be benefitted in a month by the installation of 10 units. Conservation of water allows for additional water supply, which implies for additional benefactors of the system.

In terms of project milestones, it is foreseen that the project would last for 30 years. This time period is chosen due to the lifespan of the Jalkund foundation, which is concrete. For the preparatory arrangements, legalities and permits have to be settled for the first few years. This implies that the social participation concerning Sikkim residents has to be already settled by then. At least fifty Jalkunds are then constructed and monitored every year. Depending on the water allocation, the number of units may vary. Pricing and monitoring of the water also depend on the regulations to be implemented by the current government, so negotiations have to be conducted. This makes social participation vital to the progression of the project.

VI. Opportunities for Social participation

Since Jalkund systems are a relatively familiar form of rainwater harvesting amongst the residents of Sikkim, opportunities for social participation are also envisioned. One possible endeavor is the establishment of agri-business initiatives. Since the Jalkund systems cater to both agricultural and household demand, increase in water supply would lead to increase in crop production. The Jalkund system can also be an avenue of opportunities to form citizen groups with designated roles. An example of roles is classified in the following.

1. Construction
   a. Digging
   b. Lining

2. Piping
    a. Installation
    b. Maintenance
3. Storage
    1. Installation
    2. Monitoring
4. Treatment
    a. Lamp maintenance
    b. Wiring
    c. Monitoring

These roles cane be delegated with appropriate leadership established by the residents themselves. Close cooperation with the project management and the localities is expected. The agri-based business can be utilized to increase income amongst the population, thus increasing the purchasing capacity for better water quality. Once the income is sufficient for daily household and agricultural needs, expansion via construction of additional Jalkund units can be expected.

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