SMEA 519
Raven Benko, Jessi Florendo, Greg Papp, Harshitha Sai Viswanathan

Equitable Water Security in Kiribati

Background

Problem Situation Overview

Kiribati is a young nation (independence in 1979) comprising three discrete archipelagos spread out over 3.5 million square miles. The atolls combine for only 313 square miles of land above sea level, ranking among the smallest in the world, yet the populated area on South Tarawa is as densely populated as Tokyo. Kiribati's government runs a massive deficit (estimated at -64.1% of GDP in 2017) and relies heavily on foreign aid (32.7% of government finances in 2016) (US CIA, 2021).

Despite limited infrastructure, the population of Kiribati's largest urban area, South Tarawa, continues to grow rapidly, with population rising 12% between 2010 and 2015 (Graves et al, 2021). The vast majority of nutrition for this populace comes from small coastal fisheries (Bell et al, 2018). The nearshore fisheries and reef areas are also primary drivers of tourism and income security (Hanich et al, 2018). International access to, and fishery landings from, the nation's expansive Exclusive Economic Zone (EEZ) is a major source of revenue.

Water availability and management are recurring issues of vital importance for Kiribati and all Small Island Developing States (SIDS) where the primary sources of potable water are rainwater and groundwater (Post et al, 2018). The groundwater aquifers are "highly permeable" and regularly contaminated by saltwater incursions (through storms and sea level rise). In a water security report, 25% of children under the age of 5 had experienced diarrhea in the last month and that water security and safety concerns led nearly all families to boil water before consumption (Psutka et al, 2013). Climate change and sea level rise have had an exacerbating effect, with "long dry periods strongly coupled to sea surface temperature" (White & Falkland, 2009).

Client's Inquiry

In order to meet growing water demand and address immediate water shortages in rural areas, the Kiribati government is interested in exploring water provision options on a national and regional scale. Alternatives include:

1. Small-scale (10-20 household) solar-powered desalination machines on each populated island. Includes creation of a training center on South Tarawa for maintenance and operation.
2. Overhaul and enhancement of water usage efficiency technology on South Tarawa and all populated islands. Intent is to increase capacity and recycling of public utilities in urban areas and increase storage and re-use capabilities of rural islands.
3. Status quo. This is undesired by all stakeholders. This outcome will result if funding cannot be secured.

Prior Efforts

Inundated groundwater due to sea level rise, in combination with record drought tied to climate change driven sea surface temperature changes, has led to unprecedented water security concerns in SIDS. Significant political effort has been expended by Kiribati towards mitigating climate change damages, but the current water security issue is novel and has little precedent in Kiribati or anywhere.

In 1987, the South Tarawa Water Supply Project (an Australian led endeavor) was completed. This large-scale freshwater pumping plan was immediately overwhelmed by household demand, as the designed supply was less than the actual demand due to an incorrect assumption that more households had regular access to well water (Metutera, 2002). In addition, the water-use per day exceeded the estimated "safe yield" for natural aquifer replenishment.

During a record drought in 1999, China donated two desalination plants. By 2002, they were no longer functional due to electrical and mechanical issues exacerbated by difficulties in working with the manufacturer (Metutera, 2002).

More recently, the World Bank has funded water adaptation programs which focused on mangrove planting, sea-wall construction, and rainwater catchments and storage (World Bank, 2017b). In times of prolonged drought or saltwater inundation (both more frequent in La Nina years), these strategies provide some buffer but do not adequately meet needs.

Graves et al also investigated the possibility of providing water filters for every household. However, they found "in the absence of hygiene and storage improvements, the substitution of a filter is unlikely to improve water quality" which correlates with previous literature highlighting limited water infrastructure (Graves et al, 2021).

Significance of the Problem

Evaluation of Past Policy Performance

Because there is little formal past policy to draw from, here there is significant benefit in examining the ancillary policies and conditions that have led to the problem at hand. In ***Public Policy Analysis: An Integrated Approach*** (2018), William Dunn describes multiple perspective analysis as "a method for gaining insight into problems by applying three kinds of perspectives – personal, organizational, and technical – to problem situations" (Dunn, 2018). We will apply these three lenses to the problem as it applies to Kiribati:

Technical: Kiribati lacks the technology, infrastructure, and maintenance capabilities to design, install, and maintain desalination plants to meet citizens' needs. As a whole, the country has heavily relied on household wells, and capital for infrastructure projects has often been tied to fishery access agreements (Hanich et al, 2018) and foreign aid. No nation currently has the technology to address climate change, a primary driver of Kiribati's groundwater contamination, on an adequate time-scale.

Organizational: Kiribati lacks the negotiation and bargaining skills and the social capital required to adequately leverage its situation on a global scale. Much of the nation's income is derived from exploitative access agreements and tourism, leaving Kiribati unlikely to challenge foreign nations to pay recompense for climate damages. Similarly, the vulnerability of Kiribati in the age of climate change has been one marked with "climate-doom" rhetoric both in the Pacific and in its reporting abroad (Shea et al, 2020). As climate threats become increasingly realized and effect greater shares of Kiribati's people, the Kiribati government has swung between hopelessness – a former President of Kiribati remarked "as for Kiribati? It is already too late" – and a defiant focus on adapting to an uncertain future while retaining traditional values (Tong & Rytz, 2018).

Personal: With such large reliance on residence-level water infrastructure, this problem is deeply personal. Many optimal groundwater access points lie on private property, complicating freshwater management of this scarce public resource in urbanizing areas. Unsurprisingly, cultural connections to freshwater abound. Traditional methods of access (household wells, rainwater catchments, etc) are unlikely to be abandoned. In addition, the unpalatability and taste preferences associated with deionized, desalinated water are documented and may be barriers to adoption of new technology (Boden & Subban, 2018). Furthermore, there is significant connection to nearshore fisheries and reefs on a logistical as well as social/traditional level, and so damage to that ecosystem via brine discharge from desalination is of grave concern. Potable water for fish processing is another key cultural bond to water security issues.

Assessment of scope and severity

There is no larger scope or greater severity than that of global climate change, a driver of this problem, but this analysis will focus only on near-term solutions. Kiribati's water security issues have been highlighted by many global media outlets (World Bank, 2017a). Similarly, the public health effects of saline-contaminated water consumption in Kiribati are well studied. With few new solutions available for provision of potable water and a growing population, the water security severity is **high**. Furthermore, as it affects nearly the entire populace spread across millions of miles of ocean, the scope of the problem is **large**.

Need for Analysis

This value or worth of solutions to this problem are not controversial. It is self-evident that water security is a desired outcome for all stakeholders. Therefore, a pseudo-evaluation is appropriate. The analysis focuses not on *if* a project should be implemented, but rather *which* should be pursued. This report will discuss the costs and benefits of the alternatives, analyze feasibility, and forecast outcomes variably dependent on the level of financial and social capital received from international sources.

Problem Diagnosis

As a small-island state experiencing the brunt of climate change, including drought and saltwater intrusion, freshwater resources have become a significant issue in Kiribati. At this time, there isn't significant infrastructure in place to address a dwindling drinkable water supply, leading to a freshwater scarcity that will only worsen without intervention. The problem needing to be addressed is what intervention method for increasing supply and access to freshwater best suits Kiribati and its unique host of environmental, residential, and infrastructural issues. The issues associated with water scarcity in a small island developing state (SIDS) like Kiribati are diverse, including everything from environmental impacts and political involvement to the health impacts of contaminated water and economic aspects of freshwater infrastructure (see Figure 1 for our hierarchy analysis).

While others have introduced policies for different freshwater solutions in urban or rural areas (such as the rainwater harvesting systems associated with the World Bank's Kiribati Adaptation Plan) or just on certain islands (such as UNICEF and the European Union's initiatives to improve access to clean water on the outer islands), no approaches so far have analyzed options for accessible drinking water across Kiribati's entire geographic range. Additionally, in studying the feasibility of these plans, investigating equitable distribution and access have been surface-level at best. Analyzing the utility of the different policy alternatives examined here and the associated feasibility was accomplished through a pseudo-evaluation method.

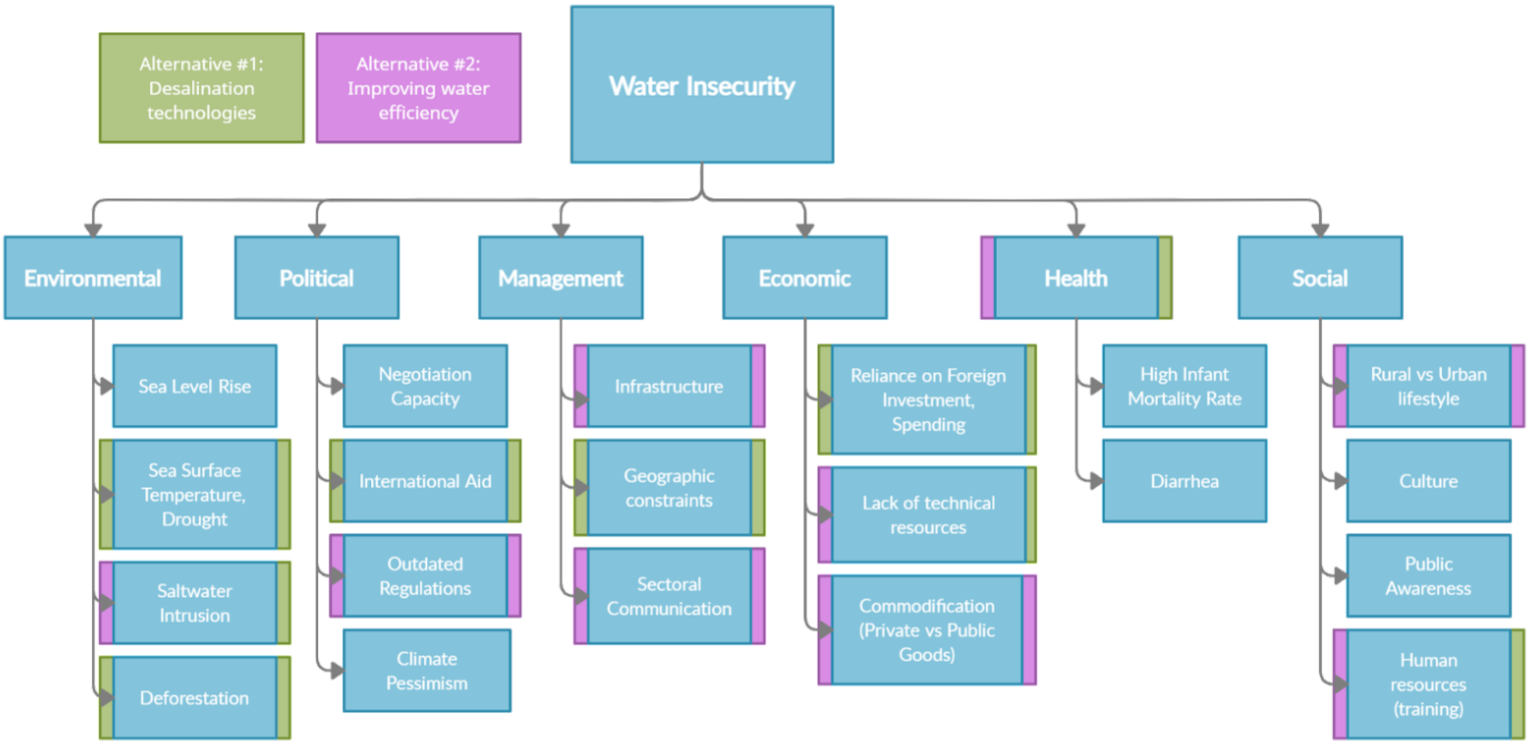

Figure 1: Brainstorming causes and effects of water insecurity in Kiribati.

Major Stakeholders

Major stakeholders include residents of Kiribati, both urban and rural; and the local government, including the Office of the President, the various ministries, and the parliament. Additional stakeholders would include NGOs like the Nature Conservancy or Conservation International that would be interested in the environmental impact of freshwater catchments or desalination plants, as well as human rights advocate non-profits and/or international funding organizations like the World Health Organization, the World Bank, or the United Nations, who may play pivotal roles in mitigating costs associated with such an undertaking.

Goals and Objectives

The goal of this policy is to create equitable water provision across the islands of Kiribati, to the benefit of residents, businesses, as well as the environment. In order to meet this goal, the objective is to implement a strategy which will increase the availability of safe drinking water to reasonable access, which is defined as "20 liters per capita per day at a distance of no more than 1,000 meters" (WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation, 2000). Options to increase freshwater access will be analyzed in terms of environmental impacts, feasibility in the geographic region, the distributional equity of access to the implemented policy, and expenses associated with each option.

Analysis of Alternatives

<u>Alternative Policy 1</u>: Implementation of small-scale desalination technologies across all islands in Kiribati. Freshwater resources in Kiribati are threatened by climate change (drought and inundation of groundwater resources via sea level rise) and poor water management. Providing a direct source of new freshwater for drinking through the implementation of local to household scale desalination technologies directly counters water scarcity due to climate change.

Geographical Context - Kiribati spans over 3 million square kilometers with transportation infrastructure between islands lacking (National Water and Sanitation Committee, 2006). Thus, methods to decentralize freshwater production are needed so that households in the outer islands become more self-sufficient (National Water and Sanitation Committee, 2006). While a new international investment project approved in 2020 by the World Bank plans to improve transportation infrastructure between islands by strengthening maritime navigation safety, investing in island access infrastructure (ports and roads), and increasing climate resiliency, little headway has been made with the project (The World Bank, 2020). It is unclear whether transportation infrastructure would be improved quickly enough to support large-scale, daily water transport from island to island. Uncertainty in infrastructure development timelines as well as climate change induce rainfall variability makes decentralized freshwater production all the more appealing. Additionally, due to the difficulty of transporting needed supplies and expertise for maintenance of technically complex infrastructure, solutions for the outer islands should rely on mechanisms that require little technical expertise and those that can be easily maintained (Republic of Kiribati, 2014).

Recommended Technologies

Solar Powered Reverse Osmosis (RO): involves the separation of water from dissolved solutes by forcing saline water through a semipermeable membrane polymer with the use of pressure (Boden and Subban, 2018).

1. ***Benefits***: RO is a widely used and well researched desalination technology which has reached economies of scale. Therefore, parts and maintenance are less scarce than newer, more efficient technologies that have not been widely tested (like mCDI, EDR and SSD). Paired with solar technologies, the plants can provide sufficient sources of water to rural communities with relatively low cost after construction.
2. ***Drawbacks***: These types of plants require high energy inputs and are well suited for communities requiring larger production capacity (Boden and Subban, 2018). Maintenance requires technical expertise and replacement parts that may be difficult to transfer to the outer islands. Decreased efficiency in desalination (20-50% for single pass systems) results in high wastewater brine output and increased environmental burden (Boden and Subban, 2018).
3. ***Current Usage***: Currently a new, large-scale RO desalination plant is being developed in South Tarawa, with funding from the World Bank, Asian Development Bank, and Green Climate Fund (Conroy, 2019). A close to 30 million dollar grant was awarded for a joint RO desalination plant and Solar energy plant to power the desalination plant (Grant Agreement, 2020). It is projected to provide up to 4000 cubic meters of freshwater per day initially, and will be completed by 2022 (Conroy, 2019). Several case studies of small-scale implementation of RO exist, though largely for sources of brackish water. Many of these are paired with renewable energy sources to power the technology but can have very expensive maintenance and pretreatment needs (Boden and Subban, 2018).

Desalination Externalities - all desalination techniques produce a hyper-saline brine waste product that, in coastal communities, is usually dumped into the ocean, threatening marine life. Kiribati's economy and food security relies heavily on tuna fisheries and highly migratory species largely in the offshore environment. Plans for the South Tarawa RO desalination plant involve disposing of the brine along with city sewage in a currently used outfall site offshore (Conroy, 2019). The waste is projected to be quickly diluted with minimal environmental impact, however, if more outfall sites are used to supply the outer islands, environmental harm could increase. However, studies have shown significant negative impacts to coral calcification rates, bacterial symbiont survival, and increased bleaching rates (Peterson et al, 2018). As Kiribati is already experiencing bleaching due to climate change, this is a significant negative externality that could threaten the food security and economy of the nation.

Constraints and Political Feasibility - there are 19 islands in Kiribati that would require the installation of a small, solar-powered RO desalination plant (Tarawa is excluded from our analysis as there are already plans for the construction of a large-scale desalination plant). Estimations for the cost of such plants range from $20,000-$80,000 and would produce between 1 to 10m^3/day (Boden & Subban 2018). The Kiribati National Plan and Strategies for Sustainable Water Management and Use water plan aimed to provide each household in urban South Tarawa with a consistent 250L/day of potable water (National Water and Sanitation Committee, 2006). In order to provide this same amount to the households of the remaining islands, the desalination plants would have to produce about 5000 cubic meters of water across all populated islands. This would require the construction of multiple small-scale desalination plants (or larger plants) on the more populated islands. Using household estimates from the most recent census in 2015 and the upper end of construction cost estimations ($80,000), building enough desalination plants to provide 250L/day to each rural household would cost an estimated 22 million USD (National Statistics Office, 2015; Boden and Subban, 2018). Additional maintenance over a 30 year period could cost about 2% of the upfront costs each year, adding an additional estimated 13 million USD to the long term costs of the project (Younos, 2005). The total project cost would be 35 million USD.

To fund a project of this scale, the Kiribati government would have to leverage foreign funding. They have had success in this arena in the past, securing about 8 million USD for water sanitation projects from the EU in 2020, about 30 million USD from the world bank, Green climate fund, and the Asian Development Bank for a desalination plant in South Tarawa in 2020, and 42 million USD for developments in inter-island transportation from the World Bank and the Asian Development Bank in 2020 (Kahn and Kasim, 2020; Conroy, 2019; World Bank, 2020) . There is clear international support for access to clean water for Kiribati.

Alternative Policy 2: **Implementing standards and incentives to manage water supply and demand.** Improve technical efficiency of water supply through an integrated water resources management approach for consumption, sanitation, and hygiene across different levels (national, local, individual, and sectorial) and introduce economic incentives to reduce demand implemented through an institutional setting.

Demand Management – The introduction of a charging mechanism to ensure financial sustainability of maintenance and replacement of water infrastructure on the island. Economic incentives to reduce demand can take place through fines at the individual level which is a good incentive for households to implement infrastructure improvements such as leakage control, installation and maintenance of water meters, and real time monitoring (Hophmayer-Tokich, 2006). Subsidies to install rainwater catchment or grey water systems in households that can reduce tax burden. Other measures may be tariff systems to cover capital expenditure, social, and environmental costs to maintain infrastructure and rational water supply on the island.

Supply Management - The improvement of technical efficiency of water supply through building codes and regulations to introduce high pressure jetting plumbing systems, dual pipe systems, metering, infiltration galleries, and cisterns, which can subsequently increase storage capacity, introduce water recycling for non-consumption uses, and manage saltwater intrusion and recharge of groundwater for consumption respectively to maintain water quality and supply on the island.

Externalities

Negative Externalities: A command and control policy to improve technical efficiency requires institutionalizing the design standards which does not take into account capacity constraints across different industrial sectors or applicability to the local context whereby these regions have the highest disparities between urban and rural water coverage (Zuniga-Teran, 2020). The costs for implementation lead to increased costs to households consequently leading to an increase in social costs as a result of maintenance, operation, and monitoring for the long run. If standards of technical efficiency are being met, there is no incentive to do better than the standard even if costs of implementing more innovative measures is negligible. Furthermore, there is a lack of incentive to improve technical efficiency and minimize groundwater use through demand management as a result of local cultural processes such as devotion to religion and traditions which limits people's capacity to diversify water usage (White, 2014). In addition, pricing mechanisms need to take into account differentiated social groups and associated uses for equitable management of water demand in introducing relevant prices which are limited by the lack of information and widening socio-economic gap between urban and rural population, with the burden falling disproportionately on low income households. Lack of centralized technical standards can lead to high transmission rates of coral sands which pollute groundwater by surface contamination and saltwater intrusion degrading water quality and increasing spread of waterborne diseases (White, 2014).

Positive Externalities: Improving technical efficiency in the sustainable management of water demand and supply would reduce pollution levels of limited freshwater sources, recharge groundwater aquifers, and improve public health due to decrease in water borne diseases. Furthermore, equitable pricing regimes can reduce social costs of those households with minimum and efficient use of water resources, improve public awareness, and integration of local sustainable water practices in the management system.

Constraints and Political Feasibility

The implementation of measures to improve water efficiency in Kiribati through an institutional approach is challenged by the fragmented institutional system. In order to implement supply management measures through dual pipe systems, pumping systems, infiltration galleries, and improving building regulations and leakage control etc. will require communication between various sectors such as the public utilities sector, land-use management, environmental management, economic industries, agencies responsible for sanitation, hygiene, and water consumption on the island, and local communities. However, their programs are rarely integrated with those of other organizations due to lack of sectoral communication, data monitoring and availability, land ownership, and outdated regulations limiting the implementation of an integrated water management approach on the island (Hophmayer-Tokich, 2006). In terms of managing water demand on this island, water governance is highly complex due to traditional cultural practices within the socio-political context of these island communities whereby standards discussed for implementation are parallel with modern instruments (Hophmayer-Tokich, 2006). Although these islands are currently experiencing increased urbanization, the distribution of water across rural and urban regions continues to be greatly skewed as a result of cultural preferences whereby rural communities prefer the taste and use of groundwater over other sources (White, 2014), geographical constraints that limit a centralized water coverage in the region, poor data, lack of public awareness of the need for water management. Hence, design standards may not be applicable to the local context.

Furthermore, developing an equitable pricing mechanism on the island for the operational management and maintenance of water supply is challenged by lack of human/technical capital and information on household water use. For example, existing sewerage tariff systems in Fiji do not cover proper operation and maintenance costs with the billing system declining in collection efficiency at 56% and 47% in Kiribati (Asian Development Bank, 2006, as cited in Hophmayer-Tokich, 2006). Although incentives to implement decentralized water management infrastructure such as rainwater catchment facilities and greywater recycling systems are more appealing to rural communities, the cost of implementation varies considerably due to location, materials used, and level of implementation. Since these systems are dependent on rainfall, water scarcity continues to be exacerbated due to extreme weather events such as droughts and hence households will likely need to support their freshwater needs through other sources as well and would need to work complementary to a disaster risk management program on the island. Although improving water efficiency may be more feasible through the leveraging of international funds and low technical operational management in comparison to alternative 1, regulations and highly variable costs of human/technical resources and implementation between urban and rural localities offset advantages and are unable to provide a continuous rationale supply of water which is still dependent on the limited freshwater resources on the island.

Assessing Constraints and Political Feasibility

Alternative 0: The TFadj (total adjusted feasibility score) value for alternative 0 is -1 which is highly negative and indicates the weakest political feasibility. The utility value for the status quo alternative is 0.23 which is lower in comparison to alternative 1. This is an undesirable alternative for Kiribati since as per a 'pseudo evaluation', the outcome of freshwater security for households is more desirable for the population than that of water insecurity.

Alternative 1: The TFadj value for alternative 1 is 0.6 which indicates a greater feasibility than alternative 0 and a slightly lower feasibility than alternative 2. This is due to the greater technical and human capital required to implement this alternative in comparison to alternative 2. However, this alternative has the highest utility function of 2.17 which guarantees the sustained availability of freshwater for rural and urban populations of Kiribati despite vulnerability to climate change.

Alternative 2: The TFadj value is 0.8 for alternative 2 which is closest to 1 and indicates a high political feasibility due to its low cost of implementation and technical operational management. However, the utility value evaluated by the multistakeholder analysis is more negative than the status quo with a value of -0.75. This is due to the high probability associated with 'movement from rural to urban communities' which is a negative attribute that has a strong negative effect on the utility function. In addition, the technical resources implemented to improve water efficiency would not be useful if freshwater resources are impacted by effects of climate change such as through saltwater intrusion or droughts, and hence, does not guarantee the sustained availability of freshwater.

Conclusions and Recommendations

Select Criteria or Decision Rules

Alternative selection, because it involves international actors, will involve an initial national-level decision followed by proposal to international funding bodies for funding. Selection criteria then depends on two factors: feasibility and utility (see Figure 2). Both of these functions were determined based on criteria sensed during the problem structuring phase, and how relevant stakeholders valued each outcome relevant to their own resources and opportunity costs. Costs have been integrated into utility and feasibility and are thus not explicitly stated here. Furthermore, because any selected alternative will be primarily funded by international actors (such as the World Bank, Asian Development Bank, Least Developed Climate Fund, etc.), their willingness to pay for each alternative was considered in the feasibility and utility analysis.

	Feasibility	Utility
Alternative 0: Status Quo	-1	0.23
Alternative 1: Desalination	0.6	2.17
Alternative 2: Water Usage Efficiency	0.8	-0.75

Figure 2: Feasibility and Utility Summary.

Conclusion and Recommendations

The utility of desalination technologies is significantly higher, and only slightly less feasible, than alternative 2 (water use efficiency technologies). The primary negative driver of feasibility for alternative 1 is cost, though this was accounted for in utility analysis. Additionally, precedent exists for external funding sources to bankroll water security projects in Kiribati at costs higher than what is estimated for bringing adequate desalination technologies to rural communities (. Furthermore, precedent exists for small-scale desalination technologies as the preferred method of water provision in rural areas (Boden & Subban, 2018). In addition, OXFAM's recommendation of these renewably-powered, small-scale desalination plants for rural areas provides "argumentation from authority" according to Dunn (Dunn, 2018). This is the preferred solution.

The status quo is undesirable for all parties. Water-borne diseases and infant mortality in Kiribati are far above the global average. Furthermore, without reliable water production, rural communities are heavily reliant on urban Kiribati resources and government as well as international aid. This alternative is not under consideration, as international fund sources have demonstrated willingness to pay for an alternative, the details of which are the purpose of this analysis.

Alternative 2 is desired by international fund sources, which have the greatest influence on utility and feasibility. This is because water efficiency technologies are lower cost in the short and long term. In addition, there is precedent for international funding of similar projects, including mangrove planting for freshwater retention, subsidized well digging, household water filters, and storage tank provision. However, because these projects do not address water provision in the event of increasingly common climate-change-driven drought and inundation events, their utility is markedly lower (see Appendix). Despite alternative 2's lower cost and higher feasibility, its low utility makes it undesirable for selection. This does not conflict with international fund interests, as humanitarian crises are likely to increase with climate change, meaning this more permanent solution will likely save them money in the long term.

Preferred Alternatives

Alternative 1, desalination technologies on all rural islands, is the recommended outcome. Despite higher upfront costs, it will save financing sources money by increasing rural autonomy and limiting increase of environmental damages in urban areas that would experience a population increase in the event a different alternative is chosen. These desalination technologies are described in Section IV.

Implementation Strategy

Phase 0: Apply for funding through Least Developed Countries Fund, Special Climate Change Fund, and Adaptation Fund (Global Environment Facility, 2021). The Kiribati government has done this before and been rewarded projects. Taking advantage of this relationship is key to success.

Phase 1: Siting and clearing of solar panels. Priority for placement is on government owned land to reduce conflict with landowners. Integration of the solar panels with existing island infrastructure is also a priority (placing them on existing structures). Community engagement and input on siting practices will begin and be maintained throughout the progressive phases.

Phase 2: Training of installation and maintenance personnel. The intent is a "train the trainers" program in which local residents are trained not only on desalination plant operation and maintenance, but also on training replacements and additional technicians. This limits ongoing costs by outside entities by creating a local base of knowledge. The cost of training is included in Section IV. In turn, this will provide rural residents with technical, high-paying jobs.

Phase 3: Installation. Initially constructed by outside contractors affiliated with funding sources, these facilities will be entirely maintained and operated by local residents. Continued support for troubleshooting and training is included in costs.

Plan for Monitoring and Evaluation

The monitoring and evaluation phase has two main measurable objectives: waterborne disease rate and daily household water availability. Initial monitoring will be completed by funding source affiliates to ensure functioning systems. Follow-on monitoring by government officials and reporting to funding agencies will be required under funding plans.

Secondary measures of success include rate of movement of citizens from rural to urban areas, reduced requests for aid during times of drought and saltwater inundation, and greater public utility capacity in urban areas.

In addition, environmental measures such as reef health and fish biomass will be of interest in the vicinity of brine outflows, though the magnitude of such flows is expected to have negligible impacts if plants are sited far enough from the reefs.

Limitations

The transition of traditional water sources to desalinated, deionized water may be a difficult one for rural residents when freshwater is not scarce. If communities are hesitant to adopt these technologies, the facilities may fail due to neglect, and then not function when needed (during drought, for example).

The amount of brine produced by these facilities is expected to be minimal. The outflow infrastructure, however, is limited or non-existent on rural islands. Outflows which are poorly sited or installed could result in localized environmental damages, especially for critical coral reef ecosystems. To minimize this externality, outflows should be sited outside of reef boundaries.

In addition, the installation, maintenance, and operation of these facilities places a burden on rural communities. These rural communities are experiencing water insecurity directly because of climate change. The communities did not contribute to climate change, but still bear disproportionate negative effects. This preferred policy solution solves a local problem but does not address the ongoing inequities associated with climate change impacts.

Appendix: Sample of Utility Calculations

	Step 4		Steps 5,6,7				Step 8	Step 9
			Rural Community Members					
	Outcomes	Attributes	Attribute value	Standardized value	Mean standardized value for all stakeholders	Sum of standardized mean values per outcome	Outcome probability	Utility of Outcome
	Job creation	Highly technical jobs created for plant	8	0.76	0.42		0.95	0.39
		Increased coral bleaching, loss of diversity	-9	-1.32	-1.27			-0.59
		Loss of land to desalination plant	-2	-0.46	-0.72	-3.03	0.47	
	Environmental Impacts	Decrease in nearshore fishing yields	-9	-1.32	-1.05			
Alternative #1: Desalination technologies		Increased desireability for living on outer islands	-2	-0.46	0.10	0.75	0.85	0.64
		Lower rates of waterborne diseases	10	1.00	1.14			
	Change in access to fresh water	Loss of cultural processes of water usage	-6	-0.95	-0.49			
	Freshwater production	Consistent freshwater availability in the	10	1.00	1.12		1.00	1.12
		Lessen impact of saltwater inundation	10	1.00	0.82			0.61
	Increased resiliency to climate change	Increased rural community autonomy	8	0.76	0.16	0.97	0.75	
				8.18			**Utility**	**2.17**

	Outcomes	Attributes	Attribute value	Standardized value	Mean standardized value for all	Sum of standardized	Outcome	Utility of
Alternative #0: Status Quo	Vulnerability to climate change	Freshwater threatened by SWI and	-9	1.15	0.77		1.00	0.77
		Increased waterborne illness	-10	-0.58	-0.54	-0.77		-0.54
	Increased migration to urban centers	Decreased sanitation	-10	-0.58	-0.24		0.70	0.00
				0.58			**Utility**	**0.23**

			Rural Community members					
	Outcomes	Attributes	Attribute value	Standardized value	Mean standardized value for all stakeholders	Sum of standardized mean values per outcome	Outcome probability	Utility of Outcome
Alternative #2: Improving Water Efficiency	Job creation	Technical jobs for monitoring	7	0.26	-0.13		0.95	-0.13
	Environmental Impacts	Reduce burden on groundwater aquifer	10	0.95	0.57		0.80	0.46
		Movement from rural to urban comm.	2	-0.90	-1.43	-0.58		-0.52
	Accessibility	Lower rates of waterborne diseases	10	0.95	0.85		0.90	0.00
	Water equity	Equitable pricing mechanism	0	-1.36	-0.67		1.00	-0.67
		Integrated water management (supply)	1	-1.13	-0.07	0.03	0.85	0.03
		Improved rainwater storage capacity	10	0.95	-0.14		0.90	
	Resilience	Water recycling for non consumption use	3	-0.67	0.24		0.80	
	Freshwater Production	Consistent freshwater availability in the	10	0.95	0.77		0.10	0.08
				4.34			**Utility**	**-0.75**

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