Technical and economic evaluation of an off-grid solar desalination system in Myanmar

Michelle A. Thompson, Rupesh Baker and Ng How Yong

ABSTRACT

Myanmar is a unique country where the majority of the people live in rural areas, away from grid electricity and reliable water supplies. The penetration of grid electricity in rural areas is minimal and even then it is often erratic. This paper focuses on the challenges of transitioning from an electricity-poor country to a renewable energy based-economy augmented with photovoltaics (PV). Based on optimization modelling and assessments of Myanmar's current energy barriers, we examine the feasibility of PV-powered desalination systems for the Ayeyarwady region and Tanintharyi region. An analysis of the technical and economic feasibility of a stand-alone solar-powered desalination system indicates that the needed price of water for economic sustainability should be approximately US$0.0224/litre. From our economic modelling, we found that the major capital cost is the installation of PV and maintenance. The major operating cost is maintenance of batteries. Minor operating costs are membrane replacement and PV maintenance. The country's limited capital inhibits the creation of these systems, and foreign investment or incentives from international financial institutions will be needed to secure off-grid, clean energy solutions for Myanmar.

Key words | financial modelling, renewable energies, seawater desalination, solar energy

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INTRODUCTION

Lack of sufficient and clean water affects about 700 million people worldwide. Population growth, droughts, and increased water contamination have led to global water scarcity. By 2025, nearly two-thirds of the global population will be affected by water issues (United Nations 2014).

The Republic of the Union of Myanmar, previously known as Burma, is the second largest country in Southeast Asia, having a population of approximately 60 million, with >70% living in rural areas. Myanmar is bordered to the north and north-east by China, to the east and south-east by Laos and Thailand, to the south by the Andaman Sea and the Bay of Bengal, and to the west by Bangladesh and India. It ranks as one of the least developed countries by United Nations criteria (Sakai 2013). Myanmar has an estimated poverty level of 26%, although the poverty level is twice as high in rural areas. Myanmar is endowed with an adequate water supply and has 2,234 km of uninterrupted coastline along the Bay of Bengal and the Andaman Sea (Water Environment Partnership in Asia 2014). Its monsoon seasons provide an abundant source of water; however, water scarcity still challenges the country and the Ayeyarwady and Tanintharyi regions are susceptible to monsoons and flooding.

Although Myanmar has access to ten river basins, the increase in population and growing need for water for economic purposes has placed pressure on surface water and groundwater extraction. Myanmar relies heavily on hydropower for most of its electricity generation. The electricity sector fails to meet the country's needs, with about 49% of the total population and only 29% of the rural population having access to electricity in 2011, according to IEA estimates (World Economic Forum 2013; Reuters 2014). Furthermore, outdated power plants and poor electricity transmission infrastructure cause severe power shortages.

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Consequently, natural resources (wood, charcoal, manure, and crop residues) are widely utilized and account for about two-thirds of the country's primary energy consumption (US Energy Information Administration 2014).

OVERVIEW OF DESALINATION

Desalination is a viable solution for the coastal areas of Myanmar because of the abundant supply of brackish water and seawater, and the ability to dispose of brine in coastal waters. As a result, over the past decade, desalination has become increasingly popular in many water-stressed areas (Schiermeier 2008). However, oceans and brackish groundwater have salinity levels >30,000 mg/L total dissolved solids and the World Health Organization (WHO) standards for drinking water require <1,000 mg/L (World Health Organization 2011).

Desalination techniques include multi-stage flash, multiple effect evaporation (MEE), vapour compression (VC), reverse osmosis (RO), ion exchange, electrodialysis (ED), phase exchange, and solvent extraction. In the early stages of their development, desalination plants relied primarily on thermal energy, which heats seawater and then condenses the vapour to produce fresh water. However, advances in membrane technology have made RO the preferred choice for desalination operations, because it is less energy-intensive than thermal desalination (Ettouney *et al.* 2002). Thermal processes such as MEE, VC, and ED have not been considered for this paper. Thus, the focus of this paper is on RO desalination plants that derive part of their electric energy from photovoltaic (PV) cells. Besides wind, solar-powered desalination is the most common renewable energy conversion method used to produce potable water. For a sustainable water supply, solar power provides a solution that does not produce carbon emissions and is becoming increasingly economically viable.

Desalination coupled with solar energy reduces the dependence on fossil fuels considerably. Thus, it is a promising solution for supplying fresh water to remote arid areas with high solar irradiance and low electrical grid connectivity. The lack of stable electricity has left over two-thirds of the country with intermittent power outages and without access to electricity (World Economic Forum 2013).

Solar energy is a clean, cost-efficient, and renewable source of energy. Additionally, solar energy provides various benefits to the environment and economy such as reducing carbon emissions, climate change mitigation, and reducing air and ground pollution. Although solar-assisted desalination has its environmental challenges, it may serve to mitigate carbon dioxide emissions, while providing clean water to rural villages. Additional sources of water are needed, and a common way of providing additional water supplies is through ultrafiltration or RO desalination. However, desalination is usually the last option for water purification since it requires a large amount of energy, with an estimated range from $1.57 to $3.55 per m^3; this varies by the type of feedwater, type of energy used, and daily capacity (Karagiannis & Soldatos 2008).

The cost of solar panels has declined substantially over the past 5 years, and energy can be stored for use during cloudy days. Thus, it is a promising solution for supplying fresh water to remote areas with high solar irradiance. This paper analyses the feasibility of solar desalination for Myanmar's Ayeyarwady and Tanintharyi regions. An economic and technical analysis is provided using parameters suitable for Myanmar.

MODELLING ASSUMPTIONS

Several sources of social, economic, and governmental data were used to build the economic model and identify the key parameters for the hypothetical desalination plant. Numerous data sources were utilized for this study, including textbooks, databases, governmental sources, and country-specific websites. Various desalination reports were used to develop a solar desalination plant for the Ayeyarwady and Tanintharyi regions using existing costs for desalination equipment, solar energy systems, and storage solutions available on the market. Although the proposed plant is based in Myanmar, variable ranges of capital and operational costs were considered to broaden the model's applicability.

Key parameters of the model are as follows:

- *Salinity*. A lower feed salinity allows for higher conversion rates and increased production. For the case study, the salinity of seawater in Myanmar was assumed to be 35,000 mg/L.

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- *Product*. The permeate (effluent) is expected to be within the standards of the WHO.
- *Plant capacity*. The plant will operate at a capacity factor of 0.85; it will thus produce 16,000 litres per day.
- *Energy requirement*. The desalination equipment consumes approximately 143 kWh/day, while auxiliary consumption is estimated to be 5 kWh/day. Hence, the daily consumption is approximately 148 kWh/day or 54 MWh per year.
- *Storage*. The system is designed to be off-grid, with 3 days' product water storage.
- Water is distributed using mobile units such as tanker trucks and containers transported by people in remote communities, so there are no costs for pipes or distribution infrastructure to be taken into consideration.
- The power storage system used is designed to cover 3 days of autonomy, which is defined as the number of days the system can operate when there is no power from the PV panels. Lead acid batteries would be used, as they are considered more durable over the 20-year plant life.

SYSTEM DESIGN

Figure 1 shows an overview of the desalination plant operation. The proposed system consists of desalination equipment powered by solar panels, and has sufficient battery storage to ensure that the system can operate for 3 days during cloud cover or other adverse weather conditions.

The solar panels proposed for the system are monocrystalline modules, which will be primarily mounted on the rooftop of the main building containing the desalination equipment, with the rest on the ground. The inverters and batteries were in the main building as well. Deep cycle flooded lead acid battery cells with a capacity of 820 Ah and 6 V will be used while the system voltage is 24 V.

CAPITAL EXPENDITURE

The capital costs of the desalination plant are shown in Table 1.

Construction and permits

The proposed solar desalination system requires an area of approximately 440 m^2. This will include one main building which houses the desalination equipment, inverters, batteries and a computer for data transfer or communication. The building is estimated to have a built area of 220 m^2, and the remaining area will contain installed solar panels. The cost of land is estimated to be in a range of \$10–13/m^2 (Reuters 2014). It was assumed that the average building construction cost for the structure only was \$321/m^2 (Invest Myanmar 2013).

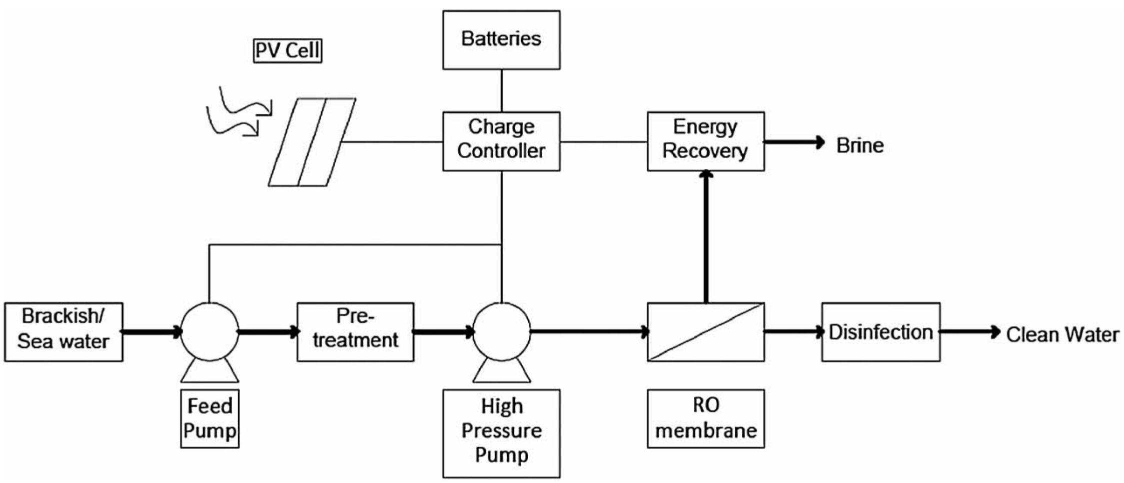

Figure 1 | Solar desalination flow diagram.

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Table 1 | Capital costs of the system

Capital expenditure

Category	Item	Parameterization	Cost (US$)
RO system	Construction costs	Function of plant size and cost of land	76,000
	Pretreatment	Function of pretreatment disinfection and membrane filtration	10,000
	Intake	Estimated at 5–20% construction costs	16,000
	Discharge	Estimated at 5–15% construction costs	8,000
	RO system equipment	Function of membrane filtration, pumps, steel welded pipe, pumping station building, and storage tank	80,000
PV with storage	Installation costs	Function of cost of solar system components per kW_p	327,000
Total			517,000

Distribution

The distribution system consists of an interconnected series of pipes, storage facilities, and components that convey desalinated water to the end user. However, for Ayeyarwady and Tanintharyi regions we assume that water will be distributed through mobile units such as tanker trucks and containers that people in those communities manually transport. Due to the undeveloped infrastructure, we excluded piping to avoid a distribution network that would need routine maintenance. The costs for distribution and infrastructure were excluded. If the desalination system is further away from the coast, costs for trucks, carts, animals, maintenance, and containers could be estimated (Jagals & Rietveld 2011).

RO system equipment

Ampac USA is a seawater desalination manufacturing company that provides a fully functional RO treatment system. A compact seawater desalination unit was the basis for the calculations. The system includes a feed pump, high pressure pump, safety stainless steel relief valve, high rejection RO membranes, dual stage micron filtration, product diversion valve, and remineralizing filter. Maximum production is rated at 19,000 litres per day with a power requirement of 460 V. The model is based on the price of Ampac Unit SW5000-BX with a retail price of US$29,000–34,000 (https://www.ampac1.com/).

Photovoltaic installation and storage

The hypothetical desalination system would be in a remote location and hence completely solar powered, with storage available for operation at night and times of reduced irradiance. As the equipment is expected to effectively run 24 hours a day for the entire year (apart from maintenance), the different items of equipment that use electricity were identified and total consumption for the year was estimated.

The solar desalination equipment requires 7 kW power, while other auxiliary equipment like computers and lights consume approximately 5.4 kW. Using these figures, the total energy requirement of the desalination system was approximately 62.8 MWh per year. The annual solar irradiation of Yangon, formerly Rangoon, was found to be 1,665 W/m^2/year, and this was used as the base to estimate the amount of energy a well-designed PV system can generate. Considering that the solar panels undergo a mean annual degradation of 0.8% (Jordan & Kurtz 2012), the system was increased in capacity by 30% to compensate for this degradation. Hence, the system size was found to be 61.41 kWp (kilowatt peak, a value that specifies the output power achieved by a solar module under full solar irradiation). Assuming that 260 Wp polycrystalline panels are used in the project, the total required area was calculated to be 461 m^2. The cost for installation of solar PV systems in Myanmar was found to be $3.00/Wp and hence the total system cost was calculated to be $184,220.

The storage system used for the solar desalination system is expected to have 3 days of autonomy, which is the number of days needed for the system to operate when there is no power produced by the PV panels. The technology for the

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batteries used would be lead acid as they are considered to be more durable over the course of 20 years, which is the time period that was assumed in the financial calculations. The battery that was selected for this purpose was Rolls Surrette Battery 8 Volt 820 AH 6-CS-25PS (http://rollsbattery.com/). The battery bank capacity that was calculated based on the total energy required and the days of autonomy was found to be 172.8 kWh, which would lead to 26 batteries used on site for the system. Based on the costs of individual batteries, the total capital expenditure for storage was found to be $38,259.

OPERATING EXPENDITURES (OPEX)

Table 2 lists the annual operational expenditures for the desalination plant. These values are a result of our proposed model. Assuming that one operator is required for two shifts per day and they are paid at three times the minimum wage of $2.80/day (Reuters 2015), the labour cost for the plant is $500/month, excluding benefits and other allowances.

Pretreatment and membrane replacement

Membrane degradation is a natural process that occurs over 2–5 years, incurring additional costs for membrane replacement. The rate of degradation increases if the feed-water is not pre-treated for de-chlorination. Assuming a year-round operation would produce 28,000,000 m^3 of water per year, the cost of membrane replacement is about $1,100 and is assumed to be replaced every 3 years (Elimelech & Phillip 2001).

Brine disposal

Residuals management costs are largely affected by the type of effluent produced post-desalination and the steps needed to treat and dispose of it (Schiermeier 2008). According to the WHO, 90% of such projects dispose of the effluent directly into the ocean via outfalls (Water Research Foundation 2010). The most direct complication results from possible shoreline impacts, such as high salt concentration in the marine ecosystems. However, ensuring full marine safety leads to increased disposal costs typically exceeding 30% of total desalination plant expenditures (Water Research Foundation & Arsenic Water Technology Partnership 2010). Using existing diffusers, as used for power plant discharges, can reduce brine disposal costs. In this model, disposal costs were a function of discharge location and salinity concentration.

Photovoltaics and storage costs

PV systems are considered to have very low maintenance costs due to the lower number of moving parts. Hence, the total operation and maintenance (O&M) cost was estimated as a factor of the total capital cost. As the system will be in a comparatively remote region, this could increase the O&M costs. Hence, as a conservative estimate $18/kWp was used for the financial analysis. The O&M costs related to storage were considered to be minimal; however it was assumed that the batteries will be replaced every 5 years.

Table 2 | Annual operational costs of system (in US$)

Operational expenditure

Category	Items	Parameterization	Cost (US$ pa)
RO system	Maintenance (pre-, equipment, post-, building, electrical)	15% of capital cost	15,000
	Labour	Function of wages cost	9,000
	Membrane replacement	Function of membrane replacement cost and plant capacity	6,000
	Residuals management	Function of plant capacity and water salinity	7,000
PV with storage	O&M of PV system	Includes cleaning and corrective maintenance	1,000
	Operation and maintenance of batteries	10% of capital cost	17,400
Total			55,400

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Labour costs

The specific cost of individual O&M positions to run an RO plant falls outside the scope of this solar-assisted desalination model. Assuming a minimum number of required personnel, the estimated labour cost for the model plant was based on two operators working at $400/month and six supporting staff at $100/month (International Development Group Building & Construction Authority 2013; Reuters 2015). These estimates exclude benefits and other allowances.

DISCUSSION

The financial analysis was performed assuming a situation of 100% equity, as the cost of capital could be very specific to an entity in order to calculate the internal rate of return (IRR). The parameter used to measure the profitability of the project was chosen to be IRR and from the financial analysis it was found that the project will have an IRR range of 11.9–16.8% if the water produced is sold at $0.015–0.03 per litre (Invest Myanmar 2013) which is a fraction of the current price of between $0.12 and $0.22 (GIZ 2014). The financial analysis included a sensitivity analysis based on the parameters which were considered to be crucial in the calculations. The financial viability is most sensitive to the changes in selling prices of water, followed by the changes to the PV system cost. It was determined that the minimum hurdle rate for this project would need to be 13–15% due to political and currency risk. In order for the IRR to be less than the hurdle rate, the price of solar desalinated water should be $0.0224/litre. This is relatively cheap compared with the current price of water of $0.12–0.22/litre (GIZ 2014).

While this model serves to detail the basic framework of desalination operation and production, many economic, construction, environmental, and planning factors remain uncertain. As rural villages in Myanmar rely heavily on agriculture and mining for their income, demand for fresh water is expected to increase, further hampering traditional sources.

Additionally, the demand for solar desalination could potentially create a market for PV panels. Ultimately, this market could create jobs and increase Myanmar's economic activity and performance, while decreasing dependence on natural resources for energy consumption. As of 2014, Myanmar has a grid emission factor of 0.7134 (tCO_2/MWh) (Institute for Global Environmental Strategies 2014). It was calculated that the carbon dioxide reduced with a solar desalination plant would be about 44 tCO_2.

A fundamental question is: how will the people of Myanmar afford a financially viable solar desalination plant? In order for the plant to be affordable, a collaborative effort would need to be made by the government, international aid organizations, grants, and donors. A potential challenge is the high interest rate the project loan may be given due to political and currency instability in Myanmar. However, the World Bank or Asian Development Bank (ADB) may be able to reduce the risky investment cost. Despite the growing awareness of using renewables to ameliorate energy demands, there are inevitable hurdles with renewable energy adoption. The most obvious is the argument that fossil fuel-sourced energy provides a cheaper option in some cases, while renewables may have high start-up costs with no long-term commitment.

CONCLUSION

This model details the economic issues of desalination, while many economic, construction, environmental, and planning factors remain uncertain. Water availability strongly correlates to food production and industrial output. As rural villages in Myanmar rely heavily on agriculture and mining for their income, the demand for fresh water will increase, placing further constraints on traditional sources.

Myanmar has a lack of basic infrastructure and limited access to social services. The characteristics and constraints for this model include intermittent power, high solar irradiance, close village density, and high precipitation. From the analysis, it was concluded that the price of water should be approximately US$0.0224/litre in order to ensure that the project is profitable. However, it is important to understand that the cost of water can be further reduced with the reduction in cost of the PV system and storage, which

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would ensure that clean water is available at an affordable price to the rural villages of Myanmar.

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