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The feasibility of Atmospheric Water Generators on small tropical islands - A case study on Koh Rong Sanloem, Cambodia

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Affidavit

I, **TIZIANO ALESSANDRI, BA BA**, hereby declare

1. that I am the sole author of the present Master's Thesis, "THE FEASIBILITY OF ATMOSPHERIC WATER GENERATORS ON SMALL TROPICAL ISLANDS - A CASE STUDY ON KOH RONG SANLOEM, CAMBODIA", 70 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

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Abstract

Water scarcity is an increasing global issue and the need for clean drinking water is set to increase with a growing global population and the effects of climate change. Small tropical islands, when not having a natural spring, cannot rely on groundwater since the freshwater lenses are merely a very thin layer, floating above the underlying seawater. Due to changes in in sea level as an effect of climate change, these lenses are predicted to further decrease. Often the only source of drinking water on small islands is importing it in bottled form. This is not only inefficient in terms of energy footprint and price, but also creates a waste problem that these islands usually fail to adequately address.

Instead of relying on groundwater, one could harvest the water needed straight from the air: Atmospheric Water Generation seems to be a viable solution when considering atmospheric conditions and spatial constraints on small tropical islands. This however requires quite some energy and when thinking of the fragile ecosystems small islands are, a clean energy source would be favourable – avoiding the environmental burdens diesel generators bring as well as being independent from the volatile oil market.

Finally, when thinking of tourism, a way of providing water in hygienic and acceptable manner is also an aspect that must be considered.

Therefore, this thesis combines these thoughts and showcases four different models of Atmospheric Water Generation: first as a standalone project, second including the option of a sustainable bottling system, third including a Photovoltaic plant to power the water generation in a sustainable manner and lastly including the bottling system and the photovoltaic plant, for a holistic approach.

Throughout a Profit and Loss Analysis it is shown that all four models would not only improve the water situation, but also offer high returns for possible investors. The aim of this thesis is essentially to create an incentive not only for governments to reduce water scarcity and improve the waste situation in such an island setting, but also show that the private sector can make a profit here and in doing so help small tropical islands become more sustainable.

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List of abbreviations

AWG	Atmospheric Water Generator
$BaSO_4$	Barium Sulphate
BPA	Bisphenol A
CAPEX	Capital Expenditures
CH_2O	Formaldehyde
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DSCR	Debt Service Coverage Ratio
EAT	Earnings After Taxes
EBT	Earnings Before Taxes
EBIT	Earnings Before Interest and Taxes
EBITDA	Earnings Before Interest, Taxes, Depreciation and Amortization
GHG	Greenhouse Gas
KHR	Cambodian Riel
kW	Kilowatt
kWh	Kilowatt hours
kWp	Kilowattpeak
LHC	Large Holding Company
MW	Megawatt
MWh	Megawatt hours
MWp	Megawattpeak
NO_x	Nitrogen Oxides
O & M	Operations and Maintenance

PAHs	Polycyclic Aromatic Hydrocarbons
PET	Polyethylenterephthalat
PM	Particle Matter
PV	Photovoltaic
TiO_2	Titanium Dioxide
USD	US Dollar
UV	Ultraviolet

1. Introduction

It has been thoroughly established in the last couple of years that in order to survive and thrive on this planet, we must not only reduce emissions of pollutants, but rethink society and its processes as a whole. Development must be achieved in such a manner, that makes progress sustainable in the long term. There are of course a plethora of approaches to this end, and one must concentrate on a small niche which to change and/or describe.

In the thesis beforehand, I will thus focus on the key sector of sustainable water production on small tropical islands, accompanied by a transition to 100% renewable energy for its production (Pröstler, 2014; Lim, 2017; Mathiesen et al., 2011; Meza et al., 2019; Ngjeqari, 2018; Pölzl, 2019).

The setting I will focus on in the course of this thesis is that of tropical islands, with a focus on Koh Rong in Cambodia as an example for the thousands of similar islands worldwide. One of the major problems on many such small islands is the unavailability of clean drinking water, which must therefore be shipped to the island – which in turn is costly and creates an additional waste problem. Often this dilemma is created by the reliance on tourism as main source of income. When thinking about drinking water in tourism, one must take into account that especially in countries like Cambodia, where there is a realistic threat of contracting diseases like Hepatitis through drinking water (Sreng et al., 2016), most tourists prefer tightly sealed bottles of water. So when wanting to supply drinking water one must be able to provide it in sealed containments. Another problem that is posed by local water generation is the relatively high energy demand that this entails.

Human societies are strongly dependent on energy and practically every region of the world needs an individually tailored approach towards its energy generation. It has by now become clear, that fossil fuels are not the answer. But also when it comes to renewable energy sources, not every type is well suited for every location.

The situation on the island of Koh Rong Sanloem has been deteriorating over the past several years. Tourism being the island's main source of income, energy demand has soared with the rising number of resorts and lodges. However, since no direct connection to the energy grid exists, this has been provided via a growing number of Diesel generators. This does not only annoy locals and tourists alike, but also has detrimental effects on human health and the environment in terms of leaking gasoline, air pollution and noise pollution.

Luckily on this specific island there is already a project underway concerning a photovoltaic plant for clean energy generation (“New Solar Power Station on Koh Rong Samloem,” 2021). The installation of this plant is supervised by Total Solar Distributed Generation (DG) and will presumably be a 1.25 MW Photovoltaic plant. If completed, this project would ensure a significant amount of clean energy for the island.

A viable solution to one of the other main problems, which many secluded rural areas and islands face – that of available drinking water – thus could be pulled from thin air: “The Atmospheric Water Generator (AWG) is one of the alternative solution[s] for fresh water recovery from [the] atmosphere“ (Suryaningsih and Nurhilal, 2016). In this procedure, the local humidity is directly condensed and further refined to drinkable water. In optimal cases, large mobile Atmospheric Water Generators can generate around 10.000 litres of drinking water daily (“PHANTOR-Technical-datasheet,” 2020). In the case of Koh Rong Sanloem, where there are more than 100 resorts, this water would be highly appreciated. This Thesis will therefore calculate roughly how much water is needed, show what the price of a litre of water currently is on the island and compare this to a possible price water produced via an AWG could be sold at. Would it be feasible? And how long would it take to cover the expenses? How much waste could be avoided? These questions will hopefully be answered within this thesis.

The scope of this Master‘s Thesis will be a case study of the situation on Koh Rong Sanloem, focusing on analysing the costs and benefits of generating drinking water locally via an AWG (instead of importing it). Further it will analyse the impact of an installed Photovoltaic plant and a bottling line and the benefits the implementation of these facilities could have.

Also, awareness for the growing need and demand for clean water and the laws that must accompany this process are growing (“Ministry floats new law for clean water management,” 2020). This could mean that eventual government support, such as would be needed for the transportation part addressed later in this thesis, or simply for financing, can be seen as likely.

Since tourism is so important on many tropical islands, preservation of nature, both terrestrial and aquatic, is a cornerstone of these destination's future. If development can be achieved in a sustainable manner, minimizing the negative impact on the environment, while enabling and empowering the local population through autarky (resource-wise), tropical islands can, according to the assumption of this Thesis, thrive both economically and as ecosystems. On the other hand, if such a project would be implemented not from a communal side but from private investors, a profit can be made, as this thesis will show.

1.1 Objective

The objective of this thesis will be to find out how much the installation of an AWG would cost on the island of Koh Rong Sanloem as an example for a tropical island setting, how much a litre of water could be sold at (and thus how much cheaper it would be than importing it in bottled form) and what the ecological benefits would be. If the outcome of this project proves to be positive, one could implement similar facilities on other tropical islands worldwide. The thesis should serve as guide for potential investors or communities worldwide in similar settings to implement such projects, thus reducing the burden of plastic waste and decreasing water scarcity.

1.2 Hypothesis

Installing an AWG will in the long run reduce the economic costs of the population on the island concerning water consumption, as well as drastically lower the ecological burden on the environment which occurs in terms of emissions and plastic waste, since on many of these islands there is no waste disposal system in place, which only leaves inhabitants to burn their waste in the open. With the installation of an AWG one could provide a cheaper alternative and even make a profit as supplier. Essentially, this could be a business model.

1.3 Part I: Background

The first part of this thesis will briefly cover all relevant topics and pave the way for the case study in the second part. From more general issues such as water scarcity, waste or the SDGs to more specific fields like the different kinds of water generation and their advantages and disadvantages will be thematised.

1.4 Part II: Case Study

The case study in the second part of this thesis will be based on reference values from literature as well as data provided by the AWG producer Imhotep.Industries GmbH, concerning average local temperature and humidity (the closest available dataset is from a weather station 90km from the island, but should be fairly consistent with actual values on the island) based on the year 2020. Due to the Covid Pandemic, an in-depth field research (including interviews with locals concerning willingness to buy locally produced drinking water, actual tourist numbers in high and low season to determine the maximum and minimum demand of drinking water needed, as well as to exactly determine the waste situation created by plastic bottles) was not possible, these values had to be roughly estimated and based on similar research. Also, since not being able to directly research prices of bottled water on the mainland and on the island as well as the price of electricity, this information was kindly provided by my supervisor Dipl. Ing. Dr. Mario Ortner, who runs a PV plant on the neighbouring Island of Koh Rong and has staff on site which could supply some basic information. All the estimations due to unavailability of exact information were done based on similar islands (such as the neighbouring island), relevant literature and expert opinions. The aim of this case study will be to provide an example of atmospheric water generation on small tropical islands and showcase the profit that could be made within four different models of implementation as well as indicate some of the difficulties that could occur. Optimally, this could be used as guide when planning a similar project and thus increase water security in remote places, reduce waste and even provide an opportunity for investors.

PART I: BACKGROUND

2. The importance of water

To put it simply, water is the most basic resource needed for human (or any form of) life on our planet. On a chemical level, water is essential to carbon-based life due to the physical and chemical properties that makes it, in combination with carbon molecules, an optimal compound-solvent pair. Not only is this combination optimal for life on earth, but would probably be the most common basis for life in the universe (Westall and Brack, 2018). Coming back to earth though, we humans are reliant on water not only for the most basic consumption to keep hydrated, but also to cook, wash our clothing, remove waste from our households (be it washing dishes or flushing the toilet) and production of all sorts of consumer goods. Basically, without water, neither human societies nor humans themselves would exist.

Historically, the idea that water is a scarce resource is relatively young. Just as the oceans had been seemingly endless and waste could be dumped into them, fishes could be fished endlessly from them, so have rivers and lakes been polluted continuously. With an increasing global population however, there arise more and more problems from heavy water use by the industry as well as from urban pollution. This has resulted in increasing complications concerning availability of clean drinking water. According to the World Health Organization, in 2017 roughly 2.2 billion people had no access to safely managed drinking water services (World Health Organization, 2019a). This means that these people are either exposed to health risks arising from unsafe drinking water, or that they are reliant on bottled water, whereas these (usually plastic) bottles will probably end up in the environment – assuming that the places with unsafe drinking water also lack the infrastructure for proper waste disposal or recycling. From this one can gather that there is a huge need (and therefore also a huge market, if one chooses to think economically) for clean drinking water.

The health risks of contaminated drinking water include diseases like cholera, diarrhoea, dysentery, hepatitis, typhoid, and polio (ibid). Further, when supplying clean drinking water from a safe and stable source, people spend less time on water collection and less money on health issues, increasing overall economic capabilities. And while the economic aspect is certainly not the most pressing here, it can be viewed as incentive (also for the private sector) to improve water quality from a purely monetary perspective, considering lack of a thriving economy in many of these countries. Therefore, one could generalize that having clean drinking water available to a population brings multisectoral advantages and should be prioritized when developing an area.

3. Water Scarcity

Since the setting of this thesis is on tropical islands, one must consider that these, due to their size and elevation, tend not to have surface water “in exploitable form” (Máñez et al., 2012, p. 74) and are thus usually rather short on freshwater. Therefore, one must also thematize the problem of water scarcity. But what exactly is scarcity in relation to water? A scientific approach commenced nearly fifty years ago, when Falkenmark and Lindh (1974) started linking water resources to population and pollution to estimate future needs for clean water. Closely thereafter, the so-called Water Stress Index (WSI) was developed to link food security to freshwater availability (Falkenmark, 1986). This index defines water scarcity by how many people share the same water source, competing for a flow unit of water (10^6 m^3 of water per year). These measures, among other developments, started a global consciousness concerning drinking water availability (Damkjaer and Taylor, 2017). The context at the time were African famines, but the awareness of the urgency of the problem have remained.

Over the last couple of years there has even been an increase in awareness concerning global water scarcity in many (usually developed) countries. Especially when considering an ever-increasing world population and the fact that places were population numbers are strongly rising tend to be the ones with less available freshwater per capita (Sophocleous, 2004). Therefore, it will be paramount to manage these sources effectively and find new ways of generating water in order to sustain agricultural and basic needs. Especially on small tropical islands the limitations are severe as will be shown in the next section.

However, as Máñez points out, water scarcity can not only be defined as physical unavailability of water but can also include socio-economic factors. Therefore, while the physical restrictions are quite straightforward, economic water scarcity can mean that the cost of providing an adequate water supply are prohibitively high, which can be a result of a mismanagement of water resources (ibid.). And this in turn is affected by the social perception of local water scarcity, historically formed norms and standards towards water use, etc. Insofar, one could also argue that to reduce water scarcity in an area (in our case the constrained space of an island), a simple way to improve the availability of water would be to change the inhabitants´ perception concerning how and for what water is used (e.g. not wasted unnecessarily). This form of education should therefore also be prioritized (especially considering the far lower cost compared to technologically sophisticated water generation systems) when developing a regional plan to combat water scarcity.

A study on water scarcity in Asia and the Pacific (Stocker, 2009) also found that in Cambodia the general water consumption was extremely low and that average per capita GDP would not suffice for effective management of water resources. Although no data is available for the island of Koh Rong Sanloem, where the case study of this thesis will be situated, these facts are assumed to hold nevertheless. Since the capital and know-how for water management is often unavailable in such places, projects such as the one discussed in this thesis could prove helpful.

3.1 Water scarcity on tropical islands

In this section I will now focus on the main reasons for water scarcity on tropical islands and what environmental and societal effects can influence this.

While water availability can pose a problem in all kinds of locations, tropical islands face many major challenges, which are even assumed to increase in the future (Suroso et al., 2009, cited in Máñez et al., 2012, p. 75). But first, what is the usual situation on small islands? According to Máñez et al. (2012, pp. 74–75):

“Groundwater appears as a thin lens of freshwater floating over sea water in coral sand and limestone aquifers […] on islands above a size of approximately 1.5 ha […]. There is no sharp boundary between the lens and the underlying

seawater. The lower boundary is a wide transition or mixing zone where groundwater salinity increases with depth from freshwater to seawater […].”

The less dense freshwater (usually from rain) floats on top of the denser saline ocean water “that permeates the porous geological substructure of the island, resulting in stratification, and the development of freshwater lenses” (Gössling, 2001, p. 181). Considering the usually low elevation of these islands, these circumstances contribute to a relative (physical) scarcity of freshwater. While the already relatively bad conditions for the formation of sufficient amounts of freshwater lenses (when considering increasing use of freshwater from the increasing population and – especially – the increasing tourism sector on tropical islands), climate change and the threats it poses lead to a worsening situation on islands. The predicted increases in rainfall combined with a decrease in rainy days are expected to create a situation in which droughts as well as flash-floods are favoured. This in turn will put even more stress on freshwater reservoirs. Further, “Accelerated coastal erosion, storm surges and sea level rise are supposed to cause saline intrusion into freshwater lenses […]“ (ibid.), impacting the quality and useability of the water.

3.2 Scarcity of drinking water (even with an abundance of water)

A different problem can be posed by the quality of water. In some instances, there is plenty of water around to think that water scarcity should not be an issue. However, the quality of this water can have deteriorated so far (be it by environmental or anthropogenic influences), that the water present is essentially unfit for consumption and water scarcity arises in the middle of an abundance of water. For example, Zeng et al. (2013) investigate water scarcity and criticize that this assessment is mostly based on quantity and does not include quality. This is clearly valid for vulnerable ecosystems (in terms of water) such as small tropical islands. The thin freshwater lenses that are often the only source of drinking water except for collected rainwater are increasingly contaminated by anthropogenic pollution or rising sea levels due to climate change.

4. Drinking water quality

The WHO provides a 631-page guideline concerning the recommendation for "managing the risk from hazards that may compromise the safety of drinking-water" (World Health Organization, 2017, p. 1). Essentially (but not officially) a standard is set for a minimum quality drinking water must have, while acknowledging that a higher quality might be needed for certain uses. But in general, "the Guidelines describe reasonable minimum requirements of safe practice to protect the health of consumers and derive numerical 'guideline values' for constituents of water or indicators of water quality" (ibid., p. 2). While the WHO guidelines focus on what is not (or only up to a certain level) allowed to be in drinking water, a study different study shows the detrimental effects of low mineral intake on health caused by mineral-poor water generated by reverse-osmosis (Huang et al., 2018). When generating water by desalination or using other procedures from the atmosphere, essentially what one ends up with is a kind of distilled water. Now one might be tempted to think that the purer the water one consumes, the better. But relying on pure H_2O is far from optimal.

Kozisek (2005, p. 148) investigates the adverse health effects of demineralised water, which can range from:

- Direct effects on the intestinal mucous membrane, metabolism and mineral homeostasis or other body functions.
- Little or no intake of calcium and magnesium from low-mineral water.
- Low intake of other essential elements and microelements.
- Loss of calcium, magnesium and other essential elements in prepared food.
- Possible increased dietary intake of toxic metals.

(Kozisek, 2005)

The study further concludes that the ingestion of distilled water forces the body to add electrolytes, which are in the process depleted from the body's reserves of dissolved salts in the body water. This may result in compromised organs and symptoms such as tiredness, weakness and headache (ibid, p. 152).

Therefore, when generating water, be it by desalination, fog harvesting or atmospheric water generation, it is crucial that when intended for human (or even animal) consumption the water is first mineralised. Some of the recommended thresholds thus include a minimum of 10 mg/L magnesium, 20 mg/L calcium and "for total water hardness, the sum of calcium and magnesium should be 2 to 4 mmol/L" (ibid, p. 156-157).

5. Microplastic in bottled water

Despite plastic being increasingly present in everyday life, from food and beverage packaging to medicinal devices, there is increasing awareness of microplastic and the health risks associated to it. There are two dimensions of possible health risks the WHO associates with microplastics: particles and chemicals on the one hand and biofilms on the other. While biofilms that can form around microplastic are more relevant for particles in pipes etc, these usually do not occur in bottled water since it is sterilised before filling. Also, although biofilms can act as vectors for "harmful organisms including enteric viruses and protozoa" (World Health Organization, 2019b, p. 45), "most microorganisms found in biofilms are believed to be primarily non-pathogenic" (ibid., p. 44).

A more significant health risk however is posed by particles and chemicals related to microplastics. Humans ingest a large variety of particles which consist of a plethora of different substances. The toxicity however depends on shape, size, surface or chemical composition of the particles. There is unfortunately a lack in research concerning ingested particles, including microplastics. "To date, most toxicological tests of microplastics have focused on aquatic organisms or ecotoxicology. No epidemiological or human studies on ingested microplastics have been identified" (ibid., p. 27). Therefore, when following the WHO information, it is not sure to which extent microplastics will cause harm to the human body and more research is definitely needed.

Recent studies, on the other hand, have shown that there is the possibility of Bisphenol A (BPA) leaching from plastic containers into beverages, and BPA has been shown to cause liver function alteration, changes in insulin resistance or other health issues (Karbalaei et al., 2018). In addition, several studies highlight the occurrence of microplastic particles in bottled water, with up to nearly 5000 particles counted per litre in some samples (Mason et al., 2018; Oßmann et al., 2018; Schymanski et al., 2018).

6. Plastic Waste

Plastic pollution, which seriously compromises various ecosystems on and around small islands, is an increasing problem worldwide (Zambrano-Monserrate, 2020). Poor waste management and a lack in awareness of this problem result in millions of tons of waste that ends up in the environment. Especially oceanic islands are hit hard by this, since ocean currents wash up tons of plastic waste on beaches, often from far away countries.

Now apart from this being an immense ecological problem, especially small islands who rely on tourists in search of pristine beaches face increasing pressure to clean up waste caused by others. Plastic “that ends up in the oceans can persist for decades” (ibid.) and will eventually harm marine and terrestrial life alike. Since simply collecting plastic from beaches to make them look nicer is not a sustainable solution, especially when there is no sufficient waste management as is often the case on small tropical islands, resulting in the widespread practice of burning it, the best bet for these destinations is to at least reduce or avoid the plastic waste they are generating themselves.

7. UN SDGs

Sustainable development has been an increasing issue for several decades now. Starting in 1992 at the Earth Summit in Rio de Janeiro, Brazil, most countries adopted the Agenda 21 to further sustainable development globally. Following this, the Member States unanimously adopted the Millennium Declaration in 2000 which led to the formulation of 8 Millennium Development Goals to be reached by 2015. Now while these goals have brought tremendous change and radically improved the lives of many, still a lot of work had to be done. Therefore, these were later rephrased and expanded in 2015 to the 17 Sustainable development Goals (SDGs) we have now and which are intended to be reached by 2030. In these, the connection between humans and their environment is recognised. The SDGs essentially aim at addressing most societal problems we face today, including the effects humans have on the planet we live on. Starting with reducing poverty, eliminating hunger, increasing health, eliminating inequalities and generally improving life for humans, the SDGs further aim at creating societies in which we can sustainably live on this planet in symbiosis with nature, and not destroying everything. The SDG related to this thesis is SDG 6, "ensure availability and sustainable management of water and sanitation for all" ("SDG 6", n.d.). According to the relevant UN homepage, there are currently more than 2.2 billion people worldwide who lack access to safe drinking water ("Water and sanitation", n.d.). Severe water stress, often caused by overexploitation or climate change, is of course also an issue on small tropical islands. The local population, which traditionally relied on fishing for a living, has in many places switched to the tourism sector, but has done so without realising the dire consequences of the side-effects mismanaging this sector brings. The heavy water usage of tourists and their needs places immense stress on local aquifers. Due to this, a lot of progress in the management of local water resources as well as a new way of thinking concerning wasteful water use are needed, especially on the constrained spaces small tropical islands consist of, where natural water sources are often scarce.

8. Alternatives to importing bottled water

When not having a natural local source of water like sufficient groundwater for a well or a natural spring, until quite recently the only method of procuring drinking water was either via rainwater collection or importing bottled water from elsewhere. However, since the first commercial desalination plant using reverse osmosis was constructed in 1965 in California, USA, a lot of progress has been made and different techniques for water generation invented. The most widespread and commercially viable of these will be shortly analysed in the following section.

8.1 Desalination

Of the different techniques of generating water, desalination is probably the most established and well known. Here, the feedwater (the water which is fed into the machine to eventually produce drinkable water) is usually processed in one of the two following ways:

8.1.1 Thermal process

During the thermal process (phase change), the feedwater containing salt (usually seawater or brackish water) is evaporated and then condensed. While the water evaporates at optimal temperatures and pressures, the salt is left behind. The evaporate is then condensed to obtain the sought for freshwater. The thermal process includes several methods, such as solar distillation (active or passive), multi-effect evaporation/distillation, multi-stage flash distillation, thermal vapor compression and mechanical vapor compression (Gude, 2016).

8.1.2 Membrane process

The second common method is the membrane process (non-phase change). Here a physical barrier, the membrane, is used to "separate the dissolved salts from the feed water by mechanical or chemical/electrical means using a membrane separator between feed (seawater or brackish water) and product (potable water)" (ibid.) The membrane process technologies are mainly electrodialysis and reverse osmosis.

One of the major problems however is that often the energy which is used for the desalination process is derived from fossil fuel sources, resulting in an environmentally unsustainable water production, an exchange of "oil for water" (ibid, p. 88). While the energy required for the production has drastically decreased since the advent of the desalination technology, fossil fuel emissions for energy production still pose a significant impact on air pollution, and often desalination plants are in regions that are oil-rich like Kuwait, which relies primarily on desalination for its freshwater ("Desalination by country," n.d.), making the cost of fossil fuel derived energy very low (and thus desalination economically viable), one of the main environmental concerns remains: when extracting H_2O from a salty solution like seawater, what remains is essentially brine - highly concentrated saltwater (Sadhwani et al., 2005). Additionally, "Desalination plants also utilize significant amounts of chemicals for pretreatment of saline water and posttreatment of desalinated water. Discharge of large amounts of chemicals into the coastal waters results in ecological imbalances and major impacts are usually observed in confined water bodies" (Gude, 2016, p. 93). According to Gude's findings, about 2 units of concentrate are generated for every unit of desalinated water that is produced. And the problem is that this concentrate is usually simply discharged back into the ocean. The high salinity and the additional chemicals can cause severe damage to local marine life. Also, this can affect the quality of the feedwater in the long run. So while the energy costs (kWh/m^3) for desalination, especially the reverse osmosis process, are rather low compared to e.g. atmospheric water generation, the side effects can be dire. And this poses a significant threat to the local environment especially on small tropical islands due to their lack in financing and thus lack in possibility to treat the discharge water from such facilities. Since small tropical islands often rely on tourism as their main source of income, degrading the local marine life (keep in mind that these are often diving destinations) will not only prove to be environmentally, but also economically unfeasible in the long run.

8.2 Fog harvesting

Now while most methods for water generation require a (often not insignificant) energy input, fog harvesting stands out as a clean and energy free alternative. There are currently three widespread uses for harvesting water from fog, presented in Figure 1 in Caldas et al. (2018):

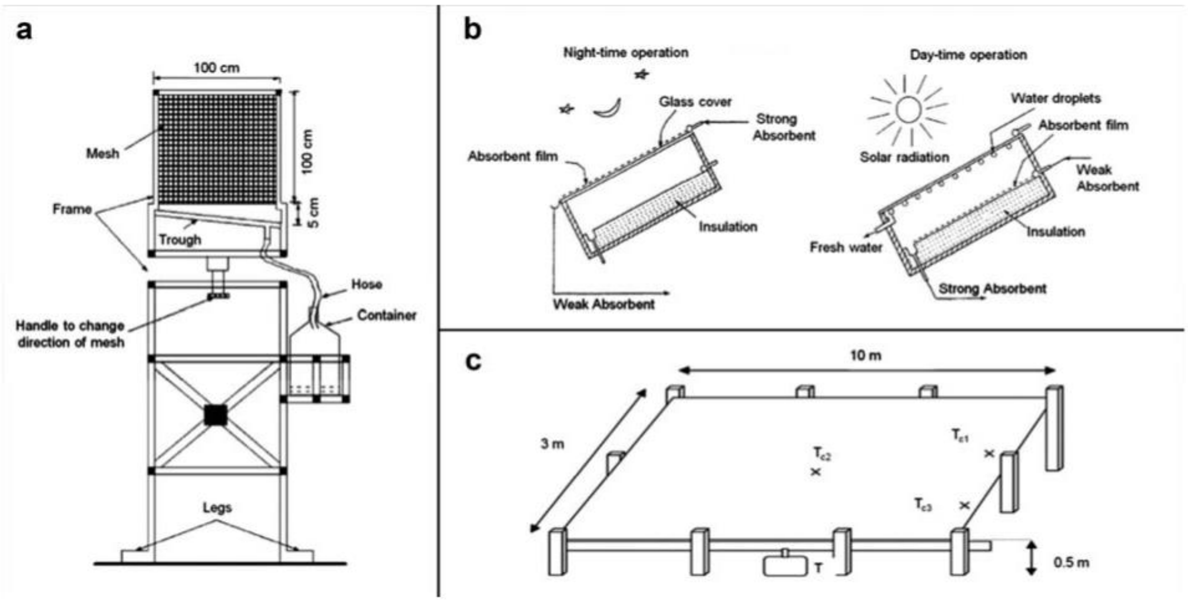

Figure 1: Water harvesting from fog, Source: Caldas et al. (2018) p.495. (a)Drop coalescence, (b) Chemical fog collectors, (c) Radiative condensers, explanation see text

(a) “Drop coalescence on vertically placed meshes”, which can be divided into standard fog collectors and large fog collectors, depending on the surface area of the mesh. In this field technical improvements are being made as to which mesh is most efficient, especially when implementing new materials with increasing hydrophobic properties. Widely used are Polypropylene Rachel mesh and polymer mesh (Caldas et al., 2018).

(b) Chemical fog collectors use absorption and desorption properties of a given desiccant placed in a container. During the night this desiccant absorbs atmospheric water and during the day this absorbed water is distilled using solar radiation and collected. “Calcium Chloride is generally used as an absorbent because of its low toxicity, reduced cost, high thermal conductivity and robustness to thermal degradation. The system is tilted so when water condenses on the glass cover it drips on one side and can be collected” (ibid, p. 496).

(c) Radiative condensers use high emissivity properties of the condensing surface material to rapidly cool down during the night and collect dew. Here different materials are used as foils and these are often coated with emissivity enhancing additives like titanium dioxide (TiO_2) or barium sulfate ($BaSO_4$). The faster the collecting foils cool down (so the higher the emissivity value is), the higher the water collection rate.

Now according to Caldas et al.’s (2018) findings, fog harvesting methods can yield between 0,38 – 6 litres of water per m² per day, depending on method and relative humidity. (p. 497). While having a relatively low cost of installation and negligible detrimental environmental effects (mainly things like mesh or foil replacements after a few years of use), fog harvesting systems thus provide a relatively low yield of drinking water and rely heavily on optimal conditions and relative humidity to work effectively. Further, to produce enough water to supply more than a handful of people, large areas are needed to set up the systems, which on small tropical islands is usually not given. Caldas et al. also investigated the use of mesh for fog harvesting on building façades: these could prove viable (though there are maintenance issues), but when investigating the use on small islands, which usually have smaller buildings, this use seems insufficient for water supply. And when considering that these islands are often touristic, one can probably assume that most resorts won’t want their bungalows covered in mesh anyway.

8.3 Atmospheric Water Generation (AWG)

The Techniques of harvesting water from thin air is still relatively new. There are, however, multiple ways and technical variations for capturing the humidity in the air and converting it to drinkable water (Li et al., 2018; Salek et al., 2018) and atmospheric water generation is definitely one of the more promising ones for commercial use.

The general principle depicted in Figure 2 is quite simple:

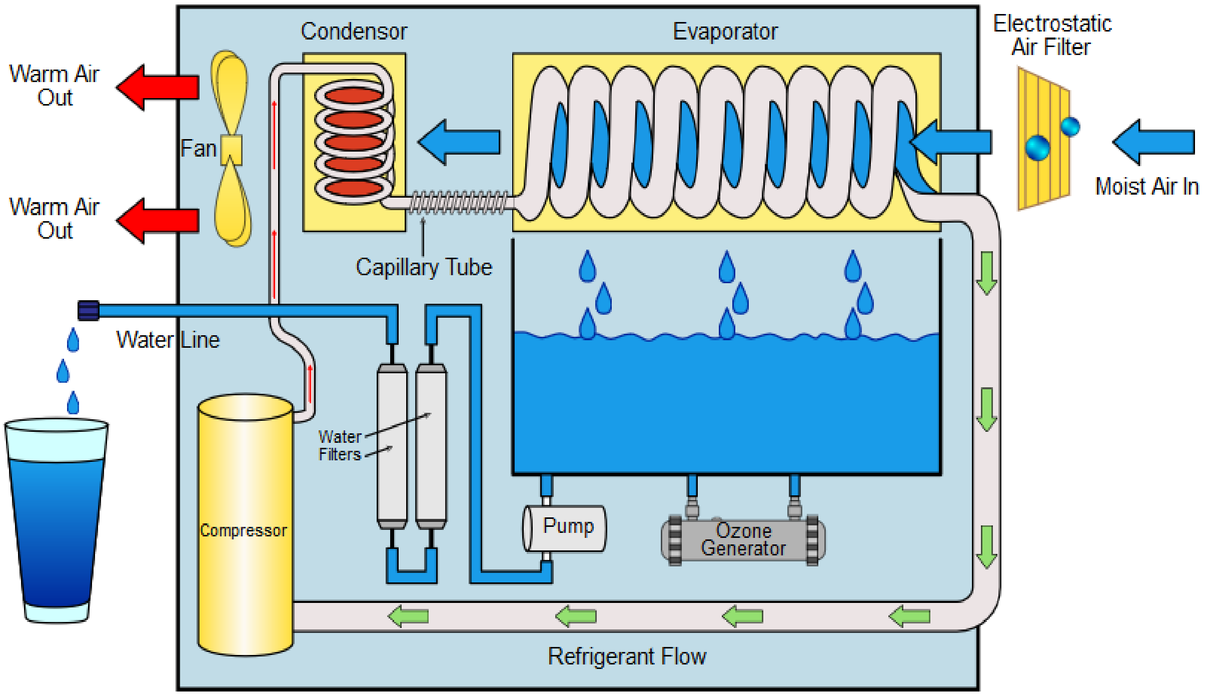

Figure 2 Atmospheric Water Generation, Source: https://upload.wikimedia.org/wikipedia/commons/9/9b/Atmospheric_Water_Generator_diagram.svg

Hot air is sucked into the machine where it is first directed through an air filter and then cooled down. By cooling down below the dew point, the humidity in the air condenses and is captured in a container. After being collected, the water is filtered with charcoal filters, usually treated with UV light to eliminate pathogens and disinfect the water, enriched with minerals to a level healthy for consumption and finally goes through a 0,2µm sterile filter (the final three steps are not depicted in Figure 2 but present in the PHANTOR AWG used for this case study). After these steps it can be tapped.

The performance of this very basic principle is strongly dependant on the quality of the implementation. Good insulation for example, will make a big difference concerning the overall energy consumption.

Also, Bergmair et al. (2014) propose membrane facilitated AWG, further enhancing the energy efficiency – which in the case of a small tropical island could be paramount due to a lack of electricity.

9. Advantages of AWG

Since the setting of this thesis is clearly defined, what would be the best technique of water generation on small tropical islands in terms of efficiency on the one hand but also considering other constraints like available space or fragile ecosystems.

When considering desalination plants, these are the most effective in terms of energy required per produced litre of water. However, the highly concentrated saltwater that is reintroduced into the ocean clearly disqualifies this method in a setting that relies on fishing and diving tourism for its subsistence and income.

Fog harvesting, while being environmentally friendly and not influencing the ecosystem around it, is disqualified for needing a lot of space and essentially not yielding enough drinking water to supply an island.

This leaves us with atmospheric water generation. Bagheri (2018) investigates the performances, functionalities and limitations of AWGs. Such decentralized atmospheric water harvesting solutions, when powered by a clean and sustainable energy source like solar or wind power, can be viewed as completely renewable and sustainable, since the atmospheric humidity that is harvested is “renewed naturally through evaporation from the ocean” (Bagheri, 2018, p. 24) and does not have any environmentally harmful side-effects. So when optimally being able to supply the AWG with clean energy, this technique is the perfect solution for such a setting.

Concerning water quality, this is regularly monitored. For example, when checking for mineral content, the conductivity of the water can be measured and when it is not conducive enough, the mineralising compartment of the AWG must be exchanged, which is part of the normal maintenance procedure. For the AWG used in the case study, a water analysis is done once the AWG has been set up, but CTO of the manufacturing company Imhotep.Industries GmbH, Manfred Ledermüller has assured that water quality exceeds WHO standards.

PART II: CASE STUDY

10. The Nexus of Tourism, Pollution, Water and Sustainable Development

The tourism industry, especially in Cambodia, is increasing strongly every year and thus also gaining in economic importance. With tourist numbers almost tripling from 2008 – 2018 from 2.1 million to over 6.2 million arrivals, also hotel occupancy has increased to over 72%, generating receipts valued at around 4.3 billion US$ (Ministry of Tourism, 2018). This is a development that can be observed in many emerging economies and as Gössling (2001) finds, many of these "have focused on tourism to generate additional jobs and income, raise foreign exchange earnings, and to diversify the economy" (p. 180). Especially on coastal and island settings there has often emerged a dependency on foreign exchange earnings from the growing tourist sector (Gössling, 2000). Therefore, there is reason to assume that the tourism industry is something that should not only be exploited, but also nourished so that it will generate income consistently in the future. Now obviously one cannot plan for everything, and the current Covid pandemic is a good example for this. However, when developing infrastructure and especially tourism-relevant infrastructure, it should be paramount to develop in a sustainable manner. While bringing certain economic advantages, these growing numbers of visitors bring with them significant environmental problems (ibid.).

When wanting to be attractive for tourists as a destination that advertises itself with paradise-like beaches, as many coastal regions do, one must first analyse what the tourists would expect to find there. And this brings us to two key aspects that tourist destinations of this kind are reliant on and that have to do with this thesis.

The first of these is that often the regions I am focusing on do not have any kind of or not sufficiently developed waste management. With growing tourist numbers, the amounts of waste one can find on the beaches increases, thus degrading the unique selling points of these destinations. Admittedly, the waste washed up on shores is not always generated on the islands themselves but is often part of a regional or even global (growing) problem. However, since the tourist numbers can be assumed to directly correlate with the state of the local environment in terms of waste occurrence, this should be seen as a priority on the local agenda. The waste problem and the simultaneous need to conserve an image of paradise has led to spatial fragmentation “into clean places for tourists and dirty places for residents” (Kerber and Kramm, 2021) in some tropical islands. Therefore, this thesis will also thematise the plastic waste occurring from the drinking water supply as it is now and roughly calculate how much could be avoided using a locally generated alternative.

The second key aspect that will be mentioned here is the availability of clean drinking water. “Small limestone island nations […] are low-lying with aquifers composed of single or multiple freshwater lenses […]. Freshwater in these islands is entirely derived from rainfall and stored in less efficient aquifers, consisting of freshwater lenses floating on the underlying seawater […]. These limestone aquifers are generally fragile systems, because shallow depths make them susceptible to evaporation, transpiration and stresses such as groundwater pumping, sea tides and climatic events […]. In many limestone islands, renewable water resources are now over-exploited or approach crisis […]” (Gössling, 2001, p. 180 and citations therein). The drinking water served on these islands, if not bottled and sealed tightly, is thus usually derived from rainwater. This poses significant dangers in the form of water borne diseases and can serve as breeding grounds for disease carrying mosquitoes. This being quite common knowledge nowadays, it affects the acceptability of locally generated water by tourists. As Cambodia is one of the highest Hepatitis endemic countries in the world, drinking water from insecure sources can pose a significant danger. Therefore, it is understandable that water that comes in unsealed containers would probably not be accepted by tourists who are aware of the danger. This problem will be addressed at a later stage of this thesis.

Finally, when developing a region of any size, in this case an island, in order to remain competitive in the long term one must develop sustainably. This clearly entails the aspect of waste, but more generally also that of economic costs. Therefore, it is in the interest of each island in such a setting and with a core focus on the tourism sector to carefully gauge if the import of water from the mainland and the ensuing waste problem is a worthwhile solution. While the plastic bottles for drinking water mentioned in this thesis represent only a fraction of the total wasted produced on such islands, reducing the overall burden can nevertheless be characterised in terms of a sustainable development.

Therefore tourism, the pollution it brings, the water it needs and the sustainable development needed to prevent environmental and long-term economic losses and resulting poverty must be seen as linked and part of a single plan of action for small tropical islands.

11. Koh Rong Sanloem

11.1 Island setting

Koh Rong Sanloem is an island with an area of roughly 24.5 km², a slightly hilly terrain with the highest hill being 200m above sea level. It is situated about 25 km from the port city of Sihanoukville, Cambodia and belongs to the Sihanoukville province.

Figure 3: Koh Rong Sanloem, Cambodia (Google My Maps)

The last accessible cencus in 2019 counted 558 local residents on the island. The number of tourists at any given time was however a much more difficult number to estimate. Neither the Cambodian Tourism Ministry, nor the “official” Koh Rong Tourism guide were reachable. Since a precise determination of the number of resorts on site is currently not possible, I must therefore rely on vague numbers such as provided by google and the like. Here, 106 “hotels” are currently listed (“Resorts on Koh Rong Sanloem,” 2021), however these are all either small shacks, dorms and guesthouses or small to medium sized bungalows. Estimating based on current room offers, the simpler resorts have around 5 bungalows while the larger ones have up to 35 bungalows usually accommodating two people.

Due to the complications encountered when gathering such information from abroad, the estimations here as well as the estimations the case study will be based on rely on a Thesis on the neighbouring island (Huber, 2020) as well as expert opinions. However, since the aim of this Thesis is essentially to see if the implementation of an atmospheric water generation system is feasible on a small tropical island, I will simply assume a population (including tourists). To this end the average number of rooms per resort was estimated (an average was calculated by checking total rooms offered by 20 random resorts on the island, giving an average of 18.13 rooms per resort) and multiplied by the 106 resorts listed for the island, totalling 1922 rooms. When calculating that each of the rooms has two people staying there, this would mean 3844 tourists on the island at full occupancy. Assuming an occupancy of 72% as indicated in the official statistics by the Cambodian Ministry of Tourism (2018), this would mean there are on average 2767 tourists plus 550 locals on the island, totalling about 3300 people. One must of course keep in mind the strong variations between high season and low season. But for the sake of simplicity and due to lack of actual data, I will assume a water-consuming population on the island of 2.000 during low season and 4.000 during high season, based on average rooms, average hotel occupancy of 72% and numbers from the neighbouring island provided by Huber (2020). Huber’s research found that for the roughly 100 resorts on the neighbouring island of Koh Rong, there were “an average of 1.800 – 2.000 tourists present daily during low season and 3.000 – 4.000 during high season” (p. 15). When taking into account that tourism has been steadily increasing on the islands and in Cambodia in general, I think the assumptions made for this islands population to calculate water consumption are fairly safe. And when then checking for the feasibility on a similar island one can compare that islands water need based on that island's population, no matter if the number for Koh Rong Sanloem was 100% exact or not.

Currently, the water consumed on Koh Rong Sanloem is imported by ferry from the mainland, usually bought in the port city of Sihanoukville. According to information provided by local sources, the current water price is 2.000 KHR per litre on the mainland and 4.000 KHR per litre on the island, which translates to 0,4€ and 0,8€, respectively. The higher price on the island is due to transport costs such as the transport from the individual shops to the ferry and the ferry ticket (once the water reaches the island it is transported on foot since there are no roads). Now since we are aiming to supply water on the island, the 4000 KHR i.e. 0,8€ are the value we are aiming to undercut, since neither the resorts nor the locals would buy the AWG water if it were more expensive. True, there would always be the benefit of reducing harmful microplastic ingestion, but (and this is probably very unscientific) a lack of education in such rural areas or knowledge concerning microplastic in general would not suffice as argument to buy the produced water, while the economic argument would.

11.2 Calculating drinking water needs for Koh Rong Sanloem

Since this thesis aims at producing (and eventually selling) drinking water, one must know how much water is actually needed on the island since production at an optimum level is most energy and cost efficient. So to maximise revenue and have lowest costs per litre of produced water, one would be aiming at constant full production and selling all of the produced water.

Now assuming the 2.000 people in low season and 4.000 people in high season as calculated above, how much drinking water would be needed? On the one hand one could simply look at how much water humans should drink per day. This varies, depending on age and sex, but also on factors such as climate and physical activity. The adequate intake of water (in a normal climate with average activity), would thus lie between 2 and 4 litres a day (Grandjean, 2005). On the other hand, this calculation would not take into account different beverages like beer, juice, etc. consumed by tourists, water used to make ice (used in beverages), water used for cooking purposes, etc. So assuming some water is also wasted, For the sake of simplicity in this thesis I will calculate with 3 litres of water from an AWG would be consumed per person per day. This would mean that, sticking to our calculation, there would be a daily need of roughly 6.000 litres of water in low season and 12.000 litres of water in high season. These are the numbers I will thus base the case study on and that would be used as reference consumption values when using the data gathered in this thesis for similar islands. It is however common practice on such islands that water for cooking or guest showers is processed water (not from plastic bottles, but not from rainwater either, since there would simply not be enough), possibly ground water (though not processed enough for drinking purposes). As an example, one of the resorts on the island purifies groundwater for their sanitary installations. Of course, it is hard to calculate how much water would be eventually bought from a local AWG, but it might be good to keep in mind that the demand for water in general is there and could be exploited economically in the case that not all would be bought as bottled drinking water. For the final calculation I will nevertheless assume that all generated water can be sold. According to the expert opinion of Dipl. Ing. Dr. Mario Ortner, it is safe to assume that tourists on the island will consume roughly 10l per capita daily – far more than our AWG could produce.

11.3 Atmospheric Water Generation

Now the question is, how much *could* the AWG produce? To produce water from the atmosphere, the most relevant parameters are temperature and relative humidity. The closest data available to this end is from Kampot, roughly 90km away from Koh Rong Sanloem. Figure 4 below shows data from 2020 concerning average monthly temperature, relative humidity, power consumtion and the hereon based monthly water yield in m^3.

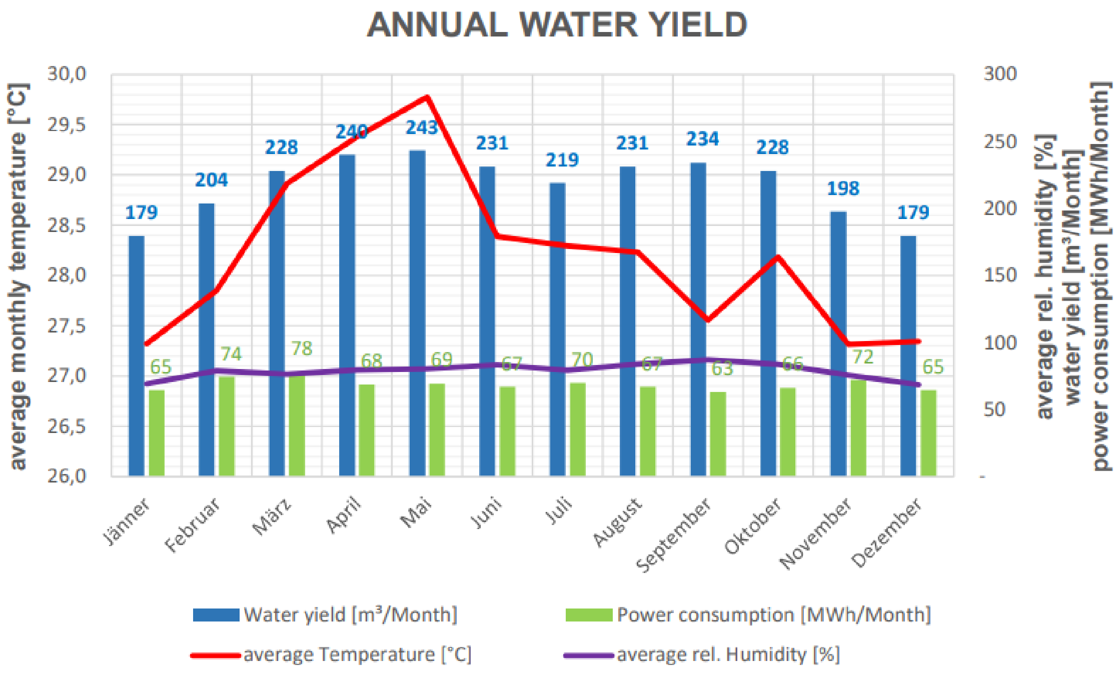

Figure 4 Annual water yield, see Annex

According to this data, at this location there could be a maximum annual water yield (running at 100% workload) of 2.615.833 litres of water, with an annual power consumption of 825 MWh and a maximum of 8760 operating hours per year. This information was kindly provided by Imhotep.Industries GmbH for this thesis. This would obviously vary from location to location and the yield will influence the calculations of this thesis.

11.4 Plastic waste from water bottles that could be avoided

The situation on Koh Rong Sanloem regarding plastic waste is dire. Most of the waste is burned in open fires, some resorts bury their waste and some of the plastic bottles are collected, without and further plans regarding disposal. Figure 5 shows a site on Koh Rong, located next to the beach, where slightly stronger winds can easily scatter waste across the beach and into the ocean.

Figure 5 Collected plastic bottles on Koh Rong, Foto ©C. M. Huber

When thinking about the plastic waste that is generated only by the consumption of drinking water on such an island, the calculation is quite simple. The usual plastic bottles (PET) (Mardi et al., 2018) sold are mostly 0.5 litres and will thus have an average weight of 20g (Schüttpelz, 2014). The calculated water consumption from above refers to total water consumption, but not all water consumed in consumed via PET bottles – some might be used for cooking, ice, etc. For the waste I will thus assume (based on plentiful personal experience from travelling to such islands) that a tourist consumes at least 1,5 litre of drinking water from PET bottles. This would mean that on average at least 6000 0,5l PET bottles are used daily in low season and 12000 in high season, resulting in 120Kg and 240Kg of daily plastic waste from PET bottles, respectively. And this is assuming people only drink1,5 litres and not 2 litres as we assume for average water consumption.

Now, for simplification, assuming that half the year is low season and the other half is high season, this would cumulate in roughly 65,7t of annual plastic waste – which, when consuming water from a local source rather than from imported water bottles, could be avoided! Of course, not all of this plastic waste would be avoided and people would not completely stop using bottled water from the mainland, but even reducing this figure by say 70% (based on a good acceptance of our produced water) would have a huge impact.

11.5 Electricity on the island

Although there is often a huge potential for the implementation of renewable energy in the form of PV or wind farms, most “islands in both developing and developed countries are heavily reliant on fossil-fuel based electricity generation” (Huber, 2020). Even though this would sometimes be possible due to their relative proximity to the mainland, the investment costs for underwater cables to connect a given island to the mainland’s power grid mean that islands are essentially cut off from power supply and must rely on local electricity generation (Curto et al., 2019). Momentarily the island population and all the resorts there generate their entire electricity using small diesel generators. Diesel generators are the most common source of electrical power in off-grid locations such as small islands, since their acquisition costs are comparatively low and the fossil fuels needed for power generation are widely available. The widespread use of these generators causes several problems and disturbances. First of all, such diesel generators have quite significant emissions. These include greenhouse gases (GHG) such as carbon monoxide (CO), carbon dioxide (CO_2), and the different nitrogen oxides (NO_X), but also particle matter (PM), which consists largely of “elemental and organic carbon soot, coated by gaseous organic substances such as formaldehyde [CH_2O] and polycyclic aromatic hydrocarbons (PAHs) which are highly toxic” (Jakhrani et al., 2012). While the fuel consumption of different models of generators may vary, as would the carbon content in different fuels, it is generally assumed (for sake of simplicity) that a litre of diesel will produce around 2.7 Kg of CO_2 when burned (ibid). So on an island like Koh Rong Sanloem, where there are around 100 resorts, each with their own generator, in addition to the local population, this adds up to a significant impact. This can also include increased mortality linked to diesel soot exposure (ibid).

Another disadvantage are the sound disturbances caused by such generators. While the exact amount of decibel emitted will vary between models, diesel generators are sure to disturb local fauna and (to not forget the economic side) tourists.

On the upside, many tropical islands have optimal preconditions for clean energy production such as Photovoltaic (PV) plants. The proximity to the equator means an optimal angle of the sun, which essentially results in improved solar energy conversion.

As a perfect example for this suitability, on the island of Koh Rong (the neighbouring one) a PV plant was constructed in the course of 2020 and is now in operation, supplying the island with clean and renewable energy, essentially eliminating a major source of emissions. One problem that remains however, is that while these plants might generate enough electricity during the day, low battery storage capacities resulting from high costs result in generators still being needed for night-time power supply. Nevertheless, a huge part of carbon emissions is offset with such installations.

In regard to Koh Rong Sanloem and the case study beforehand, there is not currently any form of PV installed. However, there are plans by the company Total Solar Distributed Generation to build a 1.25 kWp PV plant to cater for the island's electrical power needs ("Total Solar DG to build one of Southeast Asia's largest renewable energy micrograms in Cambodia," 2021). According to this article, the plant is to reduce the islands diesel consumption by 600.000 litres per year. Now while this is from an environmental perspective a great improvement, there is little change from an economic perspective. According to the supervisor of this thesis Dipl. Ing. Dr. Mario Ortner, who runs the PV plant on the neighbouring island of Koh Rong and is an expert in this field, one can calculate with energy costs of 0.5USD (0,42€) per kWh for both forms of electricity – diesel and PV – on the island. Since the company Total Solar Distributed Generation was not reachable for a quote on energy costs once the PV plant is completed, this is the value I will use for the calculation in the case study.

One of the offers made by Imhotep.Industries GmbH includes a 508 kWp PV system which includes 1.275 kWh Battery Capacity and could supply the energy needed to produce water and even generate a surplus of 98 MWh per year (these numbers were supplied by the company), which could be sold.

12. Transportation of an AWG to the island

While Imhotep.Industries GmbH, the AWG company chosen for this thesis, arranges transport of an AWG to the closest large harbour (which in our case is Sihanoukville, roughly 25km from the island) for 30.000€ for a standalone AWG and 70.000€ when including a PV system, a much larger problem is posed by the actual transport to the final location on the island. Many small tropical islands do not have a proper harbour, with cranes and infrastructure to offload a 14t container, place it on a truck and transport it to the final location. Often such islands do not even have asphalted roads. Now how could one gat such a massive cargo onto an island? One option only briefly mentioned here would be to use a heavy lifting helicopter. Not many helicopters can lift cargo of slightly more than 14t. There are only a handful of models, mostly used by the military, such as the Sikorsky CH-53 and its several variants, the MIL MI-6, MIL MI-10 and Mil MI-26. However, since they are mostly used by military, a calculation of costs would surpass the scope of this thesis, such helicopters might even be supplied by governments when considering that such a project would secure the water supply for an island's population. This route would also be proposed to be taken for the current project and thus the costs of transportation from the harbour of Sihanoukville to the final location on Koh Rong Sanloem will be valued at 0€.

13. Location on the island

Another significant risk when setting up a project in most Asian countries as a foreigner (and in this case I am a foreigner – this would not hold for communal implementation of such a project or by a national company) comes when considering a location for the AWG. Often, buying actual land as a foreign company (or even privately) is not possible. In Cambodia there are certain workarounds though, which each have their own advantages and disadvantages.

One option would be to create a Land Holding Company (LHC). While the majority (51%) of the company must be held by a Khmer national, the remaining 49% together with all the decision-making and voting rights can be contractually controlled by the foreigner. This practice is often offered by local law firms who charge an annual fee for providing the local shareholder. The setup costs for such a LHC vary between $4.000 - $12.000, depending on the law firm. In the calculation I will thus assume a mean value of 8.000€ for the setup of a LHC.

Another, significantly cheaper and faster option for property purchase in Cambodia is what is known as the "nominee structure". Usually a Khmer partner of a given project is put forward as nominee who will hold the property. Now while this could definitely carry some risk, there are several options to mitigate the risk of losing the property. For example, a mortgage agreement is registered at the government and prevents any transfer of the land title without permission. A significant benefit of this structure is that no profit taxes are to be paid and no monthly/quarterly tax statements to be submitted. Due to lack of information, a set up cost for this simpler structure is assumed to lie at 1.000€. According to information obtained from the neighbouring island (provided by Dipl. Ing. Dr. Mario Ortner), the lease for one hectare of land costs $3.000 per month, which is about 2.500€. It will be assumed for all four models that one hectare of land is leased.

The law firm that provided this information suggests using the nominee structure for investments under and LHC for investments above $1.000.000 ("IPS Cambodia," 2021).

14. Bottling of produced water

Now one of the main aims of such a project would be avoiding waste in the form of plastic bottles. The drinking water consumed on Koh Rong Sanloem is at the moment imported in single-use plastic bottles which are either burnt after use or stored indefinitely. This is standard practice on many islands of this size. However, the problem of tourist-acceptability remains. (Usually western) Tourists often do not trust water in unsealed containers.

Now to manage the problems of waste and acceptability, a solution would be the direct filling on site into glass bottles. There are quite a few standalone machines that can wash, fill and seal glass bottles which can then be reused. These come in all sizes and prices, from small craft-beer filling stations for private use to large scale food-Industry filling arrays.

For the calculation in the case study I will use a machine supplied by Jiangsu Mesure Machinery Co., Ltd., which is suited for washing, filling and capping of glass bottles (hereafter referred to as “Filling Station”). After correspondence, the company has proposed model BCGN 12-12-6 (“Automatic 3-in-1 CSD Beverage Filling Bottling Machine,” 2021). This specific machine costs around 80.000€ and is just one of many options. There are cheaper variants with less bottles filled per hour, but they often are only fitted to fill single-use PET bottles, and we are trying to eliminate those from the island. I will use the 80.000€ mentioned above for calculation, but this figure would obviously have to be adapted (or even left out if not needed) when implementing a similar project somewhere else. While the model proposed can fill up to 3000 bottles per hour, the washing process requires 500 litres of water per hour, resulting in a total water usage of 7.000 litres in an 2h operation period and 6.000 bottles of water. This must be kept in mind when calculating, since the output of water is essentially cut by 1.000 litres. There are models that would produce slower and cost less, but they would consume more water in total for washing, so this is the ideal option when no external water is available for washing. The numbers regarding price, bottles filled per hour and water usage for washing were obtained directly from the company via private communication.

One must keep in mind that the issue of bottling would probably not arise on small tropical islands with low tourism numbers, that could simply distribute their locally produced water through pipage or fill it directly from the AWG into large containers, without the need of a separate Filling Station.

The next thing one must address when choosing to provide a filling service for the produced water is the actual bottles. Since we will be producing up to 7.000 litres of water daily, there will be a need of at least 15.000 1l bottles in circulation, also accounting for backup since eventually some of them will break. The costs per glass bottle lie between 0,1€ and 0,6€ when purchasing in bulk (“Glass Bottle Prices,” 2021) and I will calculate with an average price of 0,25€ for simplicity, always keeping in mind that this is just a rough calculation that would be customized according to need. This would mean a total cost of 3.750€. In addition, one would need a structure for filling and storage of the bottles, situated next to the AWG, since the filling machine should be kept indoors – and for sanitary reasons. Construction on such islands is relatively cheap (but not easy, since everything must be done by hand!) and will be valued at 5.000€. Transport of this specific filling machine poses a similar problem as the AWG, as it comes in a 40HQ container and might also have to be airlifted from the harbour of Sihanoukville. The used Model requires 3,5 kW to run, but this will not be incorporated into the calculation (just as the 1,5 kW on the AWG roof is not incorporated into the calculation – this would eventually even out).

15. Maintenance

Maintenance of AWGs is fairly simple in general. It can be assumed that the handful of serious AWG producing companies will produce similar machines and thus the maintenance will be rather comparable throughout the range of products. Since this thesis will be using the specifications provided by the company Imhotep.Industries GmbH for their PHANTOR AWG, I will use these to showcase the maintenance needed for these machines in general. The PHANTOR will notify the operator once any of the following steps need to be done, usually with a few weeks prior notice to give the operator time to procure eventual spare parts like filters if necessary. The components that require maintenance are the following:

- The air filters need a replacement every few months, depending on local air pollution.
- There are charcoal filters that have to be exchanged roughly every 4 months, depending on location (the air pollution of the environment directly influences this). This is easily done by opening a hatch, taking out the old filter and replacing it with the new filter.
- The UV- radiator might have to be swapped up to 4 times per year. This is a relatively simple swapping of a UV-lamp.
- The minerals that provide the generate water with the necessary mineralization must be exchanged approximately 4 times per year. For this the container containing the old minerals is taken out, these are discarded

(this is essentially salt-like granulate that does not need special disposal) and the new minerals are poured into the container.

- Also the sterile filter might need a quarterly replacement.

All the replacement intervals are approximated and might vary according to location and usage but are very simple in general and the operator will receive a thorough training as to how to carry out maintenance.

Apart from these simple exchanges, the Inspection of the chiller must be carried out by a trained technician sent by Imhotep.Industries GmbH. Further, every approximately 5-6 years the air fan will have to be replaced, which will also be carried out by the producing company. The costs for the former five replacement parts were estimated for the calculation by Imhotep.Industries CTO Ledermüller. The costs for the chiller inspection as well as spare parts such as the fan are included in the annual reserves for repairs (see the calculation later).

Further, the costs for the first 3 years of filters and other exchangeable parts are included in the buying price. Therefore, in the calculation the price for maintenance is not 5.000€ per year but lower and will be rounded up to 4.000€ and 4.500€ for standalone AWG and including PV, respectively.

16. Staff

To carry out needed maintenance, eventually guard the site and machinery as well as carry out the filling in case of this option, local staff is needed. This staff would receive the training from Imhotep.Industries GmbH regarding any necessary maintenance, be instructed on how to operate the filling machine and optimally live on site or close by to prevent theft, vandalism, etc. It is estimated that for these operations two full-time personnel will be required, operating and monitoring the site (also to prevent theft or vandalism). Their monthly salary is estimated to amount to 700€ each and could eventually include living space on property as well as other living costs, depending on the project. While this would definitely have positive implications such as creating two high paying jobs for locals, finding and training trustworthy people to safely and efficiently operate the facility might prove difficult. The salary is based on a similar operational position

Huber (2020) proposes in her pilot project on the neighbouring island and would probably be comparable to this case.

17. Earnings

The main earning of a project as described come from selling the generated water. At the location chosen, a maximum of 2.615.833 litres of water can be generated, based on temperature and relative humidity. This would mean an average daily production of 7167 litres of water, which I will round to 7000l generated per day for the calculations. When looking at the monthly production (see Figure 4 or Annex), one could remark that for example only 5774 litres could be produced (179m³ / 31 days) and thus sold on a daily average in January, but since this is low season, and since in the months where more could be produced also more tourists would be on the island (high season), this discrepancy is expected to even out, thus the average of 7000 litres for the calculation. Since the current price of 1 litre of water on the island is 4000 KHR, so 0,8€, we could sell the produced water at a price of 3000 KHR, which would translate to 0,6€/l. This will be the main form of revenues.

In addition, when installing a PV plant, one could sell the surplus electricity generated during the day, which, as provided by Imhotep.Industries GmbH, could amount to 98 MWh per year. This could be sold at the local price of 0,42€ per kWh.

18. Expenses

First of all, all calculations and numbers in this thesis, as far as possible and when not referring to other scientific papers as source, will be done in Euro (€). Since I will be calculating for different scenarios, there are several expenses one must mention beforehand. The PHANTOR AWG by Imhotep.Industries GmbH used for this thesis costs 503.058€. When choosing the option including a sufficient PV plant, the total system costs are valued at 1.750.377€. Transportation to the closest harbour is estimated to be 30.000€ and 70.000€, respectively. While there is no material needed to produce water via an AWG, there are the above-

Figure 6 The PHANTOR AWG, www.imhotep.industries

mentioned maintenance costs of 3.854€ for the AWG or 3.651€ per year when including a PV plant to cover energy needs (this value is lower because with PV we would be running at 90% capacity, essentially prolonging the lifetime of the spare parts). However, for the calculation I will use a value of 4.000€ per year to be on the safe side (and for simplicity) – this would be location specific anyway since it is capacity-dependent. Additionally, there will be reserves for repairs of 3.773€ or 8.752€ annually (based on CAPEX), for the standalone setup and when including PV, respectively – rounded to 4.000€ and 9.000€ in the calculation. In addition to this, there will be cloudservice costs of roughly 6.000€ per year. This feature would eventually be calculated per litre and includes all monitoring and informing of the customer when maintenance is needed and supplies any other needed operational information. All these numbers were kindly provided by Imhotep.Industries GmbH for this calculation (see Annex).

Then there are the two local staff with a monthly wage of 700€ each. Insurance of the project will be valued at 1% of total investment costs. For a Filling Station I will use a placeholder value of 80.000€ based on an offer made by Jiangsu Mesure Machinery Co., Ltd. in personal communication, since there are various different machines and manufacturers specialising on different needs. For the glass bottles that will be filled, 3.750€ were calculated and for the structure to house the filling machine and the bottles another 5.000€ were assumed. The following table will depict all investment and running costs for clarity.

Information provided by Jiangsu Mesure Machinery Co., Ltd. Concerning maintenance of the Filling Station calculate roughly 1.000-2.000 USD per year for maintenance, therefore I will calculate with 2.000€ per year for maintenance, reserves for repairs and restocking of broken bottles.

Table 1: List of various CAPEX (own processing)

CAPEX		
PHANTOR AWG		503.058
PHANTOR AWG + PV		1.750.377
Transportation AWG		30.000
Transportation AWG + PV		70.000
Filling Station		80.000
Bottles		3.750
Housing facility		5.000
Contract setup costs	CAPEX < 1.000.000	1.000
Contract setup costs	CAPEX > 1.000.000	8.000

Table 2: List of various operational and maintenance costs (own processing)

Operational costs and maintenance		
Electrical self demand AWG	0,42€/kWh, 825 MWh per year	346.500
Electrical self demand AWG + PV		0
Maintenance AWG		4.000
Maintenance AWG + PV		4.500
Maintenance + Reserves for repairs Filling machine		2.000
Reserves for repairs AWG		4.000
Reserves for repairs AWG + PV		9.000
Cloudservice AWG		6.000
Staff	2ppl á 700€ per month	16.800
Land lease	2.500€ per month	30.000
Insurance	1% of investment costs	Depending on model
Administration	2% of revenues	Depending on model
Interest	7% of loan	Depending on model

19. Financing

In order to reduce the risk, a widely used financing strategy is to provide 30% equity capital and take out a loan on the remaining 70% of capital expenditures (CAPEX). This way investors are faced with a lower risk and can result in a better performance of equity capital. As will be shown later, due to a very high revenue if selling all the produced water, the amortization period will be very short. The loan used for the calculations will be taken out for a 6-year period and the interest will be 7%, values which would have to be adapted to any given scenario and available conditions. In addition, there could be the possibility of co-financing by development bank or governments, since essentially such a project could eliminate water scarcity on small islands.

20. Profit and Loss Analysis

When calculating a possible profit from selling a product one must of course consider demand for said product. In this case there are some uncertainties which must be addressed. First of all, sales of the produced water are obviously reliant on the rate of acceptance. This is a value that is hard to calculate and will differ according to setting of such a project. I must therefore assume that all water that can be produced will also be sold. Currently water in 0,5l PET bottles costs 2000 KHR on Koh Rong Sanloem, which is around 0,4€, so 0,8€ per litre. This is the price one would have to undercut to increase acceptability by the local population (who would also be supplying it to the tourists). This thesis will therefore explore if a profit can be made when selling the water at 0,6€ per litre.

A second uncertainty lies in the mode of distribution: is there an existing pipe system for distribution? Must the water be filled first? Since an aim of this thesis is also to reduce the burden of plastic waste, the calculations that include filling will be based on costs for the Filling Station mentioned above, supplied by Jiangsu Mesure Machinery Co., Ltd., to showcase how much such an option would cost.

Finally, a sustainable production of water is to be achieved. This includes the energy used for production. So when there is a local source of energy (and this is optimally a source of clean energy), this can be used. For the calculation I will use a price of 0,42€/kWh, since this is the price on the neighbouring island and a similar price can be assumed here. There will be cases, however, of tropical islands that do not have sufficient electrical energy available. To not have to rely on yet another diesel generator, an option will be included for a project that has a PV plant.

This leaves us with four Profit and Loss calculations:

- A standalone AWG using locally produced electricity.
- An AWG using locally produced electricity with an adjacent Filling Station.
- An AWG with a PV plant to produce sufficient electricity for production.
- An AWG, with a PV plant and a Filling Station.

These four models will give possible communities or investors contemplating such a project different options for implementation, depending on need.

21. Performance indicators

Following each model, I will analyse how the performance would be, based on three values. The Debt Service Coverage Ratio (DSCR) is an indicator which shows how easily (if at all!) an investment will generate earnings to repay any liabilities such as a loan taken and the interest payments thereof. A good DSCR value should lie above 130% to assure a feasible investment, able to pay off the loan and generate profit. The calculation is EBITDA minus the tax and this then divided by the annual redemption and the interest. The second indicator I will use is the Return On Equity (ROE), which indicates how well the invested equity capital performs. This could be comparable to the interest rate one receives when depositing capital in a bank but is usually much higher (the downside is that one cannot simply withdraw the capital as from a bank, since it is invested). Since the risk in developing countries is often higher due to political instability, corruption, etc., one should aim at a ROE of at least 20% to offset the risks. The final indicator is the Return On Assets (ROA), which instead of using only the equity capital calculates the "interest" earned from the entire invested capital, including loans.

21.1 Model 1: Standalone AWG

This calculation will focus on the setup of an AWG and the sales of the produced water. The calculated water generation is based on the island of Koh Rong Sanloem and rounded to 7.000 litres per day. The electricity needed to produce water is bought locally for 0,42€.

Table 3: Model 1 – Profit and Loss Analysis AWG (own processing)

Profit and Loss Analysis

	Reference	Sum €
Revenues		
Water sold at 0,6€/l	7.000l generated per day, 365 days	1.533.000
Gross margin		**1.533.000**
O & M		
Electrical self-demand	0,42€/kWh, 825 MWh per year	-346.500
Maintenance AWG		-4.000
Reserves for repairs AWG		-4.000
Cloudservice AWG		-6.000
Staff	2ppl á 700€ per month	-16.800
Insurance	1% of investment cost	-5.341
Administration	2% of revenues	-30.660
Land lease	2.500€ per month	-30.000
Total O&M cost		**-443.301**
EBITDA		**1.089.699**
Depreciation	15 years	-35.604
EBIT		**1.054.096**
Interest	7% of loan, 6 years payback period	-13.084
EBT		**1.041.011**
Tax	20%	-208.202
EAT		**832.809**

Table 4: Parameters AWG (own processing)

Parameters Standalone AWG		
Investment cost AWG		503.058
Transport AWG		30.000
Location	Contract setup costs	1.000
Total investment costs	**(CAPEX)**	**534.058**
Depreciation period	15 years	
Water sales revenues	0,6€/l	
Financing	6 years payback	
Loan	70%	373.841
Equity	30%	160.217
Annual redemption	6 years	62.307
Interest payment year 1		26.169
Average interest rate	7% interest rate	13.084

Table 5: Model 1 - performance indicators (own processing)

Performance indicators	
DSCR = (EBITDA – tax) / (annual redemption + interest)	1169%
ROE = EAT / Equity	520%
ROA = EAT / CAPEX	156%

For this option, Debt Service Coverage Ratio is at an incredible 1169%, providing a good opportunity for investors. One must keep in mind, that the water in only produced and not distributed, so one would have to include distribution means into any further calculation. For example, locals could bring their own containers to fill as much water as needed, existing pipage could be used, etc. Exploring all possible various options would surpass the scope of this thesis and would need further investigation. ROE, which can be viewed as the interest earned on invested equity capital, is 520% in this model, so seems to be a very good investment. Similarly the ROA of 156% would essentially mean that the complete investment costs would be earned in less than a year.

21.2 *Model 2: AWG + Filling Station*

This calculation will be for an AWG and an adjacent Filling Station, including a facility to set up the Filling Station indoors. Since the bottle-washing process before filling requires water, the amount of water filled is less than is produced in total.

Table 6: Model 2 – Profit and Loss Analysis AWG + Filling Station (own processing)

Profit and Loss Analysis

	Reference	**Sum €**
Revenues		
Water sold at 0,6€/l	6.000l bottled per day, 365 days	1.314.000
Gross margin		**1.314.000**
O & M		
Electrical self-demand	0,42€/kWh, 825 MWh per year	-346.500
Maintenance AWG		-4.000
Reserves for repairs AWG		-4.000
Maintenance / reserves for repairs Filling Station		-2.000
Cloudservice AWG		-6.000
Staff	2ppl á 700€ per month	-16.800
Insurance	1% of investment cost	-6.228
Administration	2% of revenues	-26.280
Land lease	2.500€ per month	-30.000
Total O&M cost		**-441.808**
EBITDA		**872.192**
Depreciation	15 years	-41.521
EBIT		**830.671**
Interest	7% of loan, 6 years payback period	-15.259
EBT		**815.413**
Tax	20%	-163.083

EAT	**652.330**

Table 7: Parameters AWG + Filling Station (own processing)

Parameters AWG + Filling Station		
Investment cost AWG		503.058
Transport AWG		30.000
Location	Contract setup costs	1.000
Filling Station		80.000
Bottles		3.750
Housing facility		5.000
Total investment costs	**(CAPEX)**	**622.808**
Depreciation period	15 years	
Water sales revenues	0,6€/l	
Financing	6 years payback	
Loan	70%	435.966
Equity	30%	186.842
Annual redemption	6 years	72.661
Interest payment year 1	7% interest rate	30.518
Average interest rate	7% interest rate	15.259

Table 8: Model 2 - performance indicators (own processing)

Performance indicators	
DSCR = (EBITDA – tax) / (annual redemption + interest)	807%
ROE = EAT / Equity	349%
ROA = EAT / CAPEX	105%

The option of AWG and Filling Station results in Debt Service Coverage Ratio of 807%, which is still very high. This option would be better suited than without filling for locations catering to water needs of tourists. ROE is 349% in this model, about 100 times what any bank could offer as interest on capital. The ROA of 105% would mean that the complete investment costs would be earned in slightly under a year.

21.3 Model 3: AWG + PV

This model calculates the performance of an AWG with an adjacent PV plant to supply the energy required. Excess solar energy will be sold. Distribution is not included in this model.

Table 9: Model 3 – Profit and Loss Analysis AWG + PV (own processing)

Profit and Loss Analysis

	Reference	**Sum €**
Revenues		
Water sold at 0,6€/l	7.000l generated per day, 365 days	1.533.000
PV sold	98 MWh á 0,42€/kWh	41.160
Gross margin		**1.574.160**
O & M		
Electrical self-demand	0,42€/kWh, 825 MWh per year	0
Maintenance AWG + PV		-4.500
Reserves for repairs AWG + PV		-9.000
Cloudservice AWG		-6.000
Staff	2ppl á 700€ per month	-16.800
Insurance	1% of investment cost	-18.284
Administration	2% of revenues	-31.483
Land lease	2.500€ per month	-30.000
Total O&M cost		**-116.067**
EBITDA		**1.458.093**
Depreciation	15 years	-121.892
EBIT		**1.336.201**
Interest	7% of loan, 6 years payback period	-44.795
EBT		**1.291.406**
Tax	20%	-258.281
EAT		**1.033.125**

Table 10: Parameters AWG + PV (own processing)

Parameters AWG + PV		
Investment cost AWG + PV		1.750.377
Transport AWG + PV		70.000
Location	Contract setup costs	8.000
Total investment costs	**(CAPEX)**	**1.828.377**
Depreciation period	15 years	
Water sales revenues	0,6€/l	
Financing	6 years payback	
Loan	70%	1.279.864
Equity	30%	548.513
Annual redemption	6 years	213.311
Interest payment year 1	7% interest rate	89.590
Average interest rate	7% interest rate	44.795

Table 11: Model 3 - performance indicators (own processing)

Performance indicators	
DSCR = (EBITDA – tax) / (annual redemption + interest)	465%
ROE = EAT / Equity	188%
ROA = EAT / CAPEX	57%

The option of AWG and adjacent PV plant provides a Debt Service Coverage Ratio of 465%. This option would be better suited than without filling for locations catering to water needs of tourists. ROE is 188% in this model. The ROA of 57% would mean that the complete investment costs could be earned back in two years.

21.4 Model 4: AWG + PV + Filling Station

This final model calculates the performance of an AWG, with a Filling Station (including housing) and a PV plant. The PV could be (partially) mounted on the roof of the facility to save space. Less water is bottled than is generated since some is needed for the washing process. Excess solar energy can be sold.

Table 12: Model 4 – Profit and Loss Analysis AWG + PV + Filling Station (own processing)

Profit and Loss Analysis		
	Reference	**Sum €**
Revenues		
Water sold at 0,6€/l	6.000l generated per day, 365 days	1.314.000
PV sold	98 MWh á 0,42€/kWh	41.160
Gross margin		**1.355.160**
O & M		
Electrical self-demand	0,42€/kWh, 825 MWh per year	0
Maintenance AWG + PV		-4.500
Reserves for repairs AWG + PV		-9.000
Maintenance / reserves for repairs Filling Station		-2.000
Cloudservice AWG		-6.000
Staff	2ppl á 700€ per month	-16.800
Insurance	1% of investment cost	-19.171
Administration	2% of revenues	-27.103
Land lease	2.500€ per month	-30.000
Total O&M cost		**-114.574**
EBITDA		**1.240.586**
Depreciation	15 years	-127.808
EBIT		**1.112.777**
Interest	7% of loan, 6 years payback period	-46.970

EBT		**1.065.807**
Tax	20%	-213.161
EAT		**852.646**

Table 13: Parameters AWG + PV + Filling Station (own processing)

Parameters AWG + PV + Filling Station		
Investment cost AWG + PV		1.750.377
Transport AWG		70.000
Location	Contract setup costs	8.000
Filling Station		80.000
Bottles		3.750
Housing facility		5.000
Total investment costs	**(CAPEX)**	**1.917.127**
Depreciation period	15 years	
Water sales revenues	0,6€/l	
Financing	6 years payback	
Loan	70%	1.341.989
Equity	30%	573.138
Annual redemption	6 years	223.665
Interest payment year 1	7% interest rate	93.939
Average interest rate	7% interest rate	46.970

Table 14: Model 4 - performance indicators (own processing)

Performance indicators	
DSCR = (EBITDA – tax) / (annual redemption + interest)	380%
ROE = EAT / Equity	148%
ROA = EAT / CAPEX	44%

This final option would provide the highest amount of autarky – no external electricity is needed and one could provide a means of distribution easily. This sustainable model is well suited for small remote islands reliant on the tourism industry, especially as a long-term solution. Debt is sufficiently covered with

380%, ROE is also 148% and the total investment costs are earned in less than three years.

22. Conclusion

The research done for this thesis has shown that implementing atmospheric water generation on small tropical islands has manyfold benefits, especially when comparing to other modes of water generation. One does not have the negative effects of desalination and when running via clean energy there are no emissions at all! Also, the yield one obtains is significantly higher than from the various modes of fog harvesting. Regarding waste, there are potentially tons of plastic waste from PET bottles that can be avoided.

Further, when looking at such a project from a business perspective, all four models calculated in this thesis offer very high returns. The most profitable model would be model 1, which could be implemented for communal use when acceptability could potentially be the highest and the distribution could be managed individually (as in people coming to the AWG to fill their own containers, etc.) or locally – these costs would have to be incorporated into the calculation but should not change the economic outlook drastically. Also, the communal or non-touristic use would be more efficient, since the water used for washing in the filling process could be consumed instead. However, one must keep in mind that the electrical energy consumption of producing all that water is not insignificant and a clean approach here would be preferrable and more sustainable in the long run. Also, one would contribute to a clean environment (especially when considering that on small islands it will be hard to look away from pollution – think of residual petrol films on the ocean) and not be reliant on volatile oil-prices. Especially the proposed models including PV would be sustainable and above all still highly lucrative.

One very big problem that could be faced is the issue of transport of the AWG and the Filling Station to an island. While taking the easy way and assuming that governments could facilitate and possibly provide an airlift of heavy containers to and island via military helicopters, this would need further research and possibly involve requests on ministerial level, even diplomacy in case a government in question has no such machinery in its military stock. It could also be, however, that there is a sufficient port on the island and infrastructure to transport heavy containers to their final destination. In such a case transportation should pose no problem.

Concluding, all models proposed in part II of this thesis are beneficial in an island setting and highly lucrative. While this thesis just serves as a broad approach to the feasibility of such an installation and in-depth research would have to be done on a case-by-case basis, the overall findings are very positive.

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ANNEX

1. PHANTOR -Technical-datasheet

PHANTOR
THE MOBILE WATER GIANT

TECHNICAL DATASHEET

In response to the growing demand for new ways to generate drinking water and based on the latest scientific findings, the team around Walter Kreisel develops an atmospheric water generator.

The Mobile Water Giant PHANTOR marks a new category in the field of atmospheric water generators. PHANTOR, as a high-performance mobile AWG, is designed for both stationary and semi-stationary use, unlike most conventional atmospheric water generators.

PHANTOR can extract up to 10,000 liters of drinking water from the air daily and thus belongs to the biggest AWGs.

The innovative design of the system and the integrated self-optimizing software set new standards in the field of energy efficiency of atmospheric water generators. This shows the years of experience in the field of energy systems and renewable energies of neoom group gmbh, the company behind the project. With PHANTOR, the concentrated know-how of the neoom hardware and NTUITY software team is driven to perfection.

PHANTOR is named after the elephant, who can smell water for several kilometers and even drill for it.

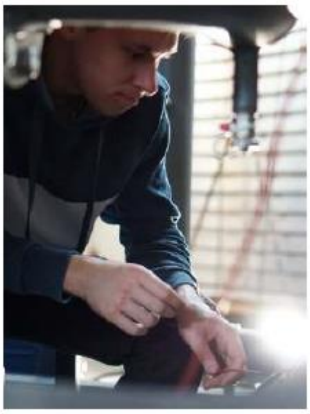
AWGs are used where water scarcity is a daily challenge: in remote locations, in dry regions or agricultural areas, during peacekeeping operations and catastrophes, but also for urban development.

Technical data	
Length	12 m
Width	2.28 m
Height	2.65 m
Weight	14,300 kg
Power supply	max 120 kW (400V, 50Hz) 4.8 kWh neoom® Li-ion off grid battery system for autonomous emergency power supply
	Oil free chiller system, contact free magnetic bearings for highest efficiency and low maintenance
Water treatment	Combi filter, UV-disinfection, mineralization, bacterial filter. Verified drinking water (above WHO standards)
Integrated water tank	1,000 Liters
Integrated photovoltaics	1.5 kW power
Housing	Suitable for installation near the cost. Housing and steel structure in C5 coating
Measuring control technology	State of the art PLC with NTUITY® Link On Board (including visualization and remote control)

The thermodynamic simulation model of PHANTOR was developed in cooperation with the **University of Applied Sciences Upper Austria**. Tests in the climatic chamber of the accredited test center **Rail Tec Arsenal** confirm the outstanding function of PHANTOR and show that the real results are in agreement with the simulation model.

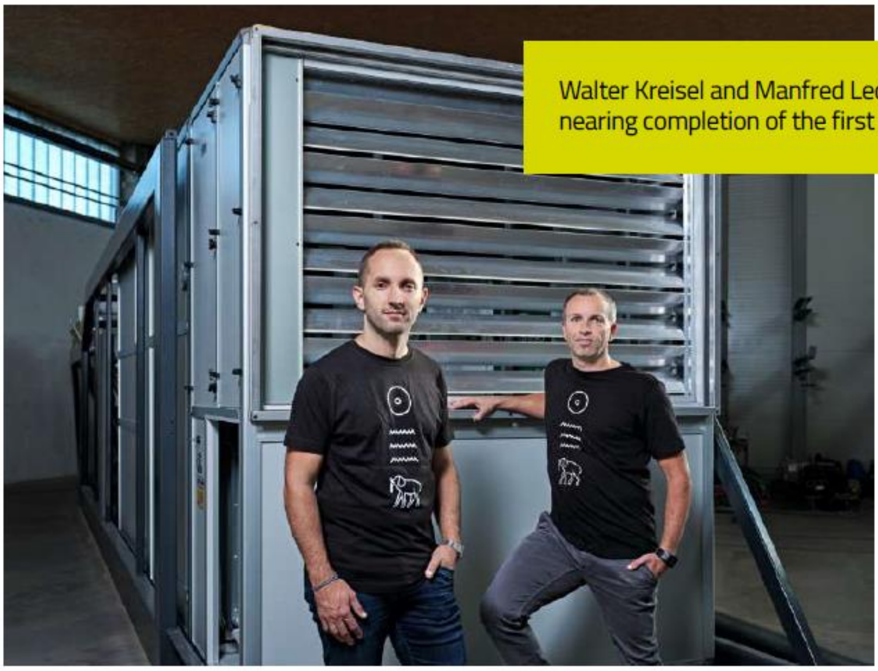
rel. F [%]	**Waterproduction per 24 hours**												**Rail Tec Arsenal Austria**
95		2 055	3 071	4 039	5 127	6 351	7 775	9 396	10 240	10 168	10 674	10 890	7 573
85			2 435	3 293	4 279	5 361	6 574	7 977	8 779	9 078	8 672	9 117	6 143
75			1 821		3 454	4 418	5 522	6 603	7 641	7 769	8 067	7 629	4 938
65					2 603	3 449	4 416	5 469	6 567	6 699	6 689	6 685	4 634
55						2 479	3 308	4 228	5 201	6 334	6 981	6 316	4 764
45								2 936	3 754	4 683	5 711	6 274	4 428
35												4 747	4 186
30													3 717
[°C]	0,01	12,50	15,00	17,50	20,00	22,50	25,00	27,50	30,00	32,50	35,00	37,50	40,00

rel. F [%]	**Energyefficiency in Watthours per litre**												**Rail Tec Arsenal Austria**
95		427	327	289	285	282	260	260	211	210	194	183	206
85			394	328	310	301	308	268	249	253	252	229	264
75			454		351	329	331	365	323	319	289	283	338
65					416	383	354	352	379	366	357	338	373
55						479	419	389	395	384	377	378	394
45								484	467	443	432	425	459
35												495	532
30													582
[°C]	0,01	12,50	15,00	17,50	20,00	22,50	25,00	27,50	30,00	32,50	35,00	37,50	40,00



As the world population continues to increase massively and water consumption increases even faster, the demand for mobile water generators is growing.

For years the World Economic Forum's Global Risks Report is reporting that the global water crisis is one of the greatest threats humanity will face over the next few decades. Global warming is changing freshwater lakes, rivers and streams. Groundwater is under threat from fracking, oil fields and oil transport, reports Greenpeace. This means that humanity needs "new water", e.g. through atmospheric water generators. PHANTOR, the mobile water giant, provides millions of people access to safe drinking water through state-of-the-art technologies and renewable energy.



Walter Kreisel and Manfred Ledermüller nearing completion of the first PHANTOR.

neoom group gmbh

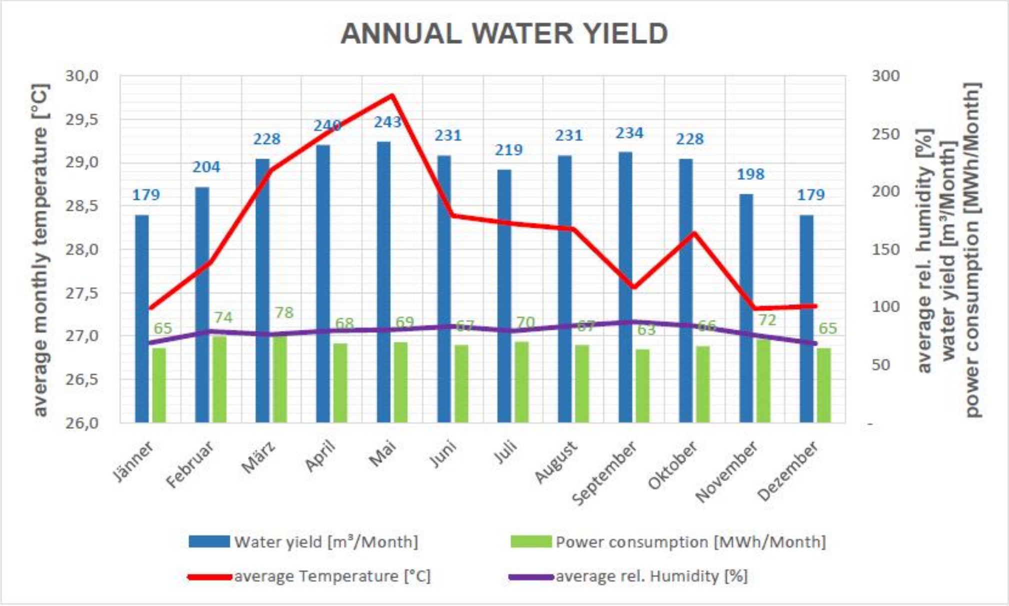
The neoom group has recognized the megatrends of decarbonisation, digitization, decentralization and e-mobility at all levels, thus taking the necessary energy transition to a new level. From renewable energy sources to efficient storage technologies and charging infrastructure with the neoom® brand (neoom.com) to the intelligent NTUITY® energy management software platform (ntuity.io), the neoom group offers comprehensive concepts and products that are tailored to the needs of the customer.

neoom group gmbh   Industriestraße 6, 4240 Freistadt, Austria   www.neoom.group

2. Calculations provided by Imhotep.Industries GmbH

CALCULATION OF THE MONTHLY WATER YIELD

Kampot, Kambodscha



max. annual water yield:	2 615 833	litres per year
annual power consumption:	825	MWh per year
max. annual operating hours:	8 760	hours per year

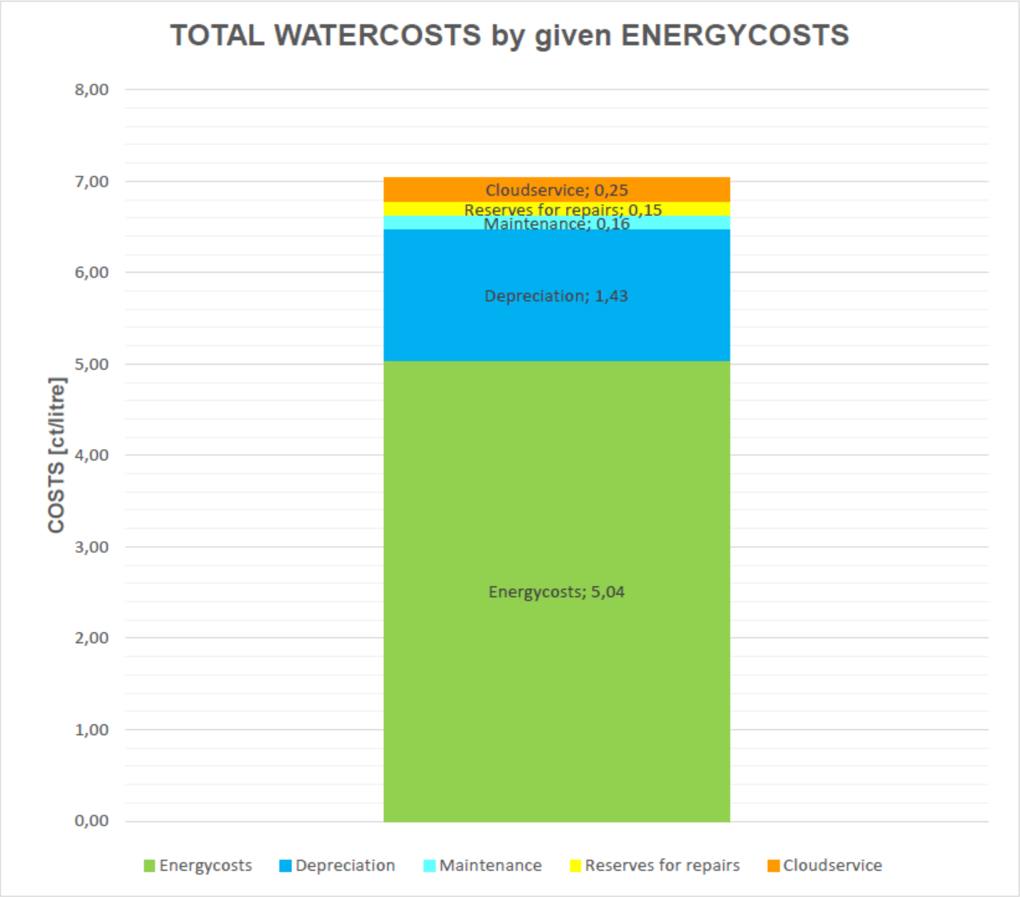
Rough Concept of WATER COSTS by given ENERGYPRICE

Phantor costs	€	503 058
Costs of Transport	€	30 000
Duty	€	-
Total CAPEX	**€**	**533 058**

Calculation Time		15	years
Workload		95%	of max.
Reserves for repairs	€	3 773	per year
Costs of energy		0,16	€/kWh

GRID

	absolute value			specific	
Energycosts	€	125 355	per year	5,04	ct/litre
Depreciation	€	35 537	per year	1,43	ct/litre
Maintenance	€	3 854	per year	0,16	ct/litre
Reserves for repairs	€	3 773	per year	0,15	ct/litre
Cloudservice	€	6 213	per year	0,25	ct/litre
TOTAL WATERCOSTS				**7,03**	**ct/litre**



Rough Concept of WATER COSTS by PV + BATTERY

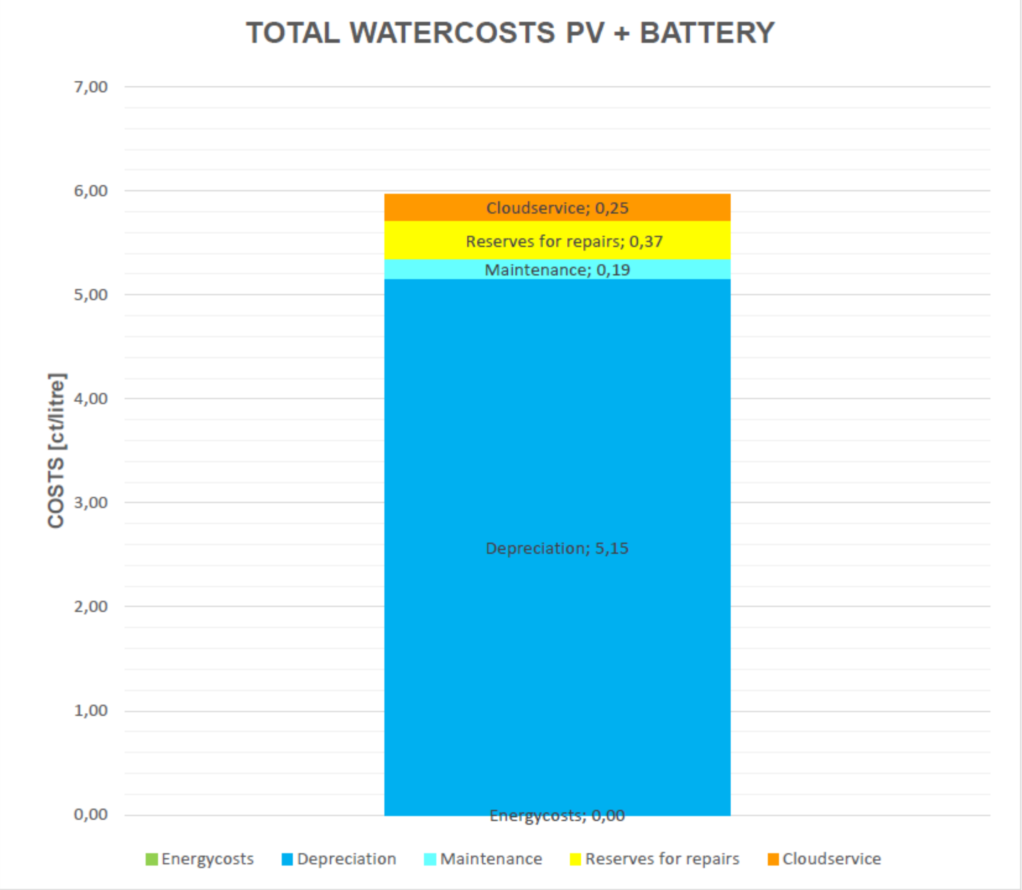
Systemcosts	€	1 750 377
Costs of Transport	€	70 000
Duty	€	-
Total CAPEX	**€**	**1 820 377**

Calculation Time		15	years
Workload		90%	of max.
Reserves for repairs	€	8 752	per year
Battery Capacity		1 275	kWh
PV power max.		508	kWp
PV surplus		**98**	**MWh/a**

PV + BATTERY

	absolute value			**specific**	
Energycosts	€	-	per year	0,00	ct/litre
Depreciation	€	121 358	per year	5,15	ct/litre
Maintenance	€	4 564	per year	0,19	ct/litre
Reserves for repairs	€	8 752	per year	0,37	ct/litre
Cloudservice	€	5 886	per year	0,25	ct/litre
TOTAL WATERCOSTS				**5,97**	**ct/litre**

any PV surplus is not taken into account in the calculation



Rough Concept of WATER COSTS by GEN.SET

Systemcosts	€	599 058
Costs of Transport	€	40 000
Duty	€	-
Total CAPEX	**€**	**639 058**

Calculation Time		15	years
Workload		95%	of max.
Reserves for repairs	€	8 986	per year
fuel costs	€	0,70	€/litre
Energy content fuel		10	kWh/litre
efficiency gen.set		40%	

Gen.set

	absolute value			**specific**	
Energycosts	€	137 107	per year	5,52	ct/litre
Depreciation	€	42 604	per year	1,71	ct/litre
Maintenance	€	4 817	per year	0,19	ct/litre
Reserves for repairs	€	8 986	per year	0,36	ct/litre
Cloudservice	€	6 213	per year	0,25	ct/litre
TOTAL WATERCOSTS				**8,04**	**ct/litre**