INNOVATIVE DESALINATION PLANT DRIVEN BY A COUPLED RENEWABLE ENERGY SYSTEM (QUALITATIVE CASE STUDY: POWER PLANT IN MAHDIA, TUNISIA)

WATER POLICY BRIEF

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1. Abstract

Water scarcity has become a key topic worldwide, and many international and national action plans have already been initiated to cope with this alarming issue. With water turmoil expected to worsen over the coming years due to the increasing population, limited water resources and the dramatic pressure of climate change, a thorough reflection on sound water management is needed. In particular, non-conventional water resources need to be seriously considered. Brackish water desalination for agriculture, one of the most water-hungry sectors, is a possible solution. Considering several factors – mainly water salinity – the process is relatively costly in terms of energy consumption and presents a few other technical limitations. To mitigate the environmental and financial impact of dependency on fossil fuels, the use of renewable resources for desalination seems a sustainable and cost-effective solution. In this report, we assess Tunisia’s previous experience using renewable energies in desalination and suggest an exclusive coupled desalination plant model operating with combined waste-to-energy and solar energy resources for a targeted optimal performance with a qualitative approach. The plant would be implemented on the coast of the governorate of Mahdia due to its economic, ecological and social assets. This report facilitates water resources management in Tunisia by qualitatively assessing, modelling and managing the implementation of desalination water plants based on a mix of renewable resources. The main purpose of this report is to fund this project and turn it from an idea into a tangible on-site project.

Keywords: water scarcity, renewable energy, desalination, coupled model, waste-to-energy system, solar energy, sustainable management, sustainability, circular economy, environmental assessment, brackish water, agriculture

2. INTRODUCTION

Clean waterfalls within human rights are underlined by the Sustainable Development Goals (SDGs) implemented by the United Nations General Assembly, intended to be achieved by 2030 (United Nations General Assembly 2017). Drinking water is already under the strain of demographic, industrial, geopolitical and environmental factors, and its scarcity is predicted to increase. Climate change will result in extreme weather conditions with higher temperatures, drought, heavy rain episodes and severe storms. Meanwhile, rising sea levels will result in marine intrusion, and degrading groundwater reserves (World Health Organization [WHO] 2017).

The world’s greatest groundwater systems are already dwindling (Richey et al. 2015). As assessed by the Falkenmark indicator (Falkenmark, Lundqvist and Widstrand 1989), which links the available drinking water resources to the total global population, stress levels indicated scarcity in
Central and West Asia and North Africa, with less than 1,000 m³ per capita per year, including water for food production and non-domestic use (Rijsberman 2006). Over 2 billion people live in regions with severe water shortages (United Nations Water 2018), with almost one-sixth of them condensed in agricultural areas (Food and Agricultural Organization of the United Nations [FAO] 2020) and roughly two-thirds facing severe water shortages at least one month per year (Mekonnen and Hoekstra 2016). This is putting water suppliers under increasing strain, and by 2025, half of the world’s population is expected to face water scarcity (WHO 2022).

The Mediterranean is not immune to the water crisis, with all indicators pointing towards unsustainability. The Southern Mediterranean, with more areas characterized by a desert climate, is facing a water shortage, with an average annual potential water availability below 1,000 m³ per capita per year, considering the available freshwater resource. Agriculture is the greatest consumer (Iglesias et al. 2007). For countries in a water-stressed situation, non-conventional water resources could replace or complement conventional water resources. Non-conventional water includes treated or untreated wastewater, water contaminated with sediments or/and toxic components, agricultural drainage water, seawater and brackish water desalination (Pereira, Cordery and Iacovides 2009).

The suggested treatment method to obtain drinking water and water for agricultural use is desalination, especially since recent results have proven its ability to obtain more efficient and cost-competitive desalination around the world (Darre and Toor 2018). Tunisia is a Mediterranean country with a heterogeneous climate. The north and coastal areas are marked by a Mediterranean-type climate, while the interior is semi-arid and the south is arid (European Environment Agency [EEA] and United Nations Environment Programme Mediterranean Action Plan [UNEP-MAP] 2014, Annex 6). Conventional water resource distribution is mostly concentrated in the north of the country, with an annual amount of 4,600 million cubic metres (MCM), of which 54 per cent has salinity below 1,500 parts per million (ppm). The total amount is displayed as 2,700 MCM for surface water and 1,900 MCM for groundwater (DHV Water BV and BRL Ingénierie 2004, Annex 2).

Given the diversity of available techniques for renewable energy technologies, the selection of parameters for a coupled desalination plant working with both wastes-to-energy and solar energy resources requires an optimized sizing and economic approach. Therefore, this work proposes a hybrid-fuzzy multi-criteria decision-making methodology for renewable power source selection.
The named methodology is conducted based on meteorological models, installed capacities of renewable energies, maintenance costs and Levelized cost of energy (LCoE). Moreover, it takes into consideration environmental and socioeconomic factors with respect to various crucial criteria to shape a sustainable assessment tool. These include life cycle perspective, thresholds and uncertainties, and software support. Finally, the execution and running of the proposed project and the deduction of an analytical study was supported by the cloud platform for a more feasible study. The tools supporting this work are the National Aeronautics and Space Administration (NASA) Prediction of Worldwide Energy Resources (POWER) tool for the gathering of meteorological data, RETScreen for the obtention of a financial model of microgrids, and Hybrid Optimization of Multiple Energy Resources (HOMER) Pro for the sizing of solar photovoltaics and biomass systems. HOMER was used to design a techno-economic system that achieves the smallest LCoE and smallest emissions percentage. Consequently, a feasible technical model can be obtained for use as a reference when executing similar projects in Tunisia.

3. WATER DESALINATION IN TUNISIA

The most important challenge faced by water desalination resides in its dependency on energy. Therefore, the assessment of the energetic context of Tunisia is of primary importance. Desalination was essentially driven by renewable energies and Tunisia had early small-scale experience in this field which evolved over decades.

3.1. The energy framework in Tunisia

Tunisia has made big improvements in its private investments and engagement policies. It has successfully introduced both auctions and competitive bidding schemes. Their design allowed for both medium-sized and utility-scale projects which helped attract local and international investors to the Tunisian markets. It had the potential to attract more investments in renewable energy based on its generally favourable business conditions and focus on creating
a sustainable pipeline of private renewable energy projects. Since energy prices in Tunisia are relatively high, the next consideration could be opening the power generation market further to the private-to-private sale of electricity from renewable sources (AFEX 2019).

3.1.1 Fossil energies

Until the Arab Spring, Tunisia had been supplying its demand for energy using gas royalty fees from the Algerian–Italian pipeline, ensuring a positive balance. From 2000, it started showing an increasing deficit. Since 1980, the reserve depletion led Tunisia to solve its energy issue with gas imported from Algeria (Medrest 2018). Since the Tunisian Revolution of 2011, Tunisia has been classified as a country in transition between a centrally planned and market economy (Feige 1994). However, the decline in production so far within the energy industry has been dramatic.

According to the industrial production index (IPI) (2010 = 100) (INS 2019), there was a continuous decrease between 2011 and 2019 from 93 to 63.6, and from 80.51 in August 2020 to 66.01 in December of the same year (INS 2021). Many factors contributed to the deterioration of the energy sectors such as the revolution, which resulted in a fluctuating and insecure geopolitical frame. Several factors contributed to the augmentation of the energy deficit such as smuggling with Libya, employee strikes and an increase in energy subsidies’ contribution to the depletion of natural resources, reaching 7 per cent of gross domestic product (GDP). This increase is mainly due to the energy mixture adopted by the country, which consists of 53 per cent natural gas, 46 per cent oil and no more than 0.5 per cent renewable energy.

In 2014, Tunisia started its transition based on two pillars: endorsement of energy efficiency and promotion of renewable energy. The first was intended to limit dependency on imported primary energy. Demand is expected to drop by 34 per cent in 2030 compared to a current percentage of 60 per cent (Kamel 2017). In May 2005, the Tunisian Government passed a law allowing renewable energy to be used as a source for electricity generators. Later, in 2015, a policy allowing the production of electricity through renewable energy (No. 2015-12 of 11 May 2015) was promulgated to enable private stakeholders to invest in this field via the auto-production and the concession of projects with electrical power above 10 MW, 30 MW and 5 MW for solar, wind and biomass, respectively. The privatization of projects below these thresholds was authorized in 2014 to consolidate the partnership between public and private stakeholders (Ministry of Industry, Energy and Mines 2020).
3.1.2 Renewable energy

Many projects were launched to increase the contribution of renewable energy to electricity generation, with the aim of providing a lower tariff and cleaner energy by 2030, producing 30 per cent of electricity from renewable energy sources, and achieving the SDGs (German Agency for International Cooperation [GIZ] 2015). According to the International Renewable Energy Agency (IRENA), in 2017, the main renewable energy supply source was bioenergy – in the form of biogas and dendro energy – followed by solar and wind energy, with 93 per cent, 5 per cent and 4 per cent, respectively. Geothermal and hydraulic energy were marginal (IRENA 2018). Renewable energy was substituting primary electricity resources in many industrial fields such as water desalination plants. Approximately 97 per cent of Tunisia’s electricity is generated from fossil fuels, mainly natural gas. In 2020, nearly 57 per cent of Tunisia’s natural gas needs were met through imports (mainly from Algeria), with local gas production coming from the concessions of the country’s national exploration company and foreign company concessions. The highly anticipated Nawara gas field, which finally started production in early 2020, is expected to help reduce the overall energy deficit by 20 per cent and gas imports by 30 per cent once it reaches peak production. Only 3 per cent of Tunisia’s electricity is generated from renewables, including hydraulic, solar and wind energy. Figures 1 and 2 show the potential of renewable energies in Mahdia City and how we can introduce distributed renewable resources to utilize the solar energy profile in this region.

![Figure 1: Proposed distribution of energy resources across Mahdia coast](image-url)
Figure 2: Solar irradiance distribution using NASA POWER Data Access Viewer software

Figure 3: Clearness index profile for solar irradiance using NASA POWER Data Access Viewer software
3.2. Desalination and renewable energies experience

In Tunisia, the earliest research on water desalination was conducted in the 1920s by exploiting the abundance of solar. In 1929, in the city of Ben Garden, and later in 1930, in the city of Fort Saint – commonly known as Borj El Khadhra – two desalination-by-evaporation stations were implemented to supply potable water to the French military. In 1962, a solar energy group was created within the Tunisian National Atomic Energy Commission (CENA). Between 1967 and 1968, three desalination stations monitoring solar energy were established in the cities of Chekmou, Chibou and Mahdia. The year 1982 was a turning point in desalination, with the exclusive use of reverse osmosis within the framework of a national solar energy research programme involving the French Alternative Energies and Atomic Energy Commission (CEA) in Borj Cedria. Since 1993, several projects involving wind and solar energy have been launched by the Tunisian Secretary of State for Scientific Research and Technology (SERST). Many technologies were used such as reverse osmosis, multi-stage flash, membrane desalination and electrodialysis (Ben Jemaa et al. 1998). In 2016, there were about 110 desalination units. They were more concentrated in the south of Tunisia such as Gafsa, Tozeur, Medenine, Sidi Bouzid and Kebili to deal with the acute water shortage in those areas, and on the islands of Djerba and Kerkennah. The majority of desalination plants were using brackish water to desalinate, while a few of them were implemented on the coast. They were located in Kerkennah, Gabes, Zarzis and Djerba (DHV Water BV and BRL Ingénierie 2004, Annex 2). In 2018, 200 desalination plants were implemented on the island of Djerba, producing 50,000 m³ of drinking water per day and up to 75,000 m³ per day (Awaad et al. 2020). In the city of Sfax in the south of Tunisia, specifically Gargour, the Japan International Cooperation Agency (JICA) financed a seawater desalination plant with an expected capacity of 100,000 m³ of water per day, which is intended to be extended to 200,000 m³ per day (JICA 2020).
4. CASE STUDY: AN ALTERNATIVE COUPLED MODEL FOR BRACKISH WATER DESALINATION

4.1 Plant location

4.1.1 Presentation of the selected location

The governorate of Mahdia has 11 delegations (Mahdia, Ksour Essef, Chebba, Melloulech, Boumerdes, Sidi Alouane, El Jem, Essouassi, Chorbane, Ouled Chamekh and Hebira). It has a total surface area of 2,878 km² - 1.9 per cent of the country’s total surface area. In 2014, it was home to 410,812 people, representing 3.8 per cent of the Tunisian population. It is an arid area with rainfall varying between 325 mm in the littoral subregion and 246 mm in the interior region. Water resources in Mahdia mainly constitute rainwater. The governorate has nine water tables containing 17 million m³ and four underground deep water tables with reserves estimated at 3.15 million m³. Of its total 40 million m³ of water resources 65 per cent come from groundwater, 21 per cent from surface water, 13 per cent from treated wastewater and only 1 per cent from water desalination. However, the water balance remains negative with a high salinity ranging between 5g/l and 6 g/l. Overexploitation of groundwater is a critical issue. In 2015, water tables were overused by as much as 151 per cent while deep water was overused by about 78 per cent, which is accelerating groundwater depletion. Other problems are the lack of efficient coordination between the water stakeholder within the governorate and the indebtedness of water associations (The Ministry of Development, Investing and International Cooperation 2018).

4.1.2 Selection criteria of the location

We would like to implement the desalination plant in the governorate of Mahdia, a coastal zone located in central-east Tunisia (see Figure 4). The location was chosen for five reasons: (1) it is close to the sea which will save energy consumed for energy transportation; (2) it is far from urban
areas for the safety, environment and hygiene of the riverside population (we have chosen a distance of 4km from residential areas); (3) the plant can be set up on the bare ground to avoid any land tenure problems, especially with farmers in the area; (4) it is accessible; and finally, (5) it has strong cropping areas for irrigation by the treated water. Furthermore, the governorate of Mahdia is characterized by a diverse soil occupation of olive trees, orchards and vineyards (see Figure 5). As such, this location enables irrigation of a large number of crops. The soil salinity, assessed as moderate, should be favourable for crop growth (see Figure 6). When in contact with the treated water, the salinity rate can be balanced, allowing for the cultivation of other types of crops.

Figure 4: Proposed station location within the governorate of Mahdia
4.2 Water desalination plant system model

The system model is based on powering pumps to get salty water and feedback to its membranes. The energy provided for electrical pumps would be a mixture of solar photovoltaic (PV) panels, batteries for energy storage systems and a biomass generator for sharing electricity load.
with solar PVs in times of low irradiance levels. This combination aims to achieve the highest renewable fractions, making the system fully sustainable with low emissions. However, the grid connection should also be maintained for the reliability indices of the system. A lot of repowered units such as PV-reverse osmosis (RO) are limited to small-scale desalination systems and have various specific energy consumption values ranging from 1.1 to 16 kWh m⁻³. Solar energy is variable and thus efficient storage means and batteries are required. For remote locations, instead of RO, the use of PV is also attractive for electrodialysis where Brackish Water (BW) is readily available throughout the year.

Figure 7 shows an assembly of a typical RO desalination plant coupled with a PV generator. This configuration collects (1) a set of storage battery blocks with the system to stabilize the energy input to the RO unit and compensate for solar radiation variations; and (2) a charge controller to protect the battery block from deep discharge and overcharge, and RO desalination system. Kashyout et al. (2021) discussed the different types of PV-RO combined systems. These systems are RO powered by a batteryless PV system, RO powered by PV connected to a displacement pump via a variable direct current (DC)-to-DC converter and PV connected to the power grid. Where a PV-RO system is batteryless, the desalination rate has been found to increase by 5 per cent if the feed pressure is operated under varied values depending on the PV output power.

Solar desalination technologies are also classified into direct and indirect solar desalination types. Solar PV/concentrator photovoltaics (CPV) can drive RO desalination, with several advantages including:

1. The RO process requires one source of energy (which is electricity).
2. RO is a one-phase (liquid) desalination process.
3. RO requires less specific energy consumption compared to other technologies.
4. RO plant is made up of modules which are easy to install, maintain and operate.
5. The driver PV/CPV modules can be installed on the roof of the RO building (i.e. PV/CPV panels will not need any additional areas).
Abbreviations: MED: multi-effect distillation; MSF: multi-stage flash; MD: Membrane Distillation; ED: Electro-dialysis

Figure 7: Water desalination techniques coupled with renewable energy sources

4.3 Operation modes and power balance of renewable water desalination plant

A power plant model, as shown in Figure 8, can operate according to three categories of operation mode based on surplus power compared with the required electrical load. In (1) the balanced generation mode, solar PVs sustain the electrical load for peak sun hours and the energy storage system (batteries) takes over the load in the evening. In (2) the surplus generation mode, solar PVs exceed the electrical load demand for peak sun hours and the energy storage system (batteries) is then charged from the available surplus power. In (3) the lack of generation mode, solar PVs cannot handle the electrical load demand for peak sun hours and biomass generators, and batteries start to supply the remaining load power. The appendix gives further details. Figure 9 presents an example of water desalination plants’ distribution of processes. The main objective of the proposed renewable system is to power water desalination processes without depending on fossil fuels and grid-variable prices.
5. SYSTEM MODEL AND RESULTS

The system optimization results are obtained using HOMER Pro software, which performs thousands of simulations and gives the best possible design for the system in techno-economic terms. In this project, a grid-connected alternating current (AC)/DC microgrid (MG) comprising wind, solar, a battery bank and an AC load were set up in the configuration shown in Figure 10. As Figure 11 shows, the load chosen includes both industrial and commercial profiles for 24 hours with a
renewable fraction percentage of 75 per cent. This magnitude “is the fraction of the energy delivered to the load that originated from renewable power sources”, according to the HOMER Pro website (HOMER Pro 3.15 n.d.). The purpose of this system is to provide a generic model for water desalination power plants that use fossil fuels to shift their thermal and electrical load to achieve a higher percentage of renewable fraction for power generation, for a LCoE ranging from USD 0.1/kWh to USD 0.4/kWh, based on loading schemes and the plant’s water processes.

Figure 10: AC/DC microgrid design using HOMER PRO

Figure 11: Power plant load file
5.1 The impacts of the implementation of the desalination plant

The software compares several combinations of energy sources to determine the optimal techno-economic MG mix. For the chosen resources, the software favoured the use of the grid only, but to maximize the renewable energy penetration, the following combination of wind, battery energy storage systems (BESS), PV and grid was chosen. The most considerable impact on marine ecosystems is the brine. However, this is considered an exaggeration, as desalination plants have their own treatment systems and the danger is exclusive to the plants located on closed seas, gulfs or lakes (Al-Jazeera 2019). Furthermore, cheap brine desalination techniques such as the use of algae showed decent removal efficiency (El Sergany, El Fadly and El Nadi 2014).

5.2 Environmental impact

This proposed power plant model is a good example of the energy-water nexus. Meanwhile, Tunisia and Germany recently signed a memorandum of understanding for the establishment of a green hydrogen alliance, with the aim of developing the green hydrogen market in Tunisia. That said, this energy production requires significant amounts of high-quality water. There are exciting scientific opportunities to solve that challenge (Germany, Federal Ministry of Economics and Technology 2021).

5.2.1 Climate change mitigation

By signing the Paris Agreement in 2016, the Tunisian Government committed to Nationally Determined Contributions (NDCs) and to reduce greenhouse gas (GHG) emissions by 41 per cent compared to 2010, by 2030. In 2012, the renewable energy sector was a major contributor to those emissions (GIZ 2015). Therefore, the transitional energy strategy aims at fostering renewable energies which are likely to align with this goal. The major greenhouse contributors to global warming are, in descending order, carbon dioxide (CO₂), methane (CH₄) and tropospheric ozone (O₃) of which the future growth in the atmosphere is fostered by increased CH₄, carbon monoxide (CO), nitrogen oxides (NOx), and volatile organic compounds (VOCs) (Berntsen et al. 2018). Over the course of 100 years, the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) of 2014 stated the global warming potential (GWP) of CO₂ as 1 and that of nitrogen oxide as
As shown by Table A6, the value of CO\textsubscript{2} released by our designed system is about 119.608 kg/year and that of NO\textsubscript{2} is about 254 kg/year, which quantifies the global warming environmental impact of CO\textsubscript{2} and NO\textsubscript{2} respectively at 1.20E-07 and 6.73E-05 metric tonnes of CO\textsubscript{2} equivalent (MTCO\textsubscript{2}e).

5.2.2 Waste management

According to the Agence Nationale de Gestion des Déchets [National Agency of Waste Management – ANGED], solid waste in Tunisia is composed of 63.2 per cent organic waste, 9.4 per cent plastic, 6.8 per cent paper and cardboard, 8.7 per cent textiles, 1.6 per cent metals and 1.1 per cent glass (ANGED 2019). Organic waste, the dominant waste, includes body waste from livestock, food waste, residual farm products and sewage sludge. Tunisia is an unsustainably food-wasteful country (mainly by households); this type of waste generates more important biogas than other biomass which makes it suitable for methanation (Food Industry Affairs Bureau, Ministry of Agriculture, Forestry and Fisheries 2018). Biomass, including the biodegradable fraction of municipal wastes used in this waste-to-energy plant by methanation, will reduce the potential environmental impacts of this waste. In fact, biomass emissions to the air were deemed to contribute to forest degradation, thus threatening biodiversity; soil degradation via emissions to land; ozone depletion and climate change via GHG emissions when out in the open and during the combustion of wood with domestic health risks; and energy waste, since proteins are burned instead of used (Ravindranath and Usha Rao 2005).

5.2.3 Resources

Energy subsidies contribute to the depletion of natural resources. Renewable energy creates new resources that can be permanently recycled. In our case, the coupled model of biomass-to-energy and solar energy covers two aspects: biomass is a stable energy source that does not change with the seasons, while solar energy harnesses the most widely available renewable source in Tunisia, thanks to the sun’s relatively strong radiance.

5.2.4 Human health

Several irrigation practices deemed harmful to human health are still in expansion. Since the early 1980s, Tunisia has promoted the use of treated wastewater for irrigation. The latter is generally conducted to the second treatment level. The managed surface subject to this irrigated
surface increased between 1965 and 2019, from 1,100 ha to 9,815 ha. Twenty-two per cent of the treated water was directly reused on 4,114 ha of surface in 2019 (ONAS 2019). Nevertheless, studies have shown this water to negatively impact human health: prolonged unsound use of treated wastewater under drip irrigation may lead to the bioaccumulation of heavy metals within the plant, animal and human organisms, up to toxicity thresholds (Asgari and Cornelis 2015).

In contrast with some non-conventional water types used for irrigation, such as agriculture drainage water and wastewater which includes heavy metals, petroleum hydrocarbons and pesticides (Awaad et al. 2020), treated wastewater does not pose a risk to human health. However, in the event of a transgression of the status of reuse, intoxication and infection remains considerable. The potential impact of human intoxication includes substance interiorization by ingestion, inhalation, or dermal exposure. The coupled model is expected to release sulfur dioxide, which is lethal at high doses. Short-term exposure to this gas can cause bronchial construction and changes in metabolism, while chronic exposure – either continuous or multiple – swells the mucosal tissues and increases secretions (Alberta Environment 2003). About 519 kg is dumped per year, as shown in Table A6.

5.2.5 Ecosystem quality

The increase in water turbidity may cause marine organisms to die and algae to encounter photosynthesis issues as well as contribute to the diffusion of chemical products. Furthermore, the deposit of brine results in atmospheric and marine pollution (Carneiro and Ferreira 2012). Concentrated waste brine is discharged to the ocean from the water desalination plant, which increases water temperature, salinity and current. This release also stimulates the proliferation of algae at the expense of marine fauna (Al-Mutaz 1991).

5.2.6 Agriculture

The Tunisian coast covers about 24 per cent of the entire country’s cereal lands, 29 per cent of fodder crops, 41 per cent of pulses, 50 per cent of market gardening and 53 per cent of arboriculture (Elnaas 2015, p. 152; Chaher et al. 2020), which shows the importance of agricultural activities in coastal areas. Moreover, Tunisia’s climate ranges from the Mediterranean in the north, semi-arid in the centre and the Gulf of Gabes; and arid in the south (United Nations Development Programme [UNDP] 2001). While average annual rainfall is around 400 mm/year, the distribution between regions is significantly heterogeneous. While the rainfall in two-thirds of the country is
between 50 mm and 350 mm/year, it remains extreme in the northwest with 1,500 mm and in the southwest with below 100 mm. In terms of water quality, it tends to show high salinity and pollution. Salinity increases from the north to the south passing by the centre, with 3 g/l, 4.6 g/l and 4-5 g/l, respectively (Ben Boubaker et al. 2003). Half the irrigated areas in Tunisia are threatened by high salinity (Bouksila 2011).

In the Middle East and North Africa (MENA) regions, resorting to irrigation with desalinated water was a solution to the increasing salinity of the soil (El Kharraz 2020). Our model, using brackish water, can provide a competitive water price for irrigation in the governorate of Mahdia and potential riparian areas located in the governorates of Sfax, Monastir and Kairouan; and improve the irrigation water supply and quality. These governorates have different water issues ranging from scarcity to low quality, in addition to a high population and industrial/agricultural activities.

5.3 Socioeconomic impact

5.3.1 Odour, noise and landscape

The quantification of odour and noise is more qualitative and depends on indicators taking into consideration the thresholds detected by target representative samples of people, the scope of emissions and the exposed population. Although methanation is a closed system, several emissions of odorous molecules may leak into the atmosphere. Noise and landscape would not be problematic as the location of the plant should be far enough from settlements, taking into consideration wind speed and direction.

5.3.2 Contribution to rural income and diversification

Biomass exploitation can generate direct and indirect new jobs in addition to diversifying employment opportunities in rural areas. Furthermore, the preparation of land for the production of energy crops could be a beneficial solution to the abandonment of land in rural areas, and potentially help reduce the exodus to towns (Carneiro and Ferreira 2012).
6. PROPOSAL FOR WATER DESALINATION DATA ANALYSIS

Currently, we are exploiting big data concepts to support and facilitate water resources management in the MENA region by assessing, modelling and managing the implementation of desalination water technologies. An attempt was made to develop a big data open platform using both Azure and Galileo clouds to offer a system for the manipulation of various heterogeneous statistical databases. This system provides effective tools that help assess all the possible desalination alternatives using multi-criteria decision analysis (MCDA), and hypsometric and hybrid-fuzzy logic approaches. Meanwhile, it brings diverse information technology tools based on simulation models, decisions and stochastic aspects. The big data platform has been designed such that different components are integrated, from the assessment tools to the user interface. These constituents have been adopted while taking into consideration the local conditions in each studied country. They include the preferred type of desalination process, water type, capacity range and energy sources that affect the performance and cost of the desalination and energy generation technology to be implemented or studied (see Figure 12).

![Big data model for selecting water desalination technique](image)
CONCLUSIONS

There can be no doubt that the non-conventional water resources extend the water availability which helps in the development of irrigation and improvement of soil quality. This alternative conceptual model introduces a new technology valuing waste in Tunisia and works efficiently and sustainably. The system is optimized automatically thanks to HOMER Pro software to provide an optimal design system to operate a water desalination plant with the least LCoE.

Introducing such a new model will impact the entire governorate and its neighbourhood by extending the surfaces irrigated with brackish water and valuing up to 65% of organic waste, which is usually either incinerated or left out in the open, releasing substances that contribute to global warming. The introduction of this exclusive model to Tunisia will allow biomass-to-energy technologies to prosper.

Moreover, compared to treated wastewater, water from desalination presents fewer health risks considering how the legal use of wastewater can be abused. However, the price of desalinated brackish water remains high due to the cost of energy. This model achieves the smallest LCoE (USD 0.243) and the highest percentage of renewable fraction (76 per cent), ensuring continuity of supply with the use of the national grid network. The choice of location reduces the direct impacts on human health and welfare and mitigates energy transportation effects.

This project is an incentive to foster sustainable management which takes into account potential environmental impact mitigation and endorses a circular economy approach. It is likely to attract potential sponsoring grants and funds such as climate funds; contribute to better water irrigation quality and decrease energy supply expenses. Financing such a project is desirable considering its incentives and impacts.
RECOMMENDATIONS

- Water is a necessity for life. Given the impact of climate change, water is becoming a limited resource, leading to the presence of several water treatment units. In this context, our project aims to improve the quality of water destined for irrigation and expand the areas irrigated with brackish water. This will also mitigate the burden on groundwater for agricultural use.

- This study is driven by a qualitative approach. For further comparisons with the existing desalination plant emissions and energy consumption, we first need a qualitative study. This would provide accurate measures which could provide a basis for decision-making. Furthermore, providing legal land tenure details is very helpful for selecting the precise location based on the determined criteria.

- The innovation in the desalination plant we propose is its multidisciplinary function: our unit helps protect the environment, with the reuse of organic waste contributing to the reduction of GHGs. This system will be well conceived and should be continuously adjusted using artificial intelligence techniques. It is recommended for future work to use deep reinforcement learning on how to run the water desalination plant with a reward function that maximizes water production, utilizes the available renewable energy and eliminates any expected emissions.

- The execution of the project will be facilitated after private stakeholders’ investment in renewable energy rights. The collaboration between public and private sectors should value this initiative which aims to have a sustainable impact on the environment and society. The project could be financed via applications for international funds such as climate, governmental, asset manager and organization/non-governmental organization (NGO) funds. Relying on the mitigation aspect of the system, funds dedicated to developing countries should be targeted. Due diligence must be conducted for transparency purposes.
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Arab Future Energy Index (AFEX) - Renewable Energy 2019 report


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Equation (1) identifies the balanced generation mode, where $P_{RE}$ is the power provided by the renewable resources, $P_L$ is load power and $P_{sys,losses}$ is the total system losses. In this way, the energy provided by the various renewable resources is just covering the energy demand and system losses. Equation (2) represents the surplus generation mode and equation (3), the lack of generation mode. The water desalination plant’s load can be classified into four main categories: (a) multi-stage flash (MSF), (b) multi-effect distillation (MED), (c) vapour compression and (d) reverse osmosis (RO). Figure 5 shows an example of water desalination plants’ distribution of processes. The main aim of the proposed renewable system is to supply water desalination processes without depending on fossil fuels and grid-variable prices.

$$P_{RE} = P_L + P_{sys,losses} \quad (1)$$

$$P_{RE} + P_{bat} = P_L + P_{sys,losses} \quad (2)$$

$$P_{RE} < P_L + P_{sys,losses} \quad (3)$$

Table A1: Costs of optimized microgrid (MG)

<table>
<thead>
<tr>
<th>Componenent</th>
<th>Capital (₦)</th>
<th>Replacement (₦)</th>
<th>O&amp;M (₦)</th>
<th>Fuel (₦)</th>
<th>Salvage (₦)</th>
<th>Total (₦)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Generic 1.5 MW</strong></td>
<td>₦3,000,000.00</td>
<td>₦662,629.84</td>
<td>₦324,581.33</td>
<td>₦0.00</td>
<td>₦340,698.08</td>
<td>₦3,646,513.09</td>
</tr>
<tr>
<td><strong>Generic 100KWh Li-ion</strong></td>
<td>₦70,000.00</td>
<td>₦22,553.31</td>
<td>₦10,819.38</td>
<td>₦0.00</td>
<td>–₦3,533.17</td>
<td>₦99,839.52</td>
</tr>
</tbody>
</table>
Table A2: Total MG energy production

<table>
<thead>
<tr>
<th>Production</th>
<th>kWh/yr</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Generic flat plate PV</strong></td>
<td>54,607</td>
<td>6.80</td>
</tr>
<tr>
<td><strong>Generic 1.5 MW</strong></td>
<td>558,931</td>
<td>69.6</td>
</tr>
<tr>
<td><strong>Grid Purchases</strong></td>
<td>189,253</td>
<td>23.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>802,791</td>
<td>100</td>
</tr>
</tbody>
</table>
### Table A3: Aggregated load consumption

<table>
<thead>
<tr>
<th>Consumption</th>
<th>kWh/yr</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Primary Load</td>
<td>317,331</td>
<td>39.5</td>
</tr>
<tr>
<td>DC Primary Load</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Deferrable Load</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Grid Sales</td>
<td>485,460</td>
<td>60.50</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>802,791</td>
<td>100</td>
</tr>
</tbody>
</table>

### Table A4: Electricity production-demand profile

<table>
<thead>
<tr>
<th>Quantity</th>
<th>kWh/yr</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excess Electricity</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Unmet Electric Load</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Capacity Shortage</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Table A5: Renewable energy penetration

<table>
<thead>
<tr>
<th>QUANTITY</th>
<th>VALUE</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>RENEWABLE FRACTION</td>
<td>76.4</td>
<td>%</td>
</tr>
<tr>
<td>MAX. RENEW. PENETRATION</td>
<td>100</td>
<td>%</td>
</tr>
<tr>
<td>QUANTITY</td>
<td>VALUE</td>
<td>UNITS</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>---------</td>
<td>----------</td>
</tr>
<tr>
<td>CARBON DIOXIDE</td>
<td>119,608</td>
<td>kg/yr</td>
</tr>
<tr>
<td>CARBON MONOXIDE</td>
<td>0</td>
<td>kg/yr</td>
</tr>
<tr>
<td>UNBURNED HYDROCARBON</td>
<td>0</td>
<td>kg/yr</td>
</tr>
<tr>
<td>PARTICULATE MATTER</td>
<td>0</td>
<td>kg/yr</td>
</tr>
<tr>
<td>SULFUR DIOXIDE</td>
<td>519</td>
<td>kg/yr</td>
</tr>
<tr>
<td>NITROGEN OXIDES</td>
<td>254</td>
<td>kg/yr</td>
</tr>
</tbody>
</table>
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As of July 1st, 2021, and eleven years after its creation, the CMI has officially joined the United Nations (UN), hosted by the United Nations Office for Project Services (UNOPS).

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