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Economic feasibility of a 11-MW wind powered reverse osmosis desalination system in Morocco

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ABSTRACT

In Morocco, the wind is an abundant resource in nearly all the coastal regions. In this context, an 11 MW Wind Powered Reverse Osmosis connected to the grid was planned in the Tan-Tan town. The purpose of this work is to investigate whether the wind powered reverse osmosis desalination system is economically feasible in this town. In this study, assessments of the wind power potential in Tan-Tan using Weibull functions were made. The Weibull parameters were calculated using the Standard Deviation method from the measured data. For the assessment of the Levelized Water Cost, an Excel calculation tool was developed. The research finds that the wind powered reverse osmosis desalination system is not economically feasible in Tan-Tan due to its low wind potential. The mean annual wind speed of this town was calculated to be 5.19 m/s at a height of 9 m above the ground.

Keywords: Desalination; Reverse osmosis; Wind energy; Cost; Morocco

1. Introduction

It is well known that the three major problems that mankind should face during this century are climatic change, fossil fuel depletion and growing water shortage. All these problems are threatening the future security and prosperity of Mankind [1,2].

In the Mediterranean region, the increasing scarcity of fresh water is becoming the most severe problem that one should face. The situation is becoming more complicated by increased pressure on water resources caused by population growth, urbanization, industrialization and growing needs of agriculture.

For several decades, desalination has been increasingly used worldwide to meet water needs in many scare areas.

Reverse osmosis is now a well-established technology for the desalination of brackish and sea water [3]. It gains acceptance around the world and plays a larger and more important role in the desalination market for small-, medium- and large- scale applications [4].

Furthermore, with regard to thermal processes, Reverse Osmosis is gaining increased acceptance as a viable technique, mainly because of its low energy consumption and design flexibility [5].

It is characterized by a high energy efficiency achieving specific energy consumptions as low as 3 kWh/m^3 of desalinated water [6].

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The problem with Reverse osmosis as with the other desalination commercial processes is their sensitivity to fluctuating power. It is recognized that fluctuating power causes mechanical fatigue, shortening the lifetime of the Reverse osmosis and impairing performance [3].

However, even if Reverse Osmosis is less energy demanding, desalination techniques are in general characterized by large energy expenditures to generate potable water, that makes the desalinated water cost very high for developing countries not producing fossil fuels such as Morocco.

Also, the direct and indirect use of fossil fuels for powering the desalination processes could be considered as incompatible with the sustainable development concept. It contributes to the shortage of fossil fuels and participates to the increase of the CO_2 emissions [7].

For over two decades, the increasing concern for the environment has increased the interest for the use of renewable energy sources. The case of wind energy is very revealing [8]. Its tremendous growth during this period due to its low cost and technological maturity has pushed the technology to become as a commercial source of electricity in over 50 countries around the world. It is therefore one of the most promising renewable energy sources [9,10].

The annual market volume of wind turbines increases by 20–30% per year, reaching significant contributions to the national electricity supply in some countries (Denmark, Germany, and Spain). Wind turbines have increased in size more than tenfold in 20 years. Over the past two decades, global installed capacity has increased from 2.5 GW in 1992 to almost 120 GW by the end of 2008 [11].

As the use of wind power increases around the world, the study of coupling this technology to desalination systems has increased significantly in the last decades. In recent years there has been intensified R&D effort in this field [3,6,12–17].

In Morocco, there is a growing awareness of taking more advantages from wind energy and of using it in different applications such as driving desalination process.

In this context, an 11.2 MW Wind Powered Reverse Osmosis is planned [18]. The economic analysis of this project is the main objective of the work presented in this paper.

2. The water situation in Morocco

2.1. General context

Morocco has a potential of natural water resources estimated at about 20.7 billion m^3/year, i.e. an average allocation of almost 691 m^3/year per inhabitant [19].

Moreover the rainfall is characterized by temporal and geographical disparities. It is lower than 300 mm per year in the south and it can exceed the 700 mm per year in the north.

In five months, the north of Morocco gets 90% of rainfall, whereas the south gets a lot less.

Some northern regions get up to 2000 mm of rainfall per year, while some southern regions do not get more than 40 mm per year, fifty times less.

To overcome the temporal and the geographical disparities, policy of construction of dams and of the transfer of water to arid regions has been adopted since the sixty years of the last century. Morocco has today some 103 dams for a capacity of approximately 16 billion m^3. In spite of these efforts, the availability of water decreases with the years. The availability of water in the year 2020 will be just about 500 m^3/capita/year, which corresponds to a shortage situation.

The demographic explosion in these three last decades and the growing urbanization due to rural migration because of long periods of dryness for a long time have strongly contributed to the overexploitation and the deterioration of the water quality. Morocco which had more than 80% of rural population just after independence has today only some 45%. The intense irrigation and the silting of the dams (the silting causes the loss of the equivalent of one dam per year) are also important factors in the reduction and the pollution of the water resources.

The policy of careful planning and vigilant management adopted by Morocco since 1980 gave satisfactory results for some years, but it reached its limits by 2000. Without additional water sources, the water deficit will keep growing, even if more dams are built in the future, since they alone will not mobilize more water by capita. The obligation to use non-conventional water resources such as desalinating water or waste water reuse and the need for a more rigorous policy of planning and water management become a necessity.

In the field of the non-conventional resources, the big progress in Morocco is the use of desalination in spite of the relatively high cost per cubic meter. Morocco has access to seawater along a coastline of more than 3500 km and has a big potential of brackish water.

For years, Morocco has been developing cost-effective solutions using Reverse Osmosis desalination as one of its strategies for addressing the country's water resource challenges.

Considerable efforts were done in the south of Morocco with the construction of several desalination plants in particular by the National Office of Potable Water (ONEP) and the Cherifien Office of Phosphates (OCP). The ONEP is the State Company in charge of providing the country with drinkable water. The national production capacity by desalination today exceeds 50,000 m^3/day and will increase rapidly. The ONEP continuously launches invitations to tender for extension of the existing installations and for construction of new installations in the south of the country. Among these, an installation of more than 80,000 m^3/day is envisaged in Agadir town in 2020.

Moreover, the OCP will launch a tender to build a new desalination plant with a capacity of 250,000 m^3/d in the Centre of Morocco (Jorf Lasfar) [20].

2.2. The case of the city of Tan-Tan

Tan-Tan, a city of 72,000 inhabitants in 2006 [21], is located in the arid, water scarce south of Morocco (Fig. 1). It is presently supplied with fresh water from a ground water aquifer through one of the longest mains (130 km) in Morocco. The reserved amount (about 4000 m^3/day) for Tan-Tan city hardly satisfies present fresh water needs. In 2003 the first desalinated plant was built in Tan-Tan to assure the crucial needs of potable water which compromises the social and economic development of the city. This plant desalinates brackish water with a capacity of 1700 m^3/d.

The future needs of potable water, crucial for Tan-Tan city's social and economic development, would be supplied by non-conventional resources using brackish water or seawater as an unlimited resource [22].

Fig. 1. Location of Tan-Tan in the Moroccan map.

In order to contribute to lower the cost of seawater desalination in Morocco and to re-enforce the current drinking water production in the city of Tan-Tan, the ONEP was planned, to set a wind powered Reverse Osmosis system in this city in 2009.

The Desalination plant would be located at about 10 km south of the port of Tan-Tan, which is 25 km west of the city on the Atlantic coast [23].

Its total capacity of 11,232 m^3 would be installed into three phases [18]:

- a capacity of 6,048 m^3/day in 2008,
- a capacity of 9,502 m^3/day (+ 3,454 m^3/day) in 2010,
- a capacity of 11,232 m^3/day (+ 1,730 m^3/day) in 2015.

However for technical and economical reasons, the first phase was postponed to 2011.

3. Status of renewable energy sources in Morocco

3.1. Potential of renewable energy

Morocco is characterized by intensive solar radiation, and wind is an abundant resource in nearly all the coastal regions. Mean daily global horizontal radiation varies between 4.7 and 5.7 kWh/m^2 a day, with the south of the country receiving on average more h on sunshine (3000 h) than the north (2800 h) [24]. The first large-scale development of solar energy is a combined cycle natural gas/solar thermal plant at Ain Beni Mathar (100 km from Oujda) due to be commissioned in 2012 [25].

Wind resources are even more promising for renewable energy development, both in terms of intensity and constancy. In the south of the country, average wind speeds reach 7.5–8.5 m/s, while wind speeds in the north are higher, averaging at 8–11 m/s; they are at their highest on the southern Atlantic coast [26]. There is also far more land available for wind power development in Morocco. Furthermore, the southern region is dominated by the global winds called the trade winds, which create one of the largest and steadiest wind systems on earth.

3.2. Current renewable energy measures in Morocco

The use and development of renewable energies has become a major policy incentive in the country. Morocco has formulated various strategy measures to accelerate the development of renewable energy technologies in order to enhance the long-term energy security of the country and to contribute to the global reduction of climate change [1].

Under a Renewable Energy and Energy Efficiency Law passed in May 2007, the Moroccan Government has set ambitious targets for renewable energy sources for the next five years. The objective is to ensure that 10% of the commercial primary energy and 20% of the electricity consumed in Morocco will be supplied via these forms of energy by the year 2012 [27].

Furthermore, there is an ambitious target to install 1000 MW of wind turbines by the end of 2012 [28]. Morocco has an installed wind power capacity of 124 MW in 2008. From 2008 to 2010, almost 540 MW of wind parks was planned [27].

4. Wind powered desalination configuration of the Tan-Tan plant

The Wind Powered Reverse Osmosis system that would be set in Tan-Tan will be grid connected. The advantage of this configuration is that the desalination system can continue to operate in low winds and can provide a more dependable supply of energy in general. Additionally, the system could be set up so that any residual wind energy not used for desalination could be sold back to the grid.

Figure 2 shows a scheme of the adopted configuration.

The electricity produced by the Tan-Tan wind park will be supplied to the desalination plant and to the seawater intakes pumps. The grid-connected configuration gives the system the flexibility to buy electricity when the wind speed is low, and sell the extra power when the wind speed is high. However, the selling power price will depend on the contractual agreement between the ONEP and the electricity utility (ONE).

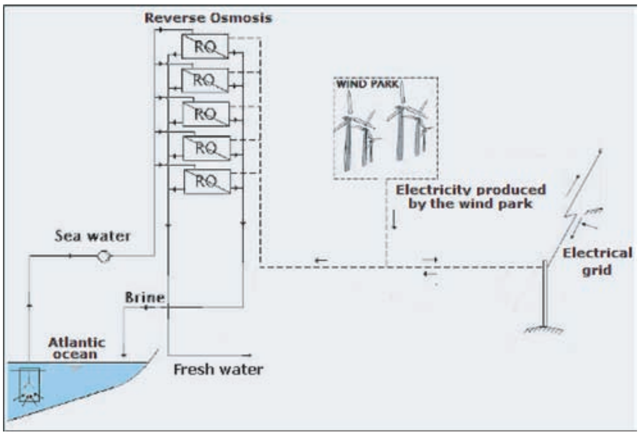

Fig. 2. Installation scheme of reverse osmosis system in combination with electric grid and wind turbine.

5. Statistical wind analysis for energy output estimation of the wind park

5.1. Introduction

As the economics of the wind-powered desalination process are strongly site dependent, a thorough analysis of local wind conditions is indispensable [3,6,7–17].

Different wind speed distribution models are used to fit the wind speed distribution and to estimate the energy output over a time period such as the Weibull, the Rayleigh and the Lognormal models. The 2-parameter Weibull function (named after the Swedish physicist W. Weibull, who applied it in the 1930s) is considered the most used by researchers involved in wind speed analysis for many years [29–30].

5.2. The Weibull distribution

The general form of the Weibull distribution function for wind speed can be characterized by its probability density function f_w(v) as follows [31]:

$$f_w(v_i) = \left(\frac{k}{c}\right)\left(\frac{v_i}{c}\right)^{k-1} \exp\left[-\left(\frac{v_i}{c}\right)^{k}\right] \tag{1}$$

where v_i is the wind speed, c is the scale factor and indicates how ‘windy’ a wind location under consideration is, and k is the dimensionless shape parameter and indicates how peaked the wind distribution is [32].

In order to estimate the two parameters of Weibull distribution, several methods can be used depending on which wind statistics are available. In this paper the method of Standard Deviation was applied for data collected from the Moroccan Wind Atlas [26].

The one-year (1994) data used in this study are grouped in Table 1. The wind speed is grouped into classes as given in the second column. The mid-value for each speed class interval is given in the third column. The probability of a given wind speed is presented in the fourth column.

The probability density distribution calculated from the Weibull function $f_w(v_i)$ is shown in column 7.

The mean annual wind speed (v_m) and standard deviation (σ) are calculated using the following equations [33]:

$$v_m = \sum_i^n v_i p(v_i) \tag{2}$$

$$\sigma = \sum_i^n p(v_i)\,(v_i - v_m)^2 \tag{3}$$

From Table 1, the mean annual wind speed v_m and the standard deviation σ for Tan-Tan city and for the year 1994 are 5.188 m/s and 2.475 m/s respectively.

Table 1
Wind measurement data; v_m and σ calculation, probability density distribution calculated from the Weibull function $f_w(v_i)$.

i	Speed class v_i	v_i	$p(v_i)$	$v_i p(v_i)$	$p(v_i).(v_i - v_m)^2$	$f_w(v_i)$
1	0–1	0.5	0.0132	0.0066	0.2901	0.0182
2	1–2	1.5	0.0597	0.0896	0.8120	0.0677
3	2–3	2.5	0.0988	0.2470	0.7139	0.1149
4	3–4	3.5	0.1517	0.5310	0.4322	0.1472
5	4–5	4.5	0.1940	0.8730	0.0918	0.1581
6	5–6	5.6	0.1799	1.0074	0.0305	0.1480
7	6–7	6.5	0.1270	0.8255	0.2186	0.1228
8	7–8	7.5	0.0700	0.5250	0.3742	0.0911
9	8–9	8.5	0.0398	0.3383	0.4366	0.0607
10	9–10	9.5	0.0240	0.2280	0.4462	0.0364
11	10–11	10.5	0.0150	0.1575	0.4233	0.0197
12	11–12	11.5	0.009	0.1047	0.3626	0.0096
13	12–13	12.5	0.0062	0.0775	0.3315	0.0042
14	13–14	13.5	0.0039	0.0527	0.2694	0.0017
15	14–15	14.5	0.0030	0.0435	0.2601	0.0006
16	15–16	15.5	0.0022	0.0341	0.2339	0.0002
17	16–17	16.5	0.0014	0.0231	0.1791	0.0001
18	17–18	17.5	0.0007	0.0123	0.1061	0.0000
19	18–19	18.5	0.0003	0.0056	0.0532	0.0000
20	19–20	19.5	0.0003	0.0059	0.0615	0.0000
21	20–21	20.5	0.00	0.0000	0.0000	0.0000

5.3. Determination of the Weibull parameters

Once the mean annual wind speed (v_m) and the standard deviation (σ_V) are calculated for a given data set (Table 1); then k and c can be found using the relations 4 and 5 [34]:

$$k = \left(\frac{\sigma}{V_m}\right)^{-1.086} \tag{4}$$

$$c = \frac{V_m}{\Gamma\left(1+\frac{1}{k}\right)} \tag{5}$$

Γ is the gamma function $\left(\Gamma(x) = \int_0^\infty t^{x-1}e^{-t}dt\right)$

The values of k and c deduced are

$k = 2.23$ and $c = 5.86$ m/s

The corresponding Weibull curve is shown in Fig. 3.

According to Fig. 3, it could be said that the Weibull distribution is successful in representing the measured data.

5.4. Estimation of the wind energy output of the wind park

The wind park would have an installed capacity of 11.2 MW. Its total capacity would be installed in three phases [18]:

- wind farm of 5.6 MW in 2008,
- wind farm of 8.8 MW (+3.2 MW) in 2010,
- wind farm of 11.2 MW (+2.4 MW) in 2015.

However for technical and economical reasons, the first phase was postponed to 2011.

To approximate generated wind energy by a wind turbine, the measured wind speed is first scaled to

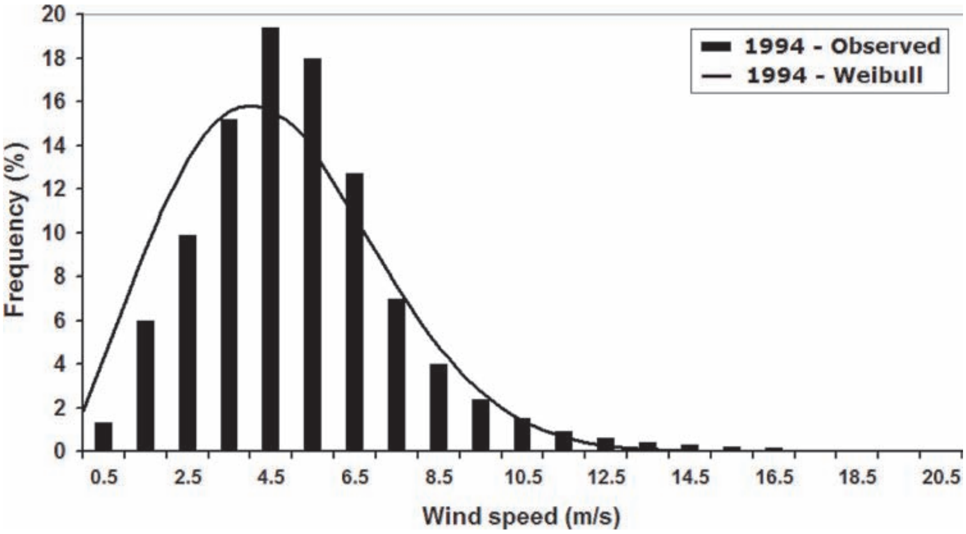

Fig. 3. Wind speed frequencies comparison between Weibull function prediction and the wind data in Tan-Tan (measured at 9 m above the ground).

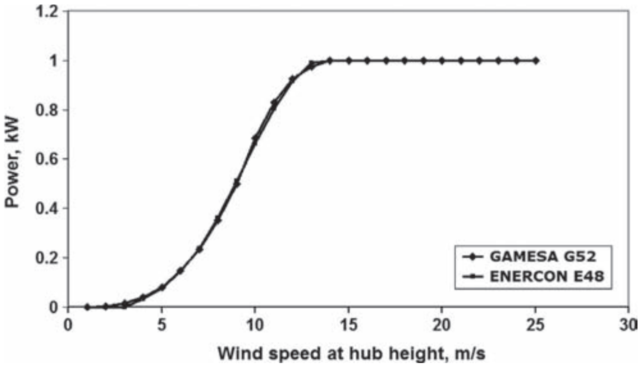

Fig. 4. Non-dimensional power curves for two selected wind turbines: Gamesa G52 and Enercon E48 [38,39].

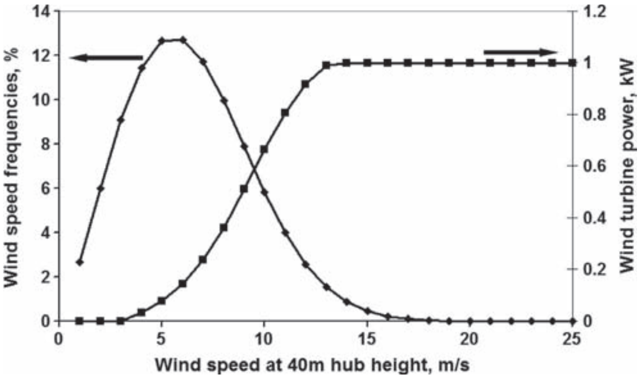

Fig. 5. The probability distribution of wind speed at 40 m above the ground and the non-dimensional Gamesa G52 power curve used for energy output estimation.

approximate wind speed at the hub height of the wind turbine; then a manufacturer's power curve is used to interpolate a generation level at given hub wind speed [35].

The problem of transformation of Weibull parameters at the hub heights of the wind turbines can be easily solved due to the features of the Weibull distribution. This can be done by applying the so-called one seven power law [36–37]:

$$\frac{c_2}{c_1} = \left(\frac{z_2}{z_1}\right)^{1/7}, \tag{6}$$

where c_1 and c_2 are respectively the Weibull scale parameters at heights z_1 and z_2. Even if the Weibull shape parameter, k, varies with height, its variation is small, and for the present analysis, the shape factor is assumed to be independent of the height [36]

In the absence till now of any decision concerning the choice of the wind turbine model for the wind park, the wind energy output calculations of the wind park were carried out using the non-dimensional power curve of the Gamesa wind turbine of 810 kW nominal power [38]. Figure 4 compares the non-dimensional power curve of this wind turbine [38] with the one of Enercon 880 [39].

This figure does not show significant difference between the two non-dimensional power curves. The technical characteristics of the two wind turbines are presented in Table 2.

By knowing the wind speed distribution of the site and the power curve of the wind turbine model adopted or its non-dimensional power curve, the total energy output of the wind park may be determined.

According to the non-dimensional power curve of the Gamesa G52 wind turbine and the wind speed distribution at 40 m (Fig. 5); the specific annual energy output of the wind park (GWh/MW) of Tan-Tan could be estimated from Eq. (7) [35].

$$E_{out} = \sum_{i}^{n} f_w(v_i) P_i(v_i) T, \tag{7}$$

where:

$f_w(v_i)$ the Weibull distribution,

P_i: the wind turbine output as a function of the wind speed v_i,

T: 8760 h/year.

Table 2
Technical characteristics of GAMESA G52 [38] and ENERCON E48 [39].

	Gamesa G52-850 kW	Enercon E48-800 kW
Rated power (kW)	850	800
Rotor diameter (m)	52	48
Hub height (m)	44–74	50–76
Turbine concept	Gearbox with 1 planetary stage / 2 helical stages, variable speed, pitch control	Gearless, variable speed, variable pitch control
Number of blades	3	3
Cut-in wind speed (m/s)	4	3
Rated wind speed (m/s)	14	13
Cut-out wind speed (m/s)	25	28-34

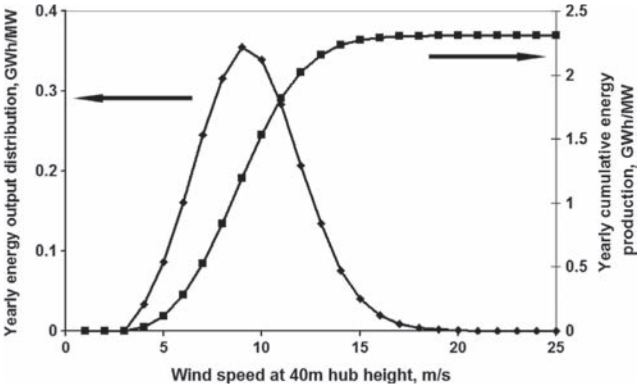

Fig. 6. The annual energy output distribution of the wind park at 40 m above the ground (GWh/MW) and the yearly cumulative energy production (GWh/MW).

The annual energy output distribution of the wind park per installed MW at height of 40 m and its yearly cumulative energy production are shown in Fig. 6.

From this figure, the annual energy production could be obtained. It is found to be equal to 2.308 GWh/MW. This annual energy production corresponds to a factor capacity of 26.3%.

6. Economic analysis

The cost of desalinated water should take into account all the costs incurred during the period of *n* years chosen for the economic analysis: investment costs and operating and maintenance costs.

All these expenses and services (cubic meter of water in this case) should be discounted [40].

This requires an 'appropriate' discount rate. For most economic analysis, discount rates of 5–10% are commonly used. In this analysis, a rate of 10% is used as it is recommended by the World Bank for developing countries [41–42].

As it is applied for delivered kWh [43], the levelized Water Cost (LWC) was calculated from the present value of total costs divided by the present value of the annual net water generation:

$$\mathrm{LWC} = \frac{\sum_{t=0}^{n} \frac{I_t + M_t - E_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{W_t}{(1+r)^t}}, \qquad (8)$$

where

LWC: levelized water cost,

I_t: investment expenditures in the year '*t*'. They include cost of wind turbines and desalination plants, civil work and different connections. The capital investment cost is assumed to be 1200 €/kW for the wind park [44] and 1000 €/m^3.d for the desalination plant [12,45],

M_t: operating and maintenance expenditures in the year *t*. They were considered to be 1 €¢/kWh for the wind park [44] and 15.3 €¢/m^3 [45] for the desalination plants which includes replacement, chemicals, repair, spare parts and insurance,

E_t: incomes from electricity sold in the year '*t*',

W_t: desalinated water production in the year '*t*',

r: discount rate. A value of 10% was considered as mentioned above.

n: lifetime of the system. It was assumed to be 20 years for each installation

t: year

In the case of this study, the investment would be devised over three years corresponding to the three phases of the Wind powered Desalination Reverse Osmosis construction.

Table 3
Technical characteristics, investment and the O&M costs of the Wind Powered Reverse Osmosis installation [12,44–45].

	Phase 1	Phase 2	Phase 3
Technical characteristics			
Wind parc			
Installed capacity (MW)	5.6	3.2	2.4
Annual electricity production per installed MW (GWh/MW)	2.308	2.308	2.308
Annual electricity production (GWh)	12.9248	7.3856	5.5392
Lifetime	20	20	20
Desalination process			
Daily water production (m^3/day)	6048	3454	1730
Annual water production (m^3/day)	2207520	1260710	361450
Specific electricity consumption (kWh/m^3)	5.0	5.0	5.0
Annual consumption (GWh)	11.0376	6.3036	3.1573
Electricity sold (GWh)	1.8872	1.0821	3.1573
Lifetime (Years)	20	20	20
Costs			
Discount rate	0.1	0.1	0.1
Investment cost			
Wind park (Million €)	6.72	3.84	2.88
Desalination process (Million €)	6.048	3.454	1.73
Total of the investment (Million €)	12.768	7.294	4.61
Part of operation and maintenance costs			
Wind park (€/kWh)	0.01	0.01	0.01
Desalination process (€/m^3)	0.153	0.153	0.153
Selling electricity price (€/kWh)	0.0437	0.0437	0.0437

The technical characteristics as well as the investment and the O&M costs for the whole Wind Powered Reverse Osmosis installation are given in Table 3.

The selling electricity price in Table 3 corresponds to the selling price of the electricity from the wind park to the grid.

Based on the data presented in the previous table and results, an Excel calculation tool was developed for the assessment of the LWC. Table 4 outlines the results.

From the calculation tool, the LWC obtained for the wind grid configuration is 0.86 €. With similar calculation, the LWC in the case of a grid-only configuration is 0.82 €. From an economical point of view, these results indicate that, it is more profitable for desalination in Tan-Tan to use the electricity from the grid than the wind electricity. The reason is the low wind potential of this town compared to other regions [7].

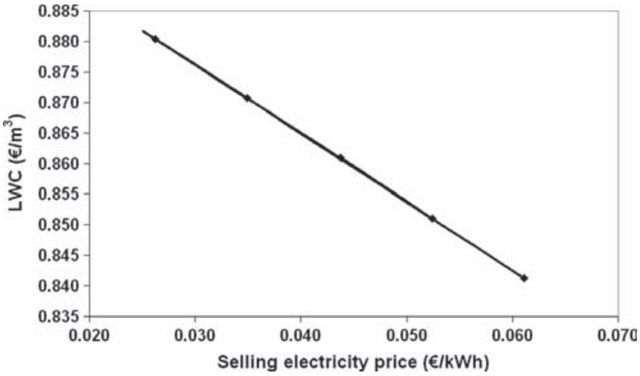

Fig. 7. Effect of the electricity selling price from the wind park to the grid on the levelized water cost of the wind-grid configuration.

Fig. 7 presents the LWC of the wind-grid configuration versus the electricity selling price from the wind park to the grid. From this figure, it could be concluded that the revenues from power sales to the grid do not have significant effect on the LWC. These revenues represent only 5.4% of the sum of the investment and O&M costs for the case of Tan-Tan.

Table 4a
Calculation tool results.

t	Year	Fixed costs = Investment (M€)			Variable costs=Operating & Maintenance (M€)			Electricity sold (M€)
		Desanitation process	Wind park	Total of the investment	Desanitation process	Wind park	Total O&M	
0	2008	6.0480	6.7200	12.7680			0.0000	
1	2009				0.3788	0.1292	0.4670	0.0824
2	2010	3.4540	3.8400	7.2940	0.3788	0.1292	0.4670	0.0824
3	2011				0.5306	0.2031	0.7337	0.1296
4	2012				0.5306	0.2031	0.7337	0.1296
5	2013				0.5306	0.2031	0.7337	0.1296
6	2014				0.5306	0.2031	0.7337	0.1296
7	2015	1.7300	2.8800	4.6100	0.5306	0.2031	0.7337	0.1296
8	2016				0.6273	0.2585	0.8857	0.2336
9	2017				0.6273	0.2585	0.8857	0.2336
10	2018				0.6273	0.2585	0.8857	0.2336
11	2019				0.6273	0.2585	0.8857	0.2336
12	2020				0.6273	0.2585	0.8857	0.2336
13	2021				0.6273	0.2585	0.8857	0.2336
14	2022				0.6273	0.2585	0.8857	0.2336
15	2023				0.6273	0.2585	0.8857	0.2336
16	2024				0.6273	0.2585	0.8857	0.2336
17	2025				0.6273	0.2585	0.8857	0.2336
18	2026				0.6273	0.2585	0.8857	0.2336
19	2027				0.6273	0.2585	0.8857	0.2336
20	2028				0.6273	0.2585	0.8857	0.2336
21	2029				0.2895	0.1292	0.4187	0.1512
22	2030				0.2895	0.1292	0.4187	0.1512
23	2031				0.0966	0.0554	0.1520	0.1040
24	2032				0.0966	0.0554	0.1520	0.1040
25	2033				0.0966	0.0554	0.1520	0.1040
26	2034				0.0966	0.0554	0.1520	0.1040
27	2035				0.0966	0.0554	0.1520	0.1040
Total								

Table 4b
Calculation tool results.

t	Year	Total Undiscounted (M€)	$1/(1+r)^t$	Total discounted (M€)	Water production undiscounted (m^3)	Water production discounted (m^3)
0	2008	12.7680	1.0000	12.7680		
1	2009	0.3846	0.9091	0.3497	2207520.0000	2006836.3636
2	2010	7.6786	0.8264	6.3460	2207520.0000	1824396.6942
3	2011	0.6041	0.7513	0.4539	3468230.0000	2605732.5319
4	2012	0.6041	0.6830	0.4126	3468230.0000	2368847.7563
5	2013	0.6041	0.6209	0.3751	3468230.0000	2153497.9603
6	2014	0.6041	0.5645	0.3410	3468230.0000	1957725.4184
7	2015	5.2141	0.5132	2.6757	3468230.0000	1779750.3804
8	2016	0.6522	0.4665	0.3042	4099680.0000	1912530.9765
9	2017	0.6522	0.4241	0.2766	4099680.0000	1738664.5241
10	2018	0.6522	0.3855	0.2514	4099680.0000	1580604.1128
11	2019	0.6522	0.3505	0.2286	4099680.0000	1436912.8298
12	2020	0.6522	0.3186	0.2078	4099680.0000	1306284.3908
13	2021	0.6522	0.2897	0.1889	4099680.0000	1187531.2643
14	2022	0.6522	0.2633	0.1717	4099680.0000	1079573.8767
15	2023	0.6522	0.2394	0.1561	4099680.0000	981430.7970
16	2024	0.6522	0.2176	0.1419	4099680.0000	892209.8154
17	2025	0.6522	0.1978	0.1290	4099680.0000	811099.8322
18	2026	0.6522	0.1799	0.1173	4099680.0000	737363.4838
19	2027	0.6522	0.1635	0.1066	4099680.0000	670330.4398
20	2028	0.6522	0.1486	0.0969	4099680.0000	609391.3089
21	2029	0.2675	0.1351	0.0362	1892160.0000	255688.6611
22	2030	0.2675	0.1228	0.0329	1892160.0000	232444.2374
23	2031	0.0480	0.1117	0.0054	631450.0000	70519.1727
24	2032	0.0480	0.1015	0.0049	631450.0000	64108.3389
25	2033	0.0480	0.0923	0.0044	631450.0000	58280.3080
26	2034	0.0480	0.0839	0.0040	631450.0000	52982.0982
27	2035	0.0480	0.0763	0.0037	631450.0000	48165.5438
Total		37.7153	10.2372	26.1906	81993600.0000	30422903.1174
Levelized Water Cost(€/m^3)						0.8609

Figure 8 shows the variation of the LWC of the grid-only configuration with grid electricity price. This figure shows that an increase of 10% in the grid electricity price leads to an increase of 4% in the LWC.

The effect of the wind park investment cost on the on the LWC for the wind-grid configuration is shown in Fig. 9. The results show that an increase in the wind park investment costs leads to an increase of 4% in the LWC of the wind-grid configuration.

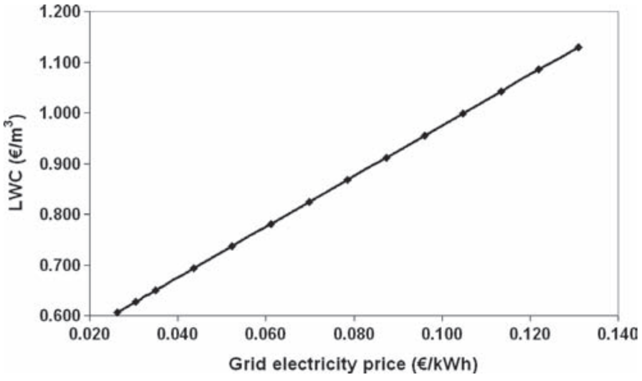

Fig. 8. Effect of the grid electricity price on the levelized water cost of the grid-only configuration.

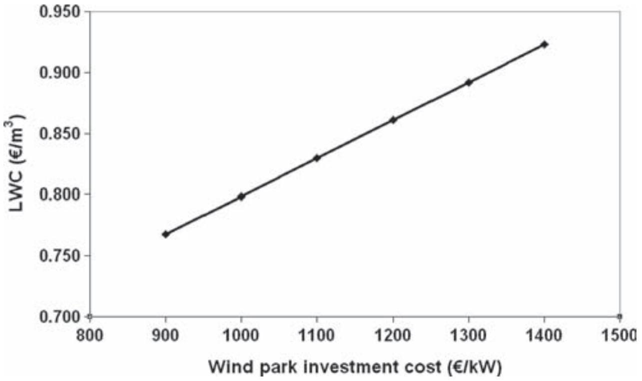

Fig. 9. Effect of the wind park investment cost on the LWC for the wind-grid configuration.

7. Conclusion

The evaluation of the economic feasibility of the 11 MW Wind Powered Reverse Osmosis in Tan-Tan has been the main aim of this paper.

In this study, assessments of the wind power potential in Tan-Tan using Weibull functions were made. The Weibull parameters were calculated using the Standard Deviation method from the measured data. For the assessment of the levelized Water Cost, an Excel calculation tool was developed.

The following conclusions can be drawn from the results of the present study.

1. The mean annual wind speed of Tan-Tan at a height of 9 m above the ground level was calculated as 5.19 m/s.
2. Weibull parameters, k and c, in the site were calculated as 2.23 and 5.86 m/s, respectively for the year 1994.
3. The annual electricity production of the 11.2 MW wind park was calculated as 25.85 GWh.
4. The wind-grid configuration LWC obtained for Tan-Tan was 0.86 € while the LWC in the case of a grid-only configuration was estimated to be 0.82 €. That shows a substantial difference between the two configurations on economic terms to the benefit of the grid-only configuration.

The wind-powered desalination could however offer in Morocco a sustainable solution to growing fresh water needs mainly in the south of the country where the wind resources are much higher than in Tan-Tan. As an example it is the case of Dakhla where the mean annual wind speed at a height of 10 m above the ground, is 8.4 m/s.

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