Feasibility assessment of a combined biomass-wind North-African micro-grid system throughout Tunisia in terms of connectivity to the projected European DC grid

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ABSTRACT

This research presents a techno-economic assessment of future possibilities for establishing a biomass-wind micro-grid system throughout Tunisia as well as the perspectives connectivity to the projected European DC grid. The study uses data collection and algorithms in order to evaluate economic, environmental and technical benefits. The European DC grid has been proposed recently as an alternative to the existent power net, with a major advantage of allowing each region, to specialize in the renewable technologies that suit it best while maintaining connection to a single grid. The obtained results gave evidence to an additional meaningful efficiency

Keywords: *Renewable energy, biomass, wind energy*

1. Introduction

It is well-known that the North-African basin is a very promising zone in the matter of wind and biomass energy as well as a key participant in the renewable energy area. Tunisia holds in this basin one of the highest wind energy potentials in the eastern part of the basin [1-8].Recently, primary energy average consumption increased by 3.7% per year whereas the average energy production increased, for the same period, only by 2.3% [1],[8]. Not far from this area, and as stated by Czisch (2008,2011), the proposed European Grid is claimed to be capable of not only linking remote wind/biomass farms, but also drawing energy from millions of micro-generation devices.

In this paper, we give some features of adequacy of future and actual projects in wind and biomass energy domain in the eastern North Africa region, in terms of both efficiency and connectivity to the European Grid. The study is organized in the following way: In the next section 2, we present the methodology of the investigations, which discusses the actual situation of energy in Tunisia along with projects and perspectives. The following section gathers results and discussion. Finally, a conclusion summarizes the main items ns passages.

2. Methodology

2.1 Actual situation of energy in Tunisia

Nowadays the energy uses are increased continuously while the proportion of fossil energy in total energy consumption is gradually reduced. This is a real problem not only in Tunisia but also in the world. According to Hadj Sassi and Gattoufi [6], wind energy potential in Tunisia is significant and may reach annually as much as 1.0 MWh/m^2. In Fig. 1, the main windy regions are outlined. The first and most important zone extends from the north-eastern coast to the north-western coast, the second covers the gulf of Gabes and the third is located at the mountainous region of

Thala. The windiest zone is that of the north-eastern region of Cap-Bon where the mean yearly wind energy exceeds 850kWh/m^2.

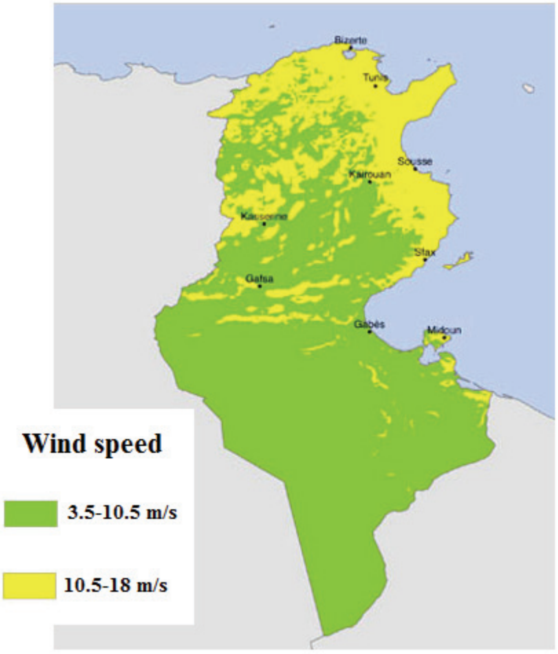

Figure 1 Tunisian wind chart

Actually, only one wind farm has been built, in Sidi Daoud (Gouvernement of Nabeul) near Cap Bon (Fig. 2). It has been in operation since 2000 [4]. Average annual wind velocity at this location is 8.4 m/s at a height of 30 m. The project was put out to tender in 1996 on the basis of a feasibility study that was drawn up between 1990 and 1992. In 2003 the wind farm was expanded by the addition of 12 turbines with a capacity of 8.7 MW. It now has a total generating capacity of almost 20 MW according to Mouldi [9], Kerkeni *et al.* [10], and Khemiri *et al.* [11].

Figure 2 Sidi Daoud wind farm

From another side, the average amount of biomass in Tunisia in the is 60.92 CO_2t/ha. Compared to results which were recorded elsewhere, the amount of biomass is greater and evident. As for the amount of biomass in each part, the part with the highest rate of biomass amount was recorded in

Bizerte region on the Mediterranean coast in Northern Tunisia. Fig. 3 represents main energy resources of Tunisia in 2013:

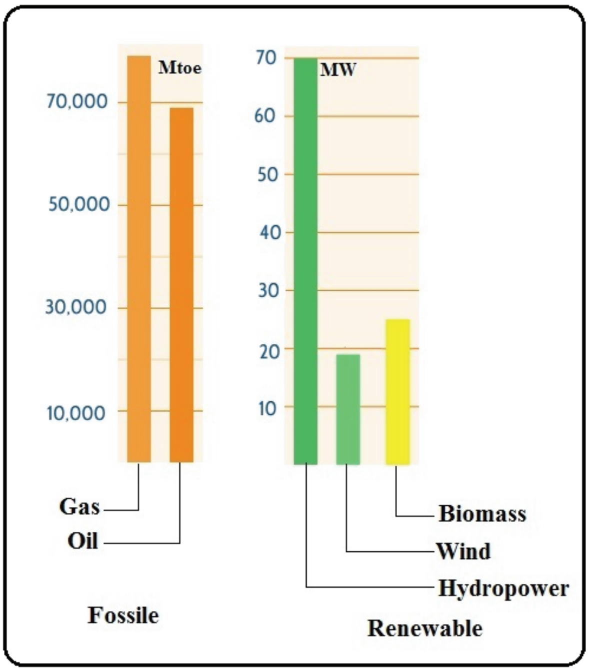

Figure 3 Main energy resources of Tunisia in 2013

2.2 Projects and perspectives

In the last two decades, wind and biomass energy, among others, has received significant attention in North Africa as in other regions of the world. As hydropower faces stagnating expansion potential in this region due to geographical limitations, major efforts are developed toward wind and solar technologies. The first motivation is undoubtedly the increase of the global demand of the region. According to Trieb *et al*. [12], Brand and Zingerle [13].Trieb and Müller-Steinhagen [14] and Trieb and Nitsch [15], Tunisia is one of the most developed countries in the North Africa zone. Its renewable electricity targets in the long run, by 2025, to reach 20% overall renewable coverage, in the proportions of 7:2:1 to CSP, wind and photovoltaic, respectively.

In the last a new configuration has been proposed a European DC (Direct Current) transmission system [16] which connects a network dominated by wind power sites throughout the entire supply area (Fig. 4).

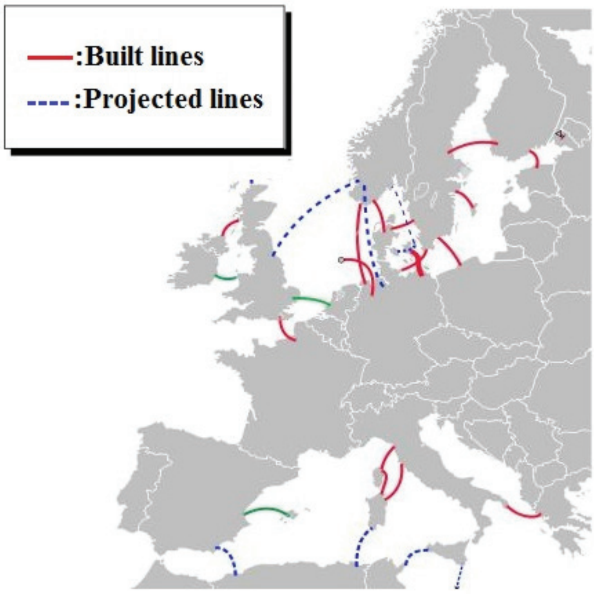

Figure 4 The projected European DC grid synopsis

This grid (Fig. 4) allows each zone to specialize in the renewable technologies that suit it best while maintaining connection to a single grid. Tunisia, for example, has promising wind and biomass potentials and an eventual connection to the European DC grid will lead to efficient and reliable renewable energy production.

Wind-biomass energy units (Fig. 5) are aimed at optimizing supply when many resources are available. With specific regard to power demand in the North African zone, the global target corresponds to the implementation of approximately 5.4 GW. If all the resources and the projected plants (53-90 MW) are taken into account, the amount of annual required installation should be equal to 0.3 GW, which is equivalent to the installation of eight plants per year, for a total period of 30 years.

Since actual loci for different kinds of plants do not match along the territory due to biomass resources disparity, this study proposes settling medium-sized hybrid Wind-biomass energy elementary units whose scheme is presented in Fig. 5.

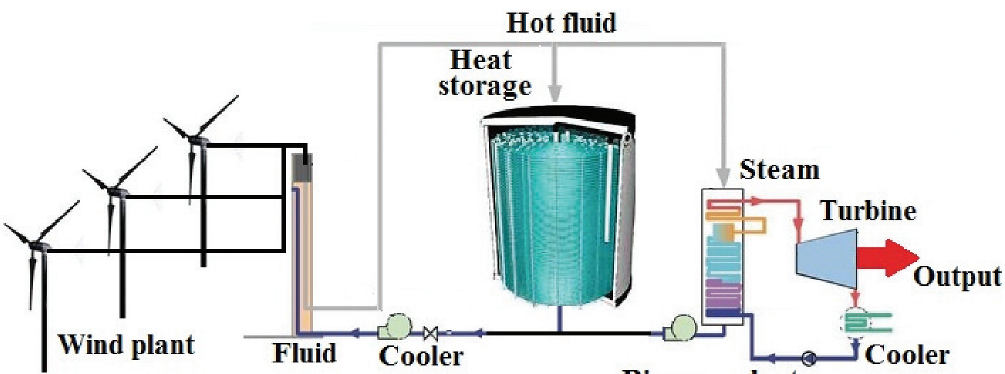

Figure 5 Elementary wind-biomass energy units

3. Results and discussion

3.1 The optimization scheme

Under the hypothesis of a connection to the lower branch of the simplified to the European DC grid, perspectives evaluation is carried out using the Data envelopment analysis (DEA) method as implemented by . This method has been implemented early by Farell [17], Banker *et al*. [18] and Charnes *et al*. [19], as a protocol to evaluate efficiency. In this protocol, a set of decision making units (DMU) share common inputs to produce an output (or a set of outputs). Thanks to an optimization protocol, an efficiency frontier, which includes all the efficient DMUs, while the remaining ones are considered as inefficient.

The initial dataset is composed of N_0 observations (DMU) with M input variables $x_i\big|_{i=1..M}$ and two output variables y_1 and y_2.

Input dimensionless variables are chosen as:

- x_1 : Total production of non-renewable energy in 2030
- x_2 : Total production of renewable energy in 2030
- x_3 : Fraction of non-renewable energy transited to EU in 2030
- x_4 : Fraction of renewable energy transited to EU in 2030
- x_5 : Unitary cost of non-renewable energy in 2030
- x_6 : Unitary cost of non-renewable transport per unit distance in 2030

Output dimensionless variables are:

- y_1 : Total relative savings for EU*.
- y_2 : Total relative savings for North Africa zone*

(*compared to the situation of 100% non-renewable energy transactions)

For standardizing purposes, each variable ξ which varies inside the range $[\xi_{\min}, \xi_{\max}]$, is normalized using Eq. 1:

$$\hat{\xi} = \left[\frac{\xi - \xi_{\min}}{\xi_{\max} - \xi_{\min}} \right] \tag{1}$$

For a general *N*-input *M*-output problem, the efficient frontier gathers the optimal DMUs which verify the following conditions:

For each *k*-ranked DMU among the N_0 ones, we set:

$$S^k = \frac{\sum_{m=1}^{M} u_m y_m^k}{\sum_{n=1}^{N} v_n x_n^k} \quad (2)$$

where x_n^k et y_m^k are the unit's output and input variables respectively, $u_m\big|_{m=1..M}$ and $v_n\big|_{n=1..N}$ are weight coefficients which verify the condition (3), for all the N_0 observations.

$$\begin{cases} \left.\dfrac{\sum_{m=1}^{M} u_m y_m^j}{\sum_{n=1}^{N} v_n x_n^j} \geq 1 \right|_{j=1..N_0} \\ u_m \geq 0; v_n \geq 0 \end{cases} \quad (3)$$

It is evident that the values of $u_m\big|_{m=1..M}$ and $v_n\big|_{n=1..N}$ depend on the totality of the observations. The variable S^k represents the DEA score S affected to the k^{th} DMU, score which corresponds, in the actual case, to the value which verifies:

$$S^k = Min\left(\frac{\sum_{m=1}^{2} u_m y_m^k}{\sum_{n=1}^{3} v_n x_n^k}\right)\Bigg|_{\begin{cases} \left.\frac{\sum_{m=1}^{2} u_m y_m^j}{\sum_{n=1}^{3} v_n x_n^j} \geq 1\right|_{j=1..20} \\ u_m \geq 0; v_n \geq 0 \end{cases}} \quad (4)$$

3.2 Application

Fig. 6 represents the output observations as DMUs representation along with the efficiency frontier. It is possible to observe i.e. that two observations (DMU 3 and 5) would be recorded as the most efficient ones with the standard DEA approach: These observations are in the efficiency frontier (Fig. 6).

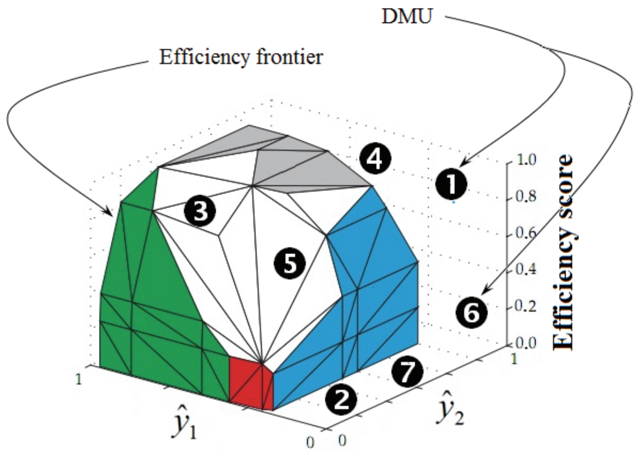

Figure 6 Decision Making Units (DMUs) along with the Efficiency frontier

DMU 3 and 5 correspond hence to scenarios of maximum total relative savings for both EU and North Africa.. The last DMU could have been equally efficient if it was not corresponding to a low investment rate in renewable energy reconversion. Fig. 7 illustrates the two possibilities.

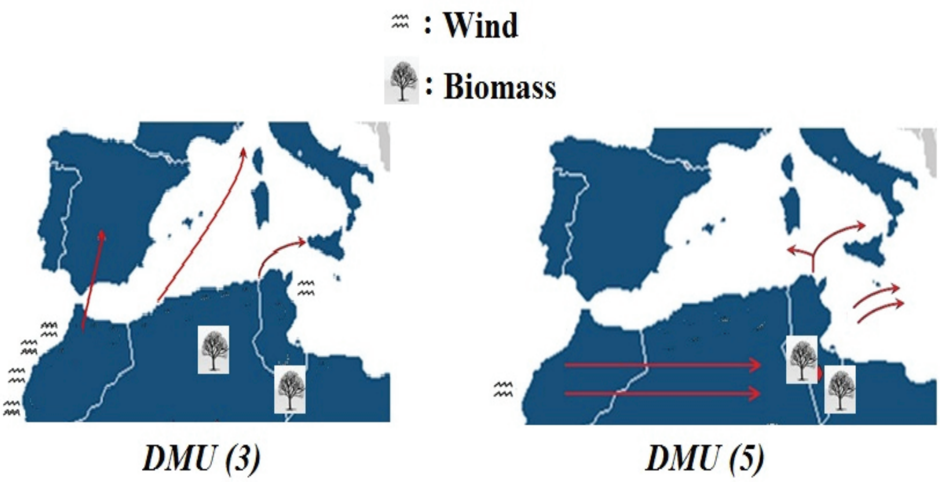

Figure 7 Scenario corresponding to the DMU 3 and 5

The two scenarios take into account availability and different transmission infrastructures which are projected, through the Mediterranean basin for 2030, as predicted by Butera [20] and Jacovides *et al*. [21]. Efficiency fluctuation induced by the additional branch is about 16%. For both scenarios, contribution optimality can be recorded for the values of 650 MW for the added compound wind-biomass power. These values support grids efficiency and present a guide to decision makers.

4. Conclusion

In this study, the feasibility study looks at different on-site wind and biomass energy which is available in the North-African zone to see in which way connectivity to outsider grid can be valorized. Energy potential and perspectives in the eastern North Africa region (Tunisia) have been investigated in terms of connectivity to the projected European DC grid. A simplified extracted scheme of this grid has been used as a guide to optimize transportation efficiency through the whole net for 2030 horizons. The availability of biomass residues and the potential of the wind power in the region are very significant for socioeconomic development in order to improve the quality and opportunities. According to the proposed scenarios, connectivity-related efficiency between North-African zone an EU grid can be up to 16 % for both sides.

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