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Analysis of Wind/ Solar Power mix for 30% and 100% renewable scenarios in Tunisia

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Abstract— **Several research studies affirm that Tunisia is endowed with a good renewable energy potential but it is underexploited. By 2030, The Tunisian Solar Plan considers a scenario of 30% renewable energy shared equitably between wind and solar energy. We focus on this scenario. We also look at a prospective scenario when 100 % of the electricity consumption might be supplied by renewable (Solar and wind Power). We analyse the energy balance defined as the time difference between generation and load. Results show that the optimal mix among renewable means of production depends on the equipment scenario and on the considered temporal scale. For 30% ER scenario, the most economical mix is made from 100% solar energy. For 100% RE scenario, results show that the share of wind power increases with the temporal scale (from daily to monthly). We note also that according to the energy balance analyse, the strategy envisaged by the Tunisian solar plan (i.e. 50% wind, 50% solar) results in higher balancing costs than using only wind power generation.**

Keywords— **Tunisian Solar Plan, wind-solar mix, Optimal Mix, temporal scale, scenario, energy balance.**

I. Introduction

To mitigate impacts of climate change which essentially refers to an increase in average global temperatures, changing in precipitation regimes and meteorological variability [1], an agreement was made by 195 countries [2]. This universal agreement was taken at the Paris climate conference (COP21) in December 2015. It sets out to hold the increase in global average temperature to well below 2°C and to achieve net zero emissions in the second half of this century [3]. To achieve this target, each country has prepared its national climate action plan to reduce gas emission.

In this context, Tunisia has submitted its INDC (Intended nationally determined contributions) to the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) [4]. It contains the Tunisian action plan to contribute in minimizing climate change impacts. According to this INDC, Tunisia will reduce its carbon intensity by 41% in 2030, compared to the year 2010 [5]. Decrease in carbon emission would be about 26 million tCO_2eq in 2030, and about 207 million tCO_2eq for the period 2015-2030 [4]. In order to reach these goals, Tunisian stakeholders have devoted a large part of the plan for the use of renewable energy [4].

Having regard to this plan, the share of renewable energy will be increased from 3% in 2016 to 30% in 2030 using Solar and wind energy (15%, 15%) [5]. This plan does not include the use of hydropower because Tunisia has no significant hydraulic resources.

Actually, the total capacity of renewable energy installed in Tunisia is about 310MW. It is split between Wind Power (75%), Hydropower (20%) and Solar Power (5%) [7]. We notice that the share of Solar power is limited compared to its potential. Indeed, several studies confirms that from one year to another Tunisia receives approximatively a constant amount of radiation that varies between 2100 kWh/year/m^2 in the far north to 5100 kWh/ year/m^2 in the far south [8]. Considering this climatic situation, the estimate of the total solar capacity installed may vary between 34 to 844 GW_C [7]. For Wind Power, a research carried out by ANME (Agence National pour la Maitrise de l'Energie) affirms that a total capacity of 8 GW can be installed mainly at three major areas: Northeast, Midwest and Southwest [9].

When comparing these results to the solar plan target, which is 3725 MW by 2030 (30% ER), we can assume that the future of Energy in Tunisia may be characterized with a more significant share of renewable sources. We can ever think about a 100% renewable energy scenario in as it was discussed for several regions in the world where renewable sources potential may be ever lower than the underexploited potential that exist in Tunisia.

No one can deny that RE are intermittent sources, whose supply depends on out-of-control condition [23]. These sources are highly related to climate and weather variabilities [26]. This feature can disrupt the electrical network because an important of RE amount can be produced when consumption is low and vice versa. It is therefore crucial to make specific analyse of renewable energy integration to optimize the energy mix [25]. In this study, we define an energy mix as optimal if it allows minimizing the energy balance variability (i.e. the time variability of the difference between generation and consumption) [11,22]. This indicator is a good proxy of the balancing costs defined as the costs related to backup and storage operations required to balance the electricity network.

We present in this paper the analyse of the optimal mix for large intermittent energy share in Tunisia (wind and solar). In the literature, many studies investigated the design of the energy mix with high share of VREs in many countries in the world. These studies highlight that although the intermittency feature, VRE production can be adjustable to consumption needs when it is well-studied and sized [10-12,14,22]. For example, the scenario 100% of renewable energy was analysed for the mix wind-hydro in Mexico [10], this study shows that it is possible

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to satisfy continuously the demand by combining wind power and hydropower. During the first five months of the year (January-May), the amount of water is limited so Hydropower can only compensate the Wind Power fluctuations. However, between June and December, the amount of available water exceeds the energy required. So that, this surplus of water could be stored for later use during the second half of the year. Hydropower was also combined with solar PV, for example the mix hydro-solar power analysis in Italy [11]. This work studies the effect of 100% renewable mix in northern Italy. Its results show that renewable energy sources are available at different times and are well complementary. This behaviour can be used to balance generation and load. The study of 100% renewable energy scenario in Italy illustrates that the optimal mix depends on the time resolution: at small time scales (hourly), this mix is composed of a large share of hydraulic power (75% hydro, 25 % Solar photovoltaic). For higher time scales (daily, monthly) optimal mix is obtained for a small share of hydropower (30% hydro, 70% solar photovoltaic). The Wind-Solar mix was also studied in Europe [12]. This analysis shows that these two energy sources have a strong seasonal pattern. The production of wind energy is higher in winter than in summer, and the opposite is true for solar energy. But when integrating these two sources for a very high share of renewable generation in Europe, complementarity between wind and solar can satisfy the seasonal pattern of consumption with an optimal mix composed by 55% wind power and 45% Solar Photovoltaic. Biomass was also integrated into the wind-photovoltaic mix in a study on Denmark [25]. This analysis shows that the Danish power system can be converted into 100% renewable energy by combining: 180 TJ / year of biomass, between 15 and 27 GW of wind energy and 5000 MW of photovoltaic energy. Another study affirms that the optimal mix for a 100% wind-photovoltaic scenario in Europe reduces the required storage capacity by a factor of two compared to the storage capacity for a 100% wind or 100% photovoltaic mix [12].

The present paper analyses the Solar-Wind Power mix in Tunisia for two scenarios: 30% RE and 100% RE. The question of the optimal Solar-Wind Power mix for these scenarios is discusses as follow: In section two, study area and the data used are described. In section three, study framework is presented. Section four presents the results. Section five concludes and gives insights for future research needs.

II. Study Area And Data

As it was pointed in the literatures [11,12,14,15], the analyse of renewable energy scenarios, needs an estimation of the produced and the consumed electricity, so that an understanding of meteorological variables that pilot these energies: wind speed data for wind power, solar radiation and temperature for solar power.

We consider in this study 30% and 100% wind-solar scenarios, so we select 10 meteorological stations in Tunisia. Figure 1 shows the location of these stations. They are well spread across the country and can be used for giving a good estimate of the climate variability in Tunisia. The north is mainly temperate and it has mild, rainy winter and hot, dry summer whereas in the south, the climate is hot, arid and desert [16].

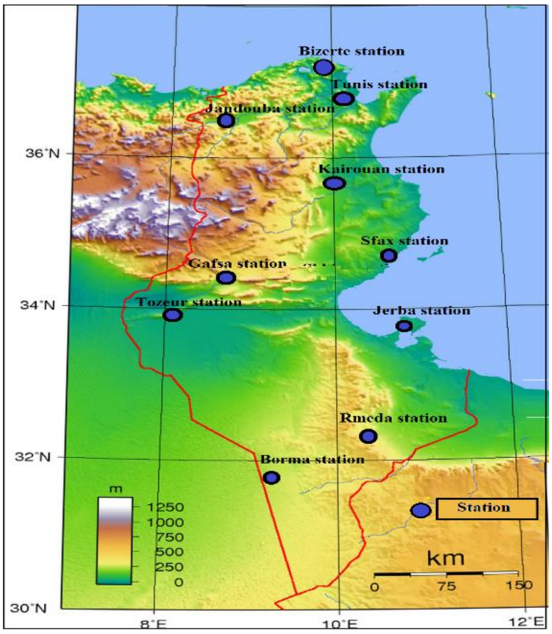

Fig. 1: The Ten Selected Stations In Tunisia

We use pseudo-observations of wind speed (m/s), temperature (°c) and solar radiation (w/m^2) from WRF model (Weather Research and Forecasting Model) [13]. Modelling time step is daily from 1980 to 2012. WRF outputs were validated in a previous work with measured data of National Meteorology Institute of Tunisia for the year 2012 [17].

Observed electricity consumption and temperature are respectively provided by the National Electricity and Gas Company of Tunisia (STEG) and by weather underground [29] for the year 2014. These data are used for calibrating an electricity consumption modelling. Simulated daily electricity consumption are obtained from 1980 to 2012 via this modelling (see Section 3).

III. Study Framework

A. *Wind Power*

To estimate the wind power, we use the model developed in Ref. [12]. This model simulates the generation from a 1MW wind turbine This model requires wind speed data at 80-meter altitude.

The WRF wind speed data are available at the altitude of 10m. To be used for power estimation, we can use the following scaling equation that links wind speeds to the corresponding heights and roughness [19].

$$V_{h_2} = \left(\frac{h_2}{h_1}\right)^C X\, V_{h_2} \qquad (1)$$

Where V_{h1} and V_{h2} are wind speeds (ms^{-1}) approximatively at the altitude h_1 and h_2. C is an air friction, based on previous study [16], it is chosen equal to 0.23 (no dimension).

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B. Solar Power

For solar power estimation, a function that related the power to solar radiation R (wm^{-2}) and air temperature T_a (°c) is used in this paper [27]. The following function (2) gives the power Ps (Watt) delivered by photovoltaic panel supposed installed horizontally [20]:

$$P_s = A.R.(1 - t(T_a - T_{C,STC}) - r.t.R) \qquad (2)$$

With t and r, are efficiency reduction factors related to temperature and radiation. A is a constant parameter which equals to the product of the surface area of the Photovoltaic panel (m^2) by an efficiency coefficient (%). This coefficient is relative to the generator and conversion efficiencies from direct to alternative current defined under standard conditions, presented in Ref. [28] as cell temperature $T_{c,STC}$= 25°C, spectral distribution corresponding to an air mass of 1.5 and incidence irradiation $R_{STC} = 10^3$ Wm^{-2}).

C. Energy load

Several studies, [11,12,14,22,23], show that energy load is affected by economic, societal features and weather variability. Figure 2 shows lower electricity consumption during weekends (especially Sundays) than during weekdays. This results from decreasing economic activity during weekends and holidays. We also note higher consumption during the summer season than during the winter season. This can be explained by the Tunisian use of electricity where the need for cooling is greater than the need for heating.

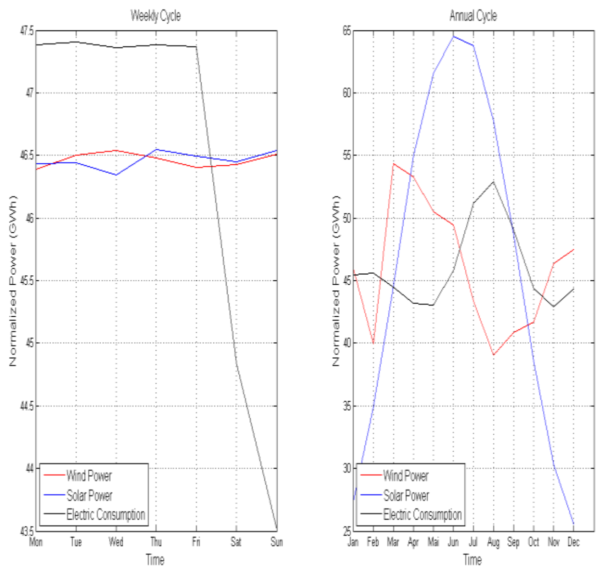

Fig. 2 Weekly and Annual Profiles normalized cycles of wind power generation (red), solar power generation (blue) and Electricity consumption (black for the year 2014).Data used for Energy modelling are meteorological measured data downloading form weather underground [29] . Wind and Solar power are then normalized by average energy load of the year 2014.

We can conclude that electricity demand in Tunisia is highly related to temperature values. To better analyse these dependency, we present on Figure 3 the energy load against temperature of Tunisia in 2014.

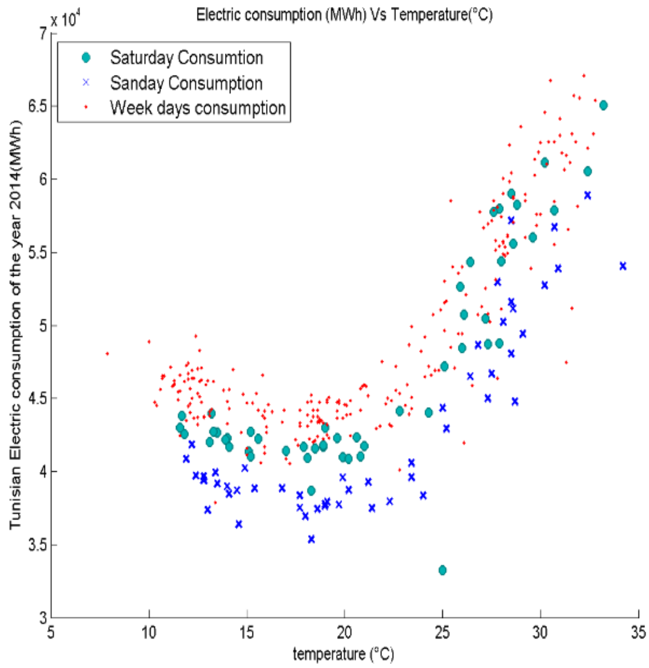

Fig. 3: Energy Load Against Temperature of Tunisia in 2014 [16]

From Figure 3, we note that daily electricity consumption variability increases with temperature. We can also pick out three temperature ranges. The first one is when temperatures are under 15°C; for this range, consumption is slightly increasing when temperatures decrease. The second one, for temperatures between 15°C and 22°C, the consumptions are almost constants. And finally the third one; when temperatures are higher than 22°C, electricity consumptions linearly increase with temperatures.

Based on these results, the daily electric consumption in Tunisia can be estimated based on the heating and cooling degree-day method (Psiloglou et al. 2009) [21]

$$\begin{array}{ll} C_{ELEC}(t) = a_1 \times T_a(t) + b_1 & if \;\; T_a(t) < T_{cooling} \\ C_{ELEC}(t) = \;Cst & if \;\; T_{cooling} < T_a(t) < T_{heating} \\ C_{ELEC}(t) = a_2 \times T_a(t) + b_2 & if \;\; T_{heating} < T_a(t) \end{array} \qquad (3)$$

With:

C_{ELEC} (t) (MWh) the daily electric consumption for temperature T(t) (°C), a_1, a_2, b_1 and b_2 are model coefficient and $T_{heating}$ and $T_{heating}$ (°C) are air conditioning and heating temperature thresholds.

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D. The energy balance of solar/wind scenarios:

To optimize the wind-solar renewable mix for 30% RE and 100% RE scenarios in Tunisia, we adopt the same method presented in [12,14,22]. Energy balance $\Delta(\mathrm{t})$, presented in formula (4), can be defined by the temporal differences between energy generation $P_{mix}(\mathrm{t})$ and consumption $\mathrm{C_{ELEC}}(\mathrm{t})$ at each time t.

$$\Delta(\mathrm{t}) = \beta \times P_{mix}(\mathrm{t}) - \mathrm{C_{ELEC}}(\mathrm{t}) \quad (4)$$

Where β is the rate of renewable energy in the electric production, for 30% RE scenario β is equal to 0.3 and for 100% RE scenario β is equal to 1. $P_{mix}(\mathrm{t})$ is the total instantaneous production by renewable energy mix. To define the generated energy provided by the wind-solar mix, we consider that over the study period, average production is equal to the mean demand share considered in the scenario. For example, for a 30% renewable scenario, average renewable generation equals to average 30% of the demand over study the period.

$$P_{mix}(\mathrm{t}) = \alpha \frac{\mathrm{P_w}(t)}{\langle \mathrm{P_w} \rangle} \times \langle \mathrm{C_{ELEC}} \rangle + (1-\alpha) \frac{\mathrm{P_s}(t)}{\langle \mathrm{P_s} \rangle} \times \langle \mathrm{C_{ELEC}} \rangle \quad (5)$$

Where $\langle \mathrm{P_w} \rangle$, $\langle \mathrm{P_{pv}} \rangle$ and $\langle \mathrm{C_{ELEC}} \rangle$ present averages of total wind production, total solar production and total load over the whole period of the study. α is the rate of wind power in the renewable energy scenario and 1- α is the rate of solar power.

As already mentioned in this article, the optimal mix is obtained for the lowest energy balance variability which leads to minimum balancing costs. To analyse this balance, we consider the standard deviation of the energy balance (6) [11,12]:

$$\sigma_\Delta = \sqrt{\langle \Delta^2 \rangle - \langle \Delta \rangle^2} \quad (6)$$

IV. INTERPRETATION AND RESULT

A. Energy load and renewable power generation

From the 2014 annual profiles of energy normalized cycles presented on Figure 2, we can notice the complementarity between solar and wind energy in Tunisia for this year. The two peaks of wind power production, which are respectively in March and December, correspond to a minimum of photovoltaic production; and the period of maximum solar production (June, July and August) coincides exactly with the minimum of wind production. So, based in these results, it seems interesting to combine wind and solar power to supply demand throughout the year.

To better analysis the seasonal variability of RE production and demand, we model these energies over 33 years. Using WRF data and modelling method presented in section 2, wind, solar and energy load are modelled in Tunisia from 1980 to 2012. For illustration, Figure 4 shows wind and solar generation, and electricity consumption for the last three years of the considered time period (2010-1012).

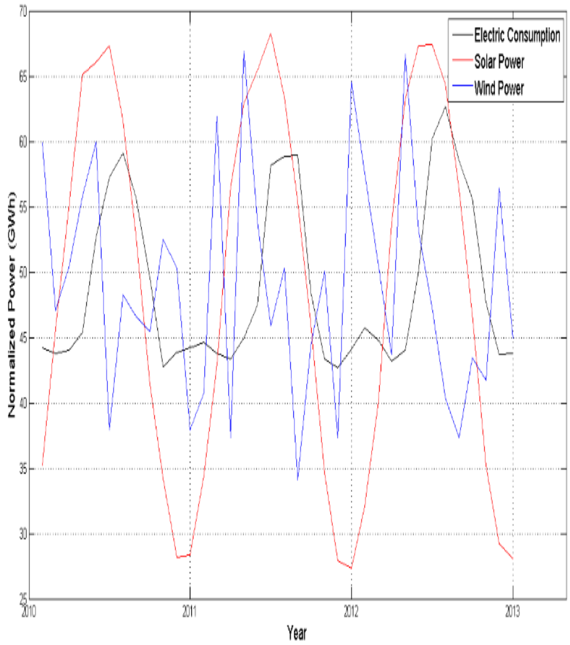

Fig. 4: Modelled Consumption and Renewable energies from 2010 to 2012 in Tunisia.

For the three years, Figure 3 illustrates the same seasonal pattern of energies variability noted from annual profiles of 2014 (Figure 3). For solar power, the cycle is frequently repeated. For wind power, the amplitude of maximum and minimum production changes from one year to another but we have always important amount of wind energy production in January, March and December.

When comparing RE to energy load, we note that wind energy variation doesn't feat the consumption curve. In fact, for the annual cycle, they are in phase position. For solar power; however, production and demand are in line with each other.

It is noticeable that in Tunisia, the spring season is the best period for RE production, and during this period consumption is low. This point has to be taken into consideration in the Energy Plan because this production could be stored or even exported in order to avoid plant curtailments.

B. The 30% and 100% renewable energy scenarios

We now focus on energy balance analyse. As already detailed, the optimal RE mix is obtained for the minimum energy balance variability. This optimum mix may also depend on temporal scale [11,15]. Thus, to identify the optimal RE mix for 30% and 100% RE scenarios in Tunisia; the energy balance standard deviation for the period 1980-2012 is calculated for different time scale: daily, weekly and monthly.

Figure 5 depicts standard deviation values of balance energy for different wind fraction in the mix. For 30% ER and 100% ER scenarios, the standard deviation resulting from each mix (from 0% wind to 100% wind) is given.

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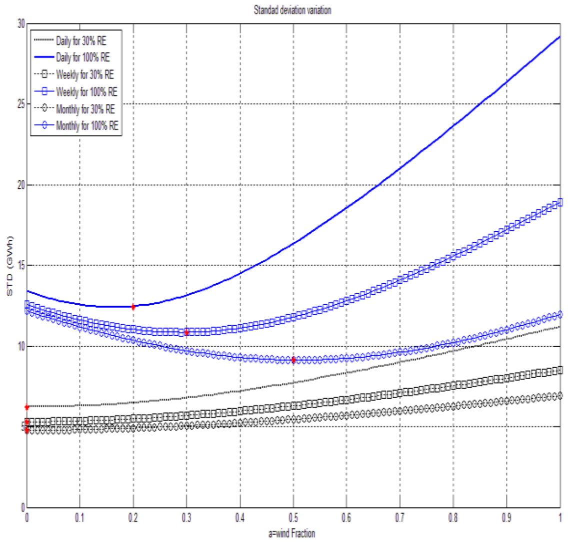

Fig. 5:Standard deviation of the energy balance for all possible wind fraction (0-1) in the mix and for the two scenarios(30%RE, 100RE) for daily, weekly and monthly time step

For the 30% renewable energy scenario, whatever the time step considered, the optima mix is obtained for 100% photovoltaic. Indeed, for such scenario the integration of wind power does not imply a decrease in energy balance time variability.

However, for a 100% renewable energy scenario, the mix that allows minimizing the balance variability is composed by both solar and wind power. The share of wind in the optimal mix depends on the considered temporal scale. It goes from 20% for daily, to 50% for monthly; and it equals 30% for weekly.

These results confirm that optimal mix for 100% RE scenario cannot be simply obtained because the three time steps must be taken into consideration. In addition to that, the storage, balancing capacity and electricity system potential in Tunisia should be viewed because these parameters highly effect the design of the mix.

When comparing the result of this work to the Tunisian Solar Plan which investigates a 30% RE scenario shared equitably between solar and wind, we note that this decision matches better with the scenario 100% RE when considering the monthly time step. However, when considering both the slight increase in energy balance variability when integrating wind power under the 30%, and the optimal mix obtained for the 100 %, one could think it is already worth investing in wind power too. This would facilitate further transition to 100 % renewable.

V. Conclusions

Tunisia is endowed with an important underexploited wind and solar potential but actually RE presents only 6% of the energy mix. By 2030, the Tunisian Solar Plan envisages a 30% RE scenario (50% wind, 50% solar). This target can be more ambitious because literature affirms the possibility to design the energy mix with high share of Renewables in many countries in the world. So, we study in this paper the two scenarios 100% and 30% ER in Tunisia.

The analyse of renewable energy profiles in Tunisia shows a complementarity between solar and wind energy. The generation of wind power is mainly in Spring (March) and Winter (December). These periods correspond to a minimum of photovoltaic production which has its maximum production insummer and that coincides exactly with the minimum of wind production.

When comparing generated RE to energy load, we note that solar power fits better the consumption profile because the pick of solar production coincides with the maximum demand. For wind energy profile, however, production and demand are in phase opposition.

Based on the literature review, we study in this work the optimal wind-solar mix for the scenario 30% ER and 100% ER in Tunisia. By analysing all possible mix, we looked for the wind-solar optimal shares that give the minimum energy balance time variability. These mix lead to the lowest cost because minimising the variability reduces extra expense needed for balancing and storing.

We consider for each scenario, three time steps; daily, weekly and monthly. Results show that the optimal mix for the scenario 30% ER is composed by 100% photovoltaic for the different time steps. But for the scenario 100% RE, the optimal wind share depends on the temporal scale: (20% for daily, 30% for weekly and 50% for monthly).

To define the optimal mix for 100% RE scenario, rather than regarding the different time-scale at the same time, strategies and different organization forms of the electric production sector should be takin into consideration. But for 30% RE scenario, it is more economic to only invest in photovoltaic because the integration of wind power disrupts the balance and increases the variability.

We can then conclude that, according to these analyse, the solar plan does not envisage the most economic renewable energy mix by 2030. Focusing only on the scenario 30%, it would be better to totally invest in photovoltaic because the mix (50% wind, 50% solar) matches well with the scenario 100% RE and not 30% RE. But Since wind power share increase with the level of equipment and considering the time required for building windmills and for connecting them to the grid, it would be wise integrating wind power even though it is not fully optimal for the 30 % scenario especially if we investigate a future with an important RE share (>30%).

In follow-up to this work, we propose to extend this study using smaller time measurements (1h, 10 min) to analyse the diurnal cycle of renewable production and to determine the optimal mix minimizing the balance from day to day. Further research taking account of special variability may optimize and facilitate the integration of RE because this lead to rational distribution of production means.

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REFERENCES

[1] M.L. Parry, C. Rosenzweig, A. Iglesias, M. Livermore, G. Fischer, Effects of climate change on global food production under SRES emissions and socio-economic scenarios, Global Environmental Change 14 (2004): 53–67

[2] Robert Falkner, The Paris Agreement and the new logic of international climate politics, The Royal Institute of International Affairs, 92 (September 2016):1107–1125

[3] UNFCCC, Adoption of the Paris agreement, December 2015, https://unfccc.int/resource/docs/2015/cop21/eng/l09.pdf

[4] Ministère de l'Environnement et du Développement Durable, Contribution prevue determine au niveau national Tunisie, Aout 2015.

[5] ANME, NAMA for Renewable Energy and Energy Efficiency in the building sector in Tunisia, 2016

[6] ANME, Renewable energy and energy efficiency in Tunisia – employment, qualification and economic effects, 2012

[7] ANME, Tunisia renewables readiness assessment report, December 2015.

[8] Belgacem B. et Nasri H., Training presentation support on the installation and maintenance of solar photovoltaic systems connected to the network, Borj Sedria Tunis, 2016.

[9] ANME, Production d'électricité renouvelable en Tunisie-perspectives et opportunités à l'horizon 2030, 2010.

[10] Jaramillo O.A., Borja M.A., Huacuz J.M. 2004, Using hydropower to complement wind energy: a hybrid system to provide firm power, Renewable Energy 29 (2004) 1887-1909

[11] François, B.., Borga M., Creutin J.D., Hingray B., Raynaud D., Sauterleute J.F., 2016a, Complementarity between solar and hydro power: sensitivity study to climate characteristics in Northern-Italy, Renew. Energy (2016) 86 543-553

[12] Heide D., von Bremen L., Greiner M., Hoffmann C., Speckmann M., Bofinger S., 2010, Seasonal optimal mix of wind and solar power in a future, highly renewable Europe, Renew. Energy 35.

[13] R. Vautard, F. Thais, I. Tobin, F.-M. Breon, J.-G.D. de Lavergne, A. Colette, P. Yiou, P.M. Ruti, Regional climate model simulations indicate limited climatic impacts by operational and planned European wind farms, Nat. Commun. 5 (2014) 3196.

[14] B. François., Hingray B., Raynaud D., Borga M., Creutin J.D., 2016b, increasing climate-related-energy penetration by integrating run-of-the river hydropower to wind/solar mix Renew. Energy (2016) 87 686-696

[15] L. (von) Bremen, Large-scale Variability of Weather Dependent Renewable Energy Sources. In Management of Weather and Climate Risk in the Energy Industry, Springer, 2010, pp. 189e206

[16] Jaber Rahma, Analysis of meteorological variables controlling energy demand and renewable energies in Tunisia, engineering final project study, ENIT. 2015

[17] Jaber Rahma, Analyse du mix éolien/photovoltaïque pour différents scénarios renouvelables en Tunisie, Master II degree, ENIT. 2016

[18] Valérie Grogna et Tanguy de Villepin, 2007, Energie éolienne: Quelle énergie hybride pour combler ses défauts? Analyse comparative et critique d'articles scientifiques dans le domaine des énergies renouvelables.

[19] Johnson G.L., 1985, Wind Characteristics. In Wind Energy Systems, Prentice-Hall Englewood Cliffs (NJ), 1985, 32-99.

[20] O. Perpinan, E. Lorenzo, M.A. Castro, On the calculation of energy produced by a PV grid-connected system, Prog. Photovolt. Res. Appl. 15 (2007) 265 e274

[21] B.E. Psiloglou, C. Giannakopoulos, S. Majithia, M. Petrakis, Factors affecting electricity demand in Athens, Greece and London, UK: a comparative assessment, Energy 34 (2009) 1855-1863

[22] B. François, B. Hingray, F. Hendrickx, J.D. Creutin, Seasonal patterns of water storage as signatures of the climatological equilibrium between resource and demand, Hydrol. Earth Syst. Sci. 18 (2014) 3787-3800

[23] Stefan Ambec, Claude Crampes, 2012, Electricity provision with intermittent sources of energy, Resource and Energy Economics 34 (2012) 319–336

[24] H. Ibrahima, A. Ilincaa, J. Perronb,2008, Energy storage systems—Characteristics and comparisons, Renewable and Sustainable Energy Reviews 12 (2008) 1221–1250

[25] Henrik Lund, 2007, Renewable energy stratégies for sustainable development, Energy 32 (2007) 912-919

[26] Ayhan Demirbas, 2005, Potential applications of renewable energy sources, biomass combustion problems in boiler power systems and combustion related environmental issues, Progress in Energy and Combustion Science 31 (2005) 171–192

[27] M. Hanif, M. Ramzan, M. Rahman, M. Khan, M. Amin, M. Aamir, Studying power output of PV solar panels at different temperatures and tilt angles, OSESCO J. Sci. Technol. 8 (2012) 9 e12

[28] J.A. Duffie, W.A. Beckman, Solar Engineering of Thermal Processes, 2nd ed., Wiley Interscience, New York, 1991

[29] https://www.wunderground.com/

ISSN 2356-5608