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Conference paper

Opportunity and feasibility studies for the deployment of green hydrogen in Algeria

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ABSTRACT

This study focuses on the technical and economic feasibility of green hydrogen production systems using three wind turbine technologies. These are the VESTAS V90, GAMESA G80 and LAGARWEY LW72 models, each with a power of 2MW. These turbines are being deployed at three distinct sites (the north, the high plateau and the Algerian south). The results obtained allow us to compare the costs and volumes of hydrogen production for the three sites and wind turbine technologies chosen. Results clearly show that VESTAS wind turbines offer the most advantageous costs for hydrogen production, with costs of \$20.16/kg, \$10.47/kg and \$9.11/kg for the Algiers, El-Bayadh and Adrar sites respectively, compared with costs of \$29.18/kg, \$14.37/kg and \$12.81/kg for the same sites using LAGERWEY wind turbines. These results highlight the importance of evaluating both the quantity of hydrogen produced and the related cost, taking into consideration the choice of site as well as the wind turbine technology used.

1. INTRODUCTION

Green hydrogen is considered a future energy that can support decarbonisation efforts. In this respect, a promising solution is emerging in the production of green hydrogen from wind energy (Hermesmann and Müller 2022; Rezaei, Akimov, and Gray 2024; Zhou et al. 2022). Algeria, with its considerable potential for renewable energies, particularly wind power, offers a significant opportunity for the diversification of energy resources and the transition to more sustainable sources (Ait Bachir Lynda 2021; Messaoudi et al. 2021; Mokhtara et al. 2021; Rahmouni et al. 2017). Such projects involve a

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careful selection of sites based on technical and energy criteria, as well as a precise assessment of the quantities of hydrogen produced and associated costs. The use of wind energy for hydrogen production represents an environmentally friendly approach, reducing greenhouse gas emissions (Douak and Settou 2015; Messaoudi, Settou, and Allouhi 2024; Mostafaeipour, Qolipour, and Goudarzi 2019). The work presented in this article concerns the development of a techno-economic feasibility study for the production of green hydrogen in various areas of Algeria, using several wind turbine technologies. The methodology adopted is structured into several sections, each focusing on a specific analysis. These sections examine in detail the technical and economic aspects of green hydrogen production in Algeria. Results regarding wind variation at different sites with different wind technologies are presented, along with conclusions drawn from the techno-economic analysis of the system.

2. GREEN HYDROGEN PRODUCTION SYSTEM DESCRIPTION

Figure 1 shows the block diagram of the proposed hydrogen production system. A case study has been conducted to analyse green hydrogen production using 20 MW wind farms (2 MW unit) in several Algerian regions.

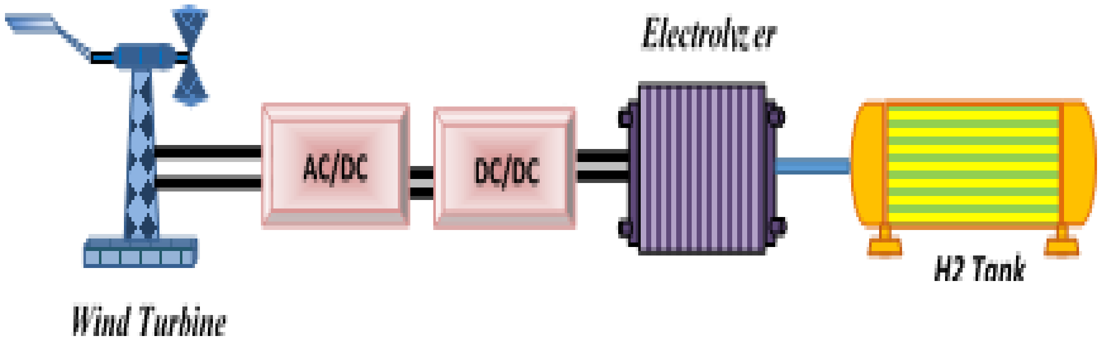

Fig 1. Hydrogen production chain using a Wind Energy Conversion System

3. MODELLING SYSTEM COMPONENTS

3.1 Wind turbine power curve fitting

Equation 1. represents the mathematical output power model P_{Out} (W) developed in this study. This model is obtained by fitting experimental power curves (supplied by the manufacturers) with analytical models (Nekkache et al. 2018). With: v_d, v_n and v_a are cut-in, rated and cut-out speeds respectively, and P_r is the wind turbine rated power.

$$P_{out}(v) = \begin{cases} 0 & (v < v_d) \\ P(v) = \sum_{k=0}^{k=6} a_k v^k & (v_d < v < v_n) \\ P_r & (v_n < v < v_a) \\ 0 & (v > v_a) \end{cases} \quad (1)$$

Figure 2 shows the experimental power curve of the VESTAS V90 wind turbine fitted with a polynomial model.

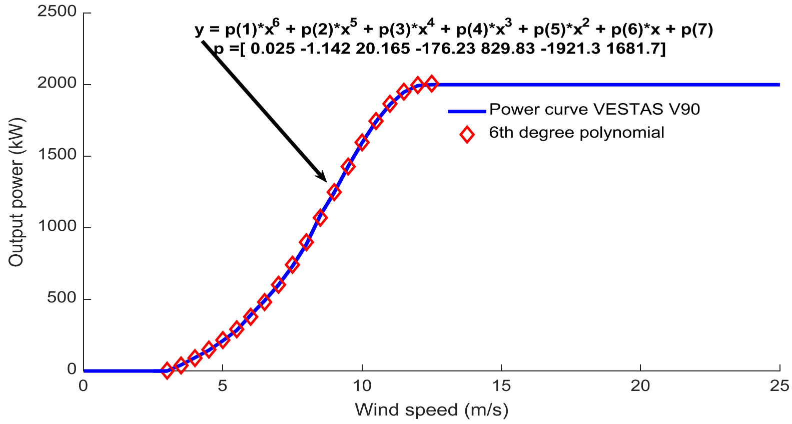

Fig 2. Wind turbine power curve fitting using polynomial regression (Vestas V90)

3.2 Wind speed extrapolation

The following power law models the vertical translation of wind speeds.(Izadyar et al. 2016; Saib et al. 2018)

$$V_2 = V_1 \times \left(\frac{h_2}{h_1}\right)^{\propto} \text{(m/s)} \tag{2}$$

Where, V_1: Wind speed measured at anemometer level (Z_1), V_2: Estimated wind speed at wind turbine hub level (Z_2), α: Exponent of the power law, is chosen to be 0.2.

3.3 Hydrogen production

The amount of green hydrogen produced (in kg) from the water electrolysis, process can be estimated using (Ayodele and Munda 2019):

$$Q_{H_2} = {AEP \times \eta_{Rect}} \Big/ {1000 * E_{Req}^{Ele}} \quad \text{(kg)} \tag{3}$$

where AEP: Annual Energy Produced, η_{Rect}: Rectifier efficiency, taken as 0.95. E_{Req}^{Ele}: Electrolyzer energy requirements are taken as 52 kWh/kg for a PEM electrolyzer.

3.4 Economic analysis of a hydrogen production project

Table 1. presents the technical and economic characteristics of the green hydrogen production system studied.

Table 1. Technical and economic characteristics of system components.

Component	Pr (kW)	Lifetime (years)	Unit cost ($/kW)	Replacement cost	Maintenance costs
Wind turbine	2000	20	1150	0	3% de C_{wt}
Rectifier	1800	10	4% wind turbine cost	8.3920 10^5	1% de C_{rec}
Electrolyser	1700	4	900	5.7525 10^7	2% de $C_{electro}$

3.4.1 Project investment costs

The investment cost of a hydrogen production project C_{inv} includes the cost of the wind energy conversion system C_{wt}, the cost of the rectifier C_{rec}, the cost of the electrolyzer $C_{electro}$, the cost of the auxiliaries C_{aux}, the C_M maintenance cost and the C_R replacement cost. Consequently, the investment cost was given by (Hinkley et al. 2016; Wali et al. 2023):

$$C_{inv} = C_{wt} + C_{rec} + C_{electro} + C_{aux} + C_M + C_R \quad (4)$$

With:

$$C_M = C_{Mwt} + C_{Mrec} + C_{Melectro} \quad (5)$$

Where: C_{Mwt}: is wind turbine maintenance cost, C_{Mrec}: is rectifier maintenance cost. $C_{Melectro}$: is electrolyzer maintenance cost. The replacement cost C_R, is given by:

$$C_R = C_{Rrec} + C_{Relectro} \quad (6)$$

With: C_{Rrec}: is rectifier replacement cost, $C_{Relectro}$: is electrolyzer replacement cost.

3.4.2 Cost of produced hydrogen

$$C_{H_2} = \frac{Cinv * C_{RF}}{MH_2 * 1000} \quad (7)$$

With: C_{RF} The Uniform series present worth factor can be calculated as follows (Khenfous et al. 2018; Khirennas et al. 2021):

$$C_{RF} = \frac{d * (1 + d)^T}{(1 + d)^{(T-1)}} \quad (8)$$

d: Interest rates (d = 8 %), T: system lifetime (T = 20 years).

4. RESULTS AND DISCUSSION

4.1 Monthly average wind data

Figures 3 and 4 show the annual wind speed profiles at 10m and 100m for three selected sites (Algiers, Adrar and El-Bayadh). It can be seen that the Adrar region has significant wind potential at both heights, with a peak wind velocity exceeding 9m/s at 100m. This potential will allow large volumes to be produced of green hydrogen. It should also be noted that hydrogen production fluctuates throughout the year, de-pending on the random nature of the wind.

4.2 Annual Electrical Energy from Wind Turbines

Figures 5 and 6 show the effect of wind power technology and potential on the annual energy production and capacity factor. It can be seen that the VESTAS V90 wind turbine has the highest capacity factor of the three sites, reaching 43.95% in Adrar, which demonstrates its exceptional performance. This percentage indicates that the VESTAS wind turbine to be installed in Adrar could exploit almost 44% of its energy potential throughout the year, generating a high annual net energy production of 7.8 GWh.

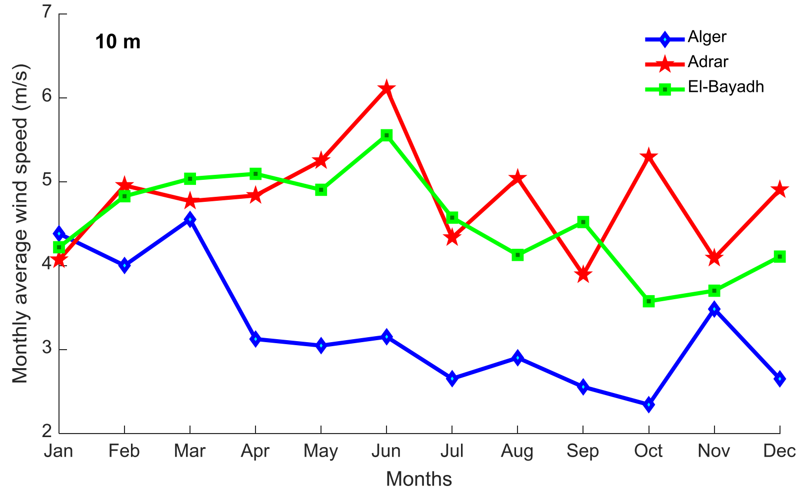

Fig 3. Monthly average wind speed in Algiers, Adrar and El-Bayadh at 10m.

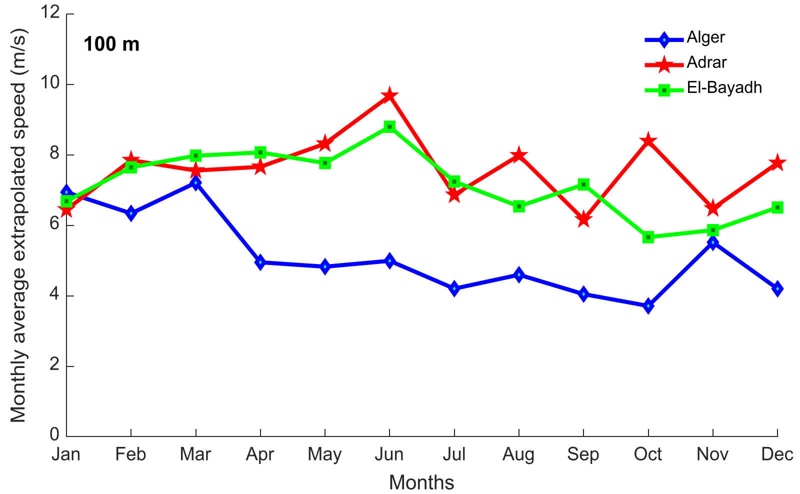

Fig 4. Monthly average wind speed in Algiers, Adrar and El-Bayadh at 100m.

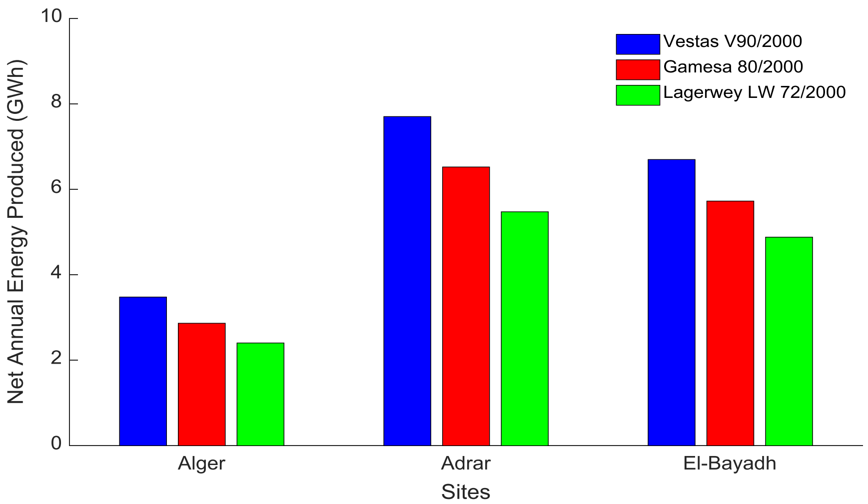

Fig. 5. Annual energy produced of the three wind turbines in Algiers, Adrar and El-Bayadh.

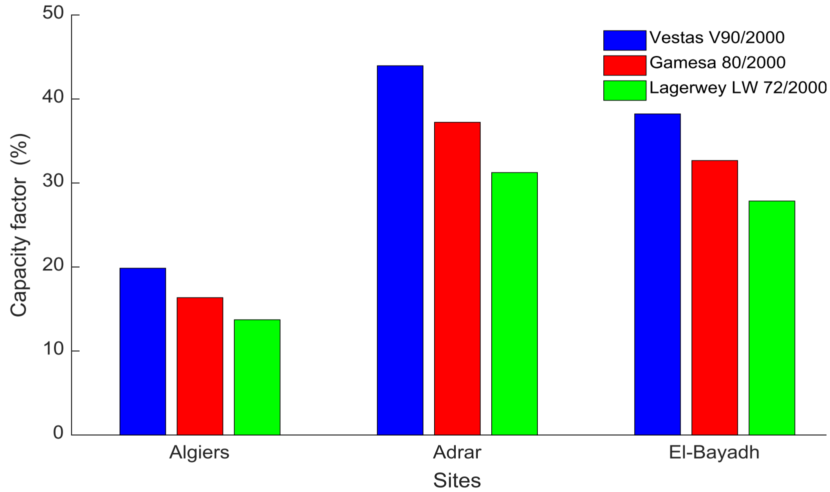

Fig. 6. Capacity factor of the three wind turbines for Algiers, Adrar and El-Bayadh.

4.3 Amount of hydrogen produced

The performance of the Vestas, Gamesa and Lagerwey wind turbines in terms of their contribution to hydrogen production is shown in Figure 7. It is clear that the Vestas V90 wind turbine distinguishes itself by its annual hydrogen production (1350 tons), which is higher than that of the GAMESA G80 (1120 tons) and LAGERWEY LW72 (980 tons) wind turbines. Similarly, variations in annual hydrogen production have been observed between sites. These results suggest that the Vestas V90 wind turbine at the Adrar site may be the best configuration for maximising hydrogen production.

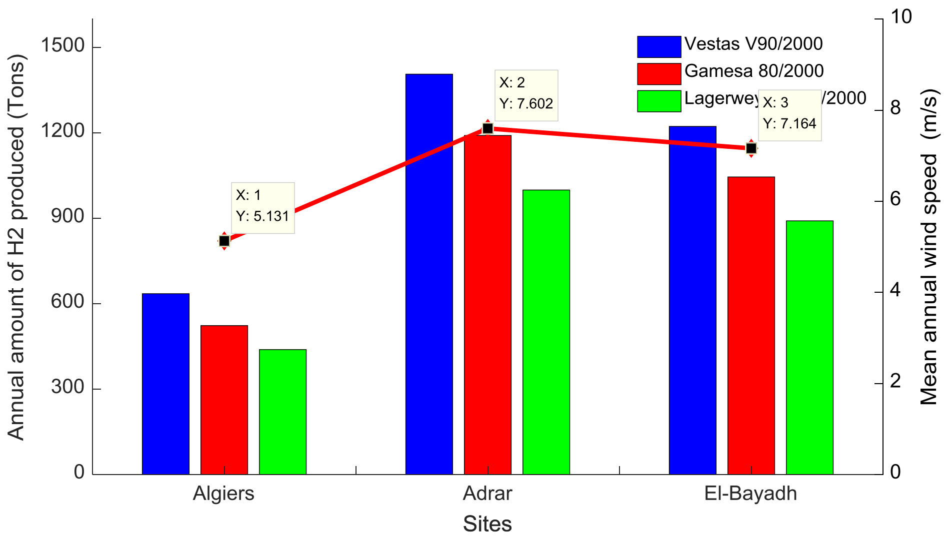

Fig. 7. Annual hydrogen production and average annual wind speed for the different sites.

4.4 Cost of hydrogen produced by 20MW farm ($/kg)

Analysis of Table 2 shows that the Adrar site offers the best green hydrogen production performance using Danish wind turbine technology (VESTAS V90), which has the lowest cost ($9.11/kg). On the other hand, LAGERWEY wind turbines offer the highest production cost with $12.81/kg.

Table 2. Net Annual Energy Produced, Capacity Factor, Annual Quantity and Price of kg of hydrogen produced by a 20MW power plant in different sites by the different wind turbines.

Sites	Indicators	Vestas V90	Gamesa GA 80	Lagerwey LW 72
	E_{ANP} (GWh)	34.784	28.647	24.033
Algiers	CF (%)	19.85	16.35	13.72
	Q_{AH2P} (Tons)	635.482	523.359	439.059
	Cost H_2 ($/kg)	20.16	24.48	29.18
	E_{ANP} (GWh)	77.0086	65.2144	54.7286
Adrar	CF (%)	43.95	37.22	31.24
	Q_{AH2P} (Tons)	1406.888	1191.418	999.850
	Cost H_2 ($/kg)	9.11	10.75	12.81
	E_{ANP} (GWh)	66.9599	57.2370	48.7945
El-Bayedh	CF (%)	38.22	32.67	27.85
	Q_{AH2P} (Tons)	1223.306	1045.676	891.439
	Cost H_2 ($/kg)	10.47	12.25	14.37

5. CONCLUSION

Green hydrogen is recognized as an essential solution for replacing fossil fuels. This article focuses on the assessment of hydrogen production from wind energy in Algeria, examining wind turbine types, site selection and comparative analysis of hydrogen production quantities and associated costs. Simulations have shown that certain configurations, notably those using VESTAS-type wind turbines in Adrar, are particularly efficient in terms of hydrogen production and economic viability. They have shown that VESTAS V90 wind turbines offer the lowest costs for hydrogen production, with costs of 20.16$/kg, 10.47$/kg and 9.11$/kg for Algiers, El-Bayadh and Adrar sites respectively, compared with costs of 29.18$/kg, 14.37$/kg and 12.81$/kg for the same sites using LAGERWEY LW72 wind turbines.

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