

# Wind-Powered Water Pumping for Livestock in Chad: A Feasibility Study in the Saharan Zone

Mahamat Kher Nédiguina<sup>1</sup>, Bali Tamegue Bernard<sup>2</sup>, Mahamat Adoum Abdraman<sup>1</sup>,  
Hamda Marcel Soulouknga<sup>3</sup>, Abakar Mahamat Tahir<sup>1</sup>, Mahamat Barka<sup>1</sup>

<sup>1</sup>Doctoral Training in Physics and Engineering Sciences, University of N'Djamena, N'Djamena, Chad

<sup>2</sup>Department of Physics, University of Abeché, Abeché, Chad

<sup>3</sup>Department of Physics, University of Sarh, Sarh, Chad

Email: mahamatkher88@gmail.com

**How to cite this paper:** Nédiguin, M.K., Bernard, B.T., Abdraman, M.A., Soulouknga, H.M., Tahir, A.M. and Barka, M. (2025) Wind-Powered Water Pumping for Livestock in Chad: A Feasibility Study in the Saharan Zone. *Journal of Power and Energy Engineering*, 13, 16-25.  
<https://doi.org/10.4236/jpee.2025.133002>

**Received:** February 5, 2025

**Accepted:** March 24, 2025

**Published:** March 27, 2025

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## Abstract

The Chadian Sahara is an area of high livestock development but often lacks water, forcing herders to travel with their animals for miles to water. In search of water, shepherds come to the south of the country where areas supposed to be pastures are often used for market gardening. The movement of animals often leads to conflicts between farmers and herders where Chad loses a large part of its population in several villages. Water production from easily accessible renewable resources can meet the needs of pastoralists in the Saharan zone of Chad. This document estimates the amount of water that a low-powered, easily usable wind turbine can produce to serve the animals at the selected sites. Two wind generators, one with a power of 3.5 kW and the other with a power of 12 kW were applied. The results obtained are such that placed in various places, these wind generators are more than enough to supply the cattle with water in the selected sites.

## Keywords

Wind Speed, Wind Power, Pumping, Water, Livestock, Chad

## 1. Introduction

Chad is livestock country, with 121 068 431 million head of cattle, 60% of surface is desert [1] [2]. It has significant water resources, 540 billion m<sup>3</sup> of exploitable underground reserves, including 20 billion m<sup>3</sup> renewable per year. Consisting of three (03) climatic zones (Saharan, Sahelian and Sudanian) and an average temperature of 35°C, 60% of Chad's surface is desert [3]. In Chad, the majority of households (72.7%) own livestock [4]. The north of Chad lacks water to serve the

population and livestock, pushing the elevators to regular movements.

Soulouknga *et al.*, compared the wind energy potential of the three climatic zones of Chad (Saharan zone, Sudanian zone and the Sahelian zone). They concluded that the windiest zones are the Saharan and Sahelian zones with average annual wind speeds of 3.575 m/s and 3.25 m/s respectively [5].

Mahamat A. Abdraman *et al.* in 2019 conducted work on “Energy Cartography of the Wind Resource in the City of Faya and Application to Water Pumping” [6].

Abakar Mahamat Tahir *et al.* Estimate in 2020 the Wind Resource of Two Cities in the Sahara and Sahel in Chad [7].

Mahamat Kher Nediguina *et al.* in 2022 conducted work on “Electric Water Pumping Powered by a Wind Turbine in Northeast Chad” [8].

In this document, we present the wind potential of the two sites using real data. We apply wind generators to evaluate the quantity of water that can be produced per day to water the animals. This water production is mechanical.

## 2. Materials and Methods

### 2.1. Site Identification

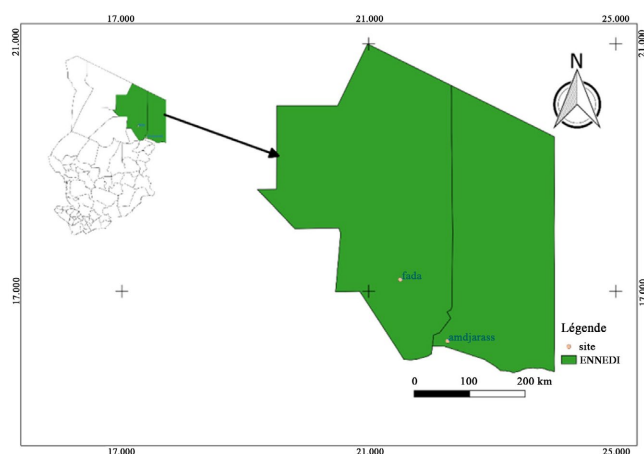
Amdjarass and Fada are the capitals of the East-Ennedi and West-Ennedi provinces in Northeast of Chad. Amdjarass is the largest city in the province and the fourth largest in Saharan (northern) Chad. Fada is a town located on the Ennedi plateau in the northeast of the country.

The pastoral situation is such that camel herding is much more practiced in East Ennedi (on average 32.9 heads per household), West Ennedi (8.8 heads per household) and Tibesti (6.15 heads per household) [4].

The geographical location of the sites is presented in the following **Table 1**:

**Table 1.** Geographical coordinates of the sites.

Long	Lat	Alt	Name
22.28	22.28	752.20	Amdjarass
21.58	21.58	742.36	Fada



**Figure 1.** Study area.

Data provided by meteorological stations at Fada and Amdjarass airports. All measurements are made at 10m from the ground over a period of eight years.

The data is recorded hour by hour and recorded in registers by technicians from the Agency for Air Navigation Safety in Africa and Madagascar (ASECNA). Measurements are made using a windsock and a weather vane.

## 2.2. Methods

The model used is the Weibull distribution given by [5]-[10]:

$$f(v) = \left(\frac{k}{c}\right) \times \left(\frac{v}{c}\right)^{k-1} \times \exp\left(-\left(\frac{v}{c}\right)^k\right) \quad (1)$$

Where:

$k$  and  $c$  are the Weibull parameters;  $f(v)$  is the probability of observing wind speed  $v$ ;  $v$  is the wind speed (m/s).

$k$  and  $c$  are determined by the wind variability method. Their expressions are:

$$k = \begin{cases} 1.05v^{0.5} & \text{if } v < 3 \\ 0.94v^{0.5} & \text{if } 3 < v < 4 \\ 1.05v^{0.5} & \text{if } v > 4 \end{cases} \quad (2)$$

$$c = \frac{\bar{v}}{\Gamma\left(1 + \frac{1}{k}\right)} \quad (3)$$

Where

$$\bar{v} = \frac{1}{N} \sum_{i=1}^N v_i \quad (4)$$

The extrapolation of wind speed for different altitudes is obtained by the following relationship [5]:

$$V(z_1) = V(z_0) \times \left(\frac{z_1}{z_0}\right)^\alpha \quad (5)$$

With  $V(z_0)$ , the exponent of the power law, a function of the surface roughness given by the expression [9]:

$$\alpha = \frac{0.37 - 0.088 \ln(V_{z_0})}{1 - 0.00881 \ln\left(\frac{z_0}{10}\right)} \quad (6)$$

The extrapolation of the parameters  $k$  and  $c$  is given by the expressions 8 and 9 [10] [11].

$$k_z = \frac{k_{z_0}}{1 - 0.00881 \ln\left(\frac{z}{10}\right)} \quad (7)$$

$$C_z = C_{z_0} \times \left(\frac{z}{z_0}\right)^n \quad (8)$$

$$\text{With } n = [0.37 - 0.088 \ln(c_0)] \quad (9)$$

The annual wind power density by [12]:

$$\frac{P(V)}{A} = \frac{1}{2} \rho \int_0^{+\infty} V^3 f(V) dv = \frac{1}{2} \rho c^3 \Gamma(x) \quad (10)$$

$$\text{With } x = 1 + \frac{3}{k} \quad (11)$$

Where:

$\rho$  = air density equal on average to 1.25 kg/m<sup>3</sup>;

$A$  = swept area of the rotor blades (m<sup>2</sup>).

The useful wind power is given by [13]-[15]:

$$P_u = \begin{cases} 0 & (v < v_{start}) \\ \frac{1}{2} \rho c^3 \Gamma(x) & (v_{start} \leq v \leq v_{rat}) \\ P_n & (v_{rat} \leq v \leq v_{stop}) \\ 0 & (v_{stop} < v) \end{cases} \quad (12)$$

$$P_u = \int_0^{+\infty} \frac{1}{2} \rho c^3 \Gamma(x) f(v, k, c) dv + \int_{v_{start}}^{v_{rate}} P_n f(v, k, c) dv \quad (13)$$

$$P_u = P_n \cdot FC \quad (14)$$

With

$$FC = \frac{\exp\left(-\left(\frac{V_{start}}{c}\right)^k\right) - \exp\left(-\left(\frac{V_{rat}}{c}\right)^k\right)}{\left(-\left(\frac{V_{start}}{c}\right)^k\right) - \left(-\left(\frac{V_{rat}}{c}\right)^k\right)} - \exp\left(-\left(\frac{V_{stop}}{c}\right)^k\right) \quad (15)$$

Where:  $V_{start}$  is starting speed,  $V_{rat}$  is rated speed,  $V_{stop}$  is machine stop speed.

The average of usable (produced) wind power is [8] [12]:

$$P_p = \eta P_u \quad (16)$$

Where  $\eta$  is the machine efficiency, it is given by:

$$\eta = 2 \frac{P_n}{\rho A V_n^3} \quad (17)$$

$P_n$ : rated power, given by the manufacturer.

The daily flow is given by [8] [14]:

$$Q_{dm} = 3600 * 24 * \frac{\eta P_{meca}}{\rho_{water} g H_{mt}} \quad (18)$$

With:

$H_{mt}$  is total manometric height;  $\eta$  pumping system overall efficiency;  $g$  gravity acceleration;  $\rho_{water}$  water density and  $P_{meca}$  mechanical power provided by wind.

### 3. Results and discussions

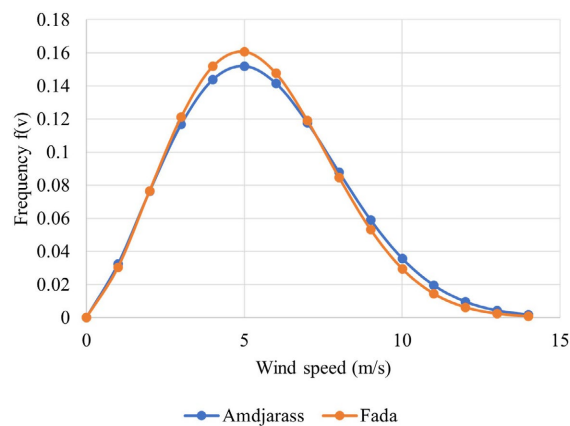
#### 3.1. Wind resource

The mean speed and Weibull parameters are represented in **Table 2**:

**Table 2.** Wind speed and Weibull parameters at 10 m.

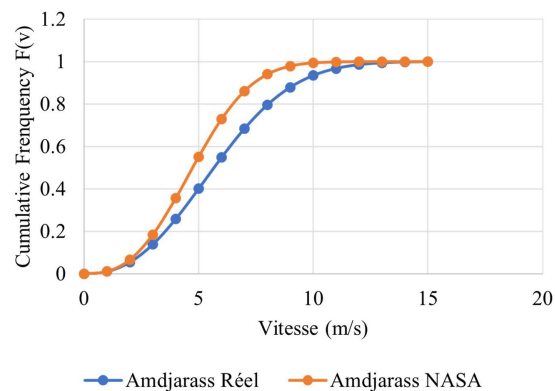
Months	Fada			Amdjarass		
	v (m/s)	c	k	v (m/s)	c	k
Jan	5.63	6.35	2.49	6.42	7.22	2.73
Feb	8.52	9.53	3.05	6.92	7.78	2.79
Mar	5.84	6.57	2.60	6.12	6.89	2.63
Apr	6.04	6.80	2.58	5.87	6.60	2.62
May	4.88	5.50	2.33	5.63	6.33	2.54
Jun	5.19	5.85	2.56	6.68	7.50	2.72
Jul	5.69	6.40	2.51	5.05	5.67	2.41
Aug	4.84	5.46	2.31	5.09	5.75	2.40
Sep	5.16	5.82	2.40	5.37	6.06	2.48
Oct	6.85	7.69	2.74	5.19	5.85	2.45
Nov	4.32	4.88	2.18	5.76	6.49	2.59
Dec	3.88	4.36	1.85	6.36	7.15	2.70

The analysis of this table shows that, the average months speeds vary between 5.05 m/s and 6.92 m/s in Amdjarass and 3.88 m/s and 8.52 m/s in Fada. The probability density and cumulative frequency are represented in **Figure 2** and **Figure 3**.



**Figure 2.** Probability density of two sites.

It must be remembered that  $f(v)$  Probability of observing wind speed  $v$ .



**Figure 3.** Cumulative frequency of two sites.

We observe through the cumulated frequencies that in Fada, 80% of the speed values are between 3 m/s and 8 m/s while. At Amdjarass, 75% of the speed values are between 3 m/s and 8 m/s. These results confirm the results obtained by M. K. Nédiguina *et al.* [9] in 2022 who used NASA data to estimate the wind potential in the same sites.

### 3.2. Turbine Performance

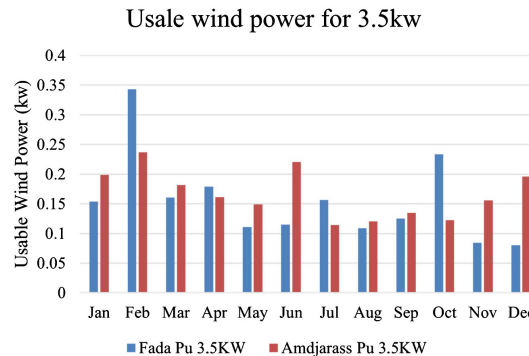
**Table 3** gives the characteristics of the selected wind generators.

**Table 3.** Wind speed and Weibull parameters at 10 m.

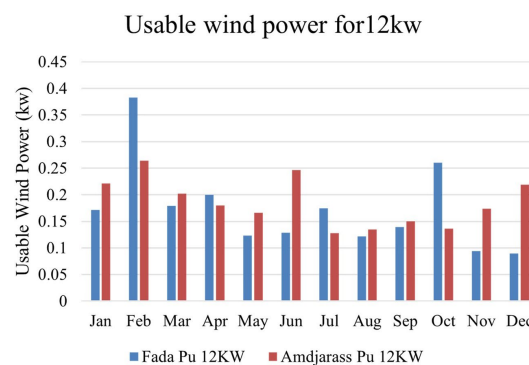
Rated power (kW)	Cut-in Wind speed (m/s)	Rated Wind speed (m/s)	Cut-off Wind speed	Rotor diameter (m)
3.5	3.5	12	14	4
12	3.5	12	14	7

When the capacity factors (FC) of the wind generators are evaluated, the values obtained are values of around 26.32% for (3.5 kW) and 26.46% for (12 kW). These values indicate that these wind generators can also produce electricity because according to reference [11], we can only speak of electricity production from wind turbines if the load factor is at least 25%.

When we apply the data to wind generators, the usable powers are given by **Figure 4** and **Figure 5**.



**Figure 4.** Usable wind power of two sites for (3.5 kW).



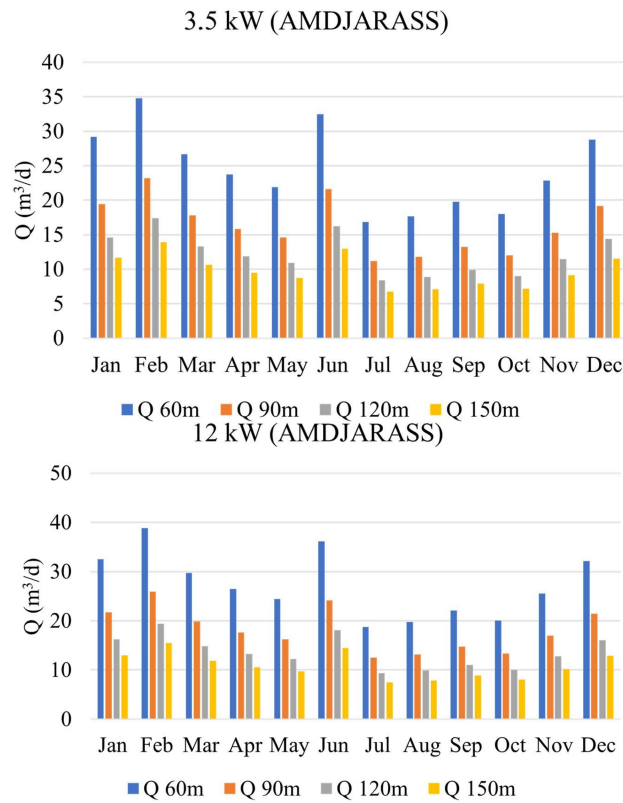
**Figure 5.** Usable wind power of two sites for (12 kW).

It can be seen that the two wind generators have usable powers almost similar on both sites.

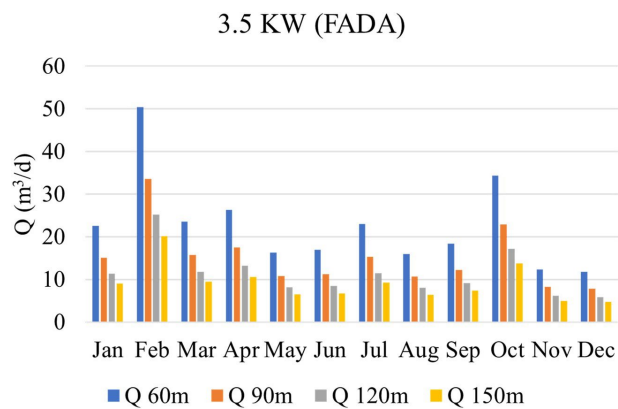
On average we have a useful power of around 100W with the (3.5 kW) -wind turbine and 150 W with the (12 kW) wind turbine. What makes the (3.5kW)-wind turbine more powerful than the (12 kW)-wind turbine taking into account their nominal power. Maximum powers are observed at both sites in February.

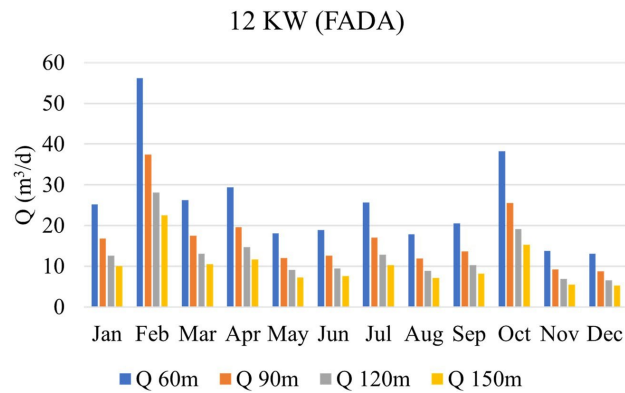
### 3.3. Water Yield

The volumes of water produced per day for each month are shown in **Figure 6** and **Figure 7**.



**Figure 6.** Volume of water in Amdjarass for (3.5 kW) and (12 kW).





**Figure 7.** Volume of water in Fada for (3.5 kW) and (12 kW).

It can be seen that the volumes of water are almost the same at the sites. Both wind turbines are of the type that can be adapted to the target area. It is noted that the water flow decreases when the head increases.

We note that in the smallest flow that can be produced per day in the two sites is of the order of 5000 l/Day.

The number of animals that can be watered is assessed by category in **Table 4** and **Table 5**. In these tables, we have considered that cattle consume 70 l of water/day, sheep 5l of water/day and camels 100 l/day [16]. Note that the greater the height of the fall, the lower the flow of water to be served.

**Table 4.** Number of animals to water in Amdjarass.

Amdjarass					
Wind Pump	Water production		Number of animals to be watered		
	Depth	Liter/Day	Cattle	Sheep	Camel
3.5 kW	60 m	24387.396	348	4877	244
	90 m	16258.264	232	3252	163
	120 m	12193.698	174	2439	122
	150 m	9754.958	139	1951	98
12 kW	60 m	27201.326	389	5440	272
	90 m	18134.217	259	3627	181
	120 m	13600.663	194	2720	136
	150 m	10880.530	155	2176	109

**Table 5.** Number of animals to water in Fada.

Fada					
Wind Pump	Water production		Number of animals to be watered		
	Depth	Liter/Day	Cattle	Sheep	Camel
3.5 kW	60 m	22651.508	324	4530	227
	90 m	15101.005	216	3020	151
	120 m	11325.754	162	2265	113
	150 m	9060.603	129	1812	91
12 kW	60 m	25265.143	361	5053	253
	90 m	16843.429	241	3369	168
	120 m	12632.572	180	2527	126
	150 m	10106.057	144	2021	101

It can be said that the mechanical production of water by an association of wind turbines can largely suffice for the watering of a large number of animals.

#### 4. Conclusions

In this paper, we evaluated the average wind speed at two sites in the Chadian Sahara. We found that the average annual wind speeds are well above the starting speed of a wind turbine. The average monthly speeds vary between 5.05 m/s and 6.92 m/s in Amdjarass and 3.88 m/s and 8.52 m/s in Fada. This makes these sites strategic areas for wind turbine development in Chad.

By applying two low-power wind turbines, which can easily be used for water production, the results obtained are such that placed in various places, these wind turbines can contribute enough to the water supply of livestock, preventing the movement of animals over kilometers. The smallest flow that can be produced per day in the two sites is of the order of 5000 l/Day.

We can conclude that the watering of animals through a wind source will contribute to the eradication of the farmer-herder conflict.

#### Acknowledgements

We are particularly grateful to the French Embassy in Chad for providing us with the necessary means, through the FSPI-Project, to collect the data.

#### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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