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Wind Power Harnessing in Sudan, Opportunities and Challenges

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Abstract: The African continent is endowed with large renewable potential, varying in types across diverse geographic areas. Wind resources are of the highest quality in the north, the east, and the southern regions [1]. This study concentrates on Sudan as one of African countries; that possess a good potential in wind power which can be integrated to support national grid as well as future regional power grid. This study uses windPRO 3.0.651 package [2] which is a software of wind energy project design and planning. In this study a comprehensive analysis for wind power in Sudan was done to verify the wind power potential in Sudan.

Keywords: *Sudan*; *Wind power; Integration; Grid code.*

1. INTRODUCTION

East Africa power sector analysis as prepared by International Renewable Energy Agency (IRENA) includes the following eleven countries: Burundi, Djibouti, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania, and Uganda. The region is endowed with a rich renewable energy sources especially wind power. For example, Somalia has the most high-quality wind power potential among all African countries, both in absolute terms (i.e. kWh …) and on a per-square-metre basis. Djibouti and Kenya also have significant potential on a per-square-metre basis; whilst Sudan, Ethiopia, Kenya, and

Tanzania have large resources in high-quality wind power on absolute basis [3]. Table 1 shows the large wind power potentials in Africa, with highest values located mainly in coastal areas.

The African energy sector faces two key challenges:

- low access to electricity
- insufficient and unreliable power supply

In this study wind power potential in Sudan is analyzed in different parts of Sudan to get good understanding of the best locations for installing wind farms. Figure 1 shows that Sudan has very promising potential for wind energy generation. Referring to Figure 1, the wind mean speed in Sudan at 50 m height varies between 5.1 – 7.1 m/s, in most of the areas is less than 5.9 m/s. and in certain places like Red Sea Coast, Northern State, and Darfur is between 6.9 – 7.1 m/s at 50 m above ground level.

2. INTRODUCTION TO WIND ENERGY

The design of wind turbine or its installation requires good understanding of the structure of the wind and the statistics used to describe it. Wind speed variations are random and so cannot be described using deterministic methods; therefore, it is necessary to use statistical descriptions of the wind. Generally recorded wind flow characteristics near the ground depict the following behavior:

- Wind speed increases with height.
- Wind speed varies with its turbulence.
- Wind turbulence is spread over a range of frequencies.

2.1 Annual Energy

Annual energy output is calculated by combining the wind speed resources curve with the power curve of the turbine

$$\text{Energy} = \sum_{i=1}^{i=n} \text{H(i)}.\text{P(i)} \quad (1)$$

where: H(i) = hours in wind speed
P(i) = power at wind speed
Energy in kWh or MWh or GWh

2.2 Wind speed statistics

For a set of wind speeds U_i, the mean wind speed is given by:

$$\overline{U} = \frac{1}{n}\sum_{i=1}^{n} U_i \quad (2)$$

Where the number of readings is n

Table 1. Potentials for Power Generation from Renewables in TWh (Values Subject to ±50% Uncertainty) [4, 5]

	CSP	PV	Wind Total	Wind CF 30-40%	Wind CF>40%	Hydro	Biomass	Geothermal
Central Africa	299	616	120	16	6	1057	1572	
Eastern Africa	1758	2195	1443	309	166	578	642	88
Northern Africa	935	1090	1014	225	69	78	257	
Southern Africa	1500	1628	852	100	17	26	96	
Western Africa	227	1038	395	17	1	105	64	
Total Africa	4719	6567	4823	667	259	1844	2631	88

CSP: Concentrated Solar Power
CF: Capacity Factor

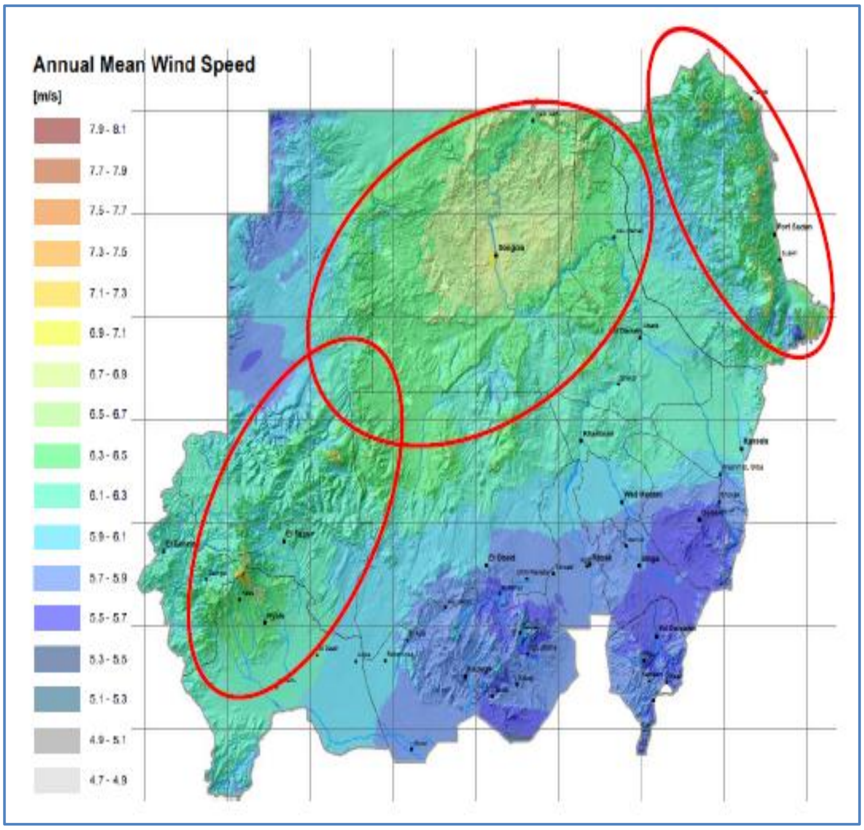

Fig. 1. Annual mean wind speeds at 50 m height for Sudan [6]

The variance of the data is given by:

$$\sigma^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(U_i - \overline{U}\right)^2 \qquad (3)$$

2.3 Weibull and Raleigh Statistics

It has been found from experience that either Weibull or the simpler Raleigh distribution can be used to describe long term records of wind speeds.
The probability density function of a Weibull distribution is given by:

$$f(U) = \frac{k}{A}\left(\frac{U}{A}\right)^{k-1} exp\left[-\left(\frac{U}{A}\right)^{k}\right] \qquad (4)$$

where “A” is the scale parameter (speed) and “k” is the shape parameter.

The cumulative distribution function (i.e. wind speed being less than or equal to U) is given by:

$$F(U) = 1 - exp\left[-\left(\frac{U}{A}\right)^{k}\right] \qquad (5)$$

The Raleigh distribution use merely a special case of the Weibull distribution with k=2.

2.4 Variation of wind speed with height

At the surface layer the variation of mean wind speed with height may be adequately represented by an expression of the form:

$$\overline{U}(z) = \frac{U^*}{k} ln\left(\frac{z}{z_0}\right) \qquad (6)$$

Where $\overline{U}(z)$ is the mean wind speed at height z
U^* is the friction velocity
k the Von Karman Constant (approx.. 0.4)
z_0 is the roughness length

3. HARNESSING SUDAN WIND ENERGY RESOURCES

By using a software called windPRO 3.0.651 the analysis covers twenty five towns in Sudan in order to get the main data, such as mean wind speed, annual energy and capacity factor. All twenty five locations are assumed to have Wind farms consisting of six wind turbines with each turbine of capacity 3 MW. The results show the high resource of wind power in Sudan. However ground data is very important and can be obtained by performing on-site wind measurements. Wind data collected in more than one year will be sufficient for wind farm planning. There are many Wind Turbine types; hence some criteria may be applied for selection such as:

- Commercial proven technology
- Experiences of the manufacturer
- Country and origin of the wind turbines
- Wind conditions on-site
- Expected energy obtained

A 3 MW generation unit was selected in this study. This high power Wind Turbine will decrease the total number of turbines in the wind farm and as a consequence the amount of the auxiliary components such as cables, busbars, earthing and auxiliary transformers, etc. will be decreased. Also this will reduce the civil work and installation cost.

Fig. 3 shows the location of Kadugli town at Nuba Mountain which is considered as an example for wind farm project in Sudan. **Fig. 4** shows the wind mean speed and frequency distribution at 90.0 m. **Table 2** and **Fig. 5** shows the Weibull Data and Weibul distribution curve at 90.0 m above ground level measurement height. **Fig. 6** shows Power Curve data used in the calculations for Kadugli town in Sudan as an example of a Sudanese town:

Table 3 shows the mean wind speed, annual energy in MWh, and capacity factor of a 3 MW generation unit at 90 m above ground level of twenty five towns in Sudan

Remote regions in Sudan like Darfur and Southern Kordofan (Nuba Mountains) might be good starting points for wind farm erection since there are no connections to the national grid transmission lines in these regions. Off-grid solutions using renewable technologies play a significant role because they allow for greater flexibility in supply expansion for villages and remote areas. Where grid expansion is not financially justifiable, the development of mini -grids or, in case of limited electricity demand of isolated households, individual energy systems fed by renewable power present optimal solutions [9]. Installing wind farms in such areas would have significant roles in the development and prosperity of the people. Electricity from wind farms can assist in lighting roads and farms which will increase working hours; also it will provide electricity for schools, medical units, pumping and treatment of drinking water. All these activities will encourage community solidarity to maintain peace and unity.

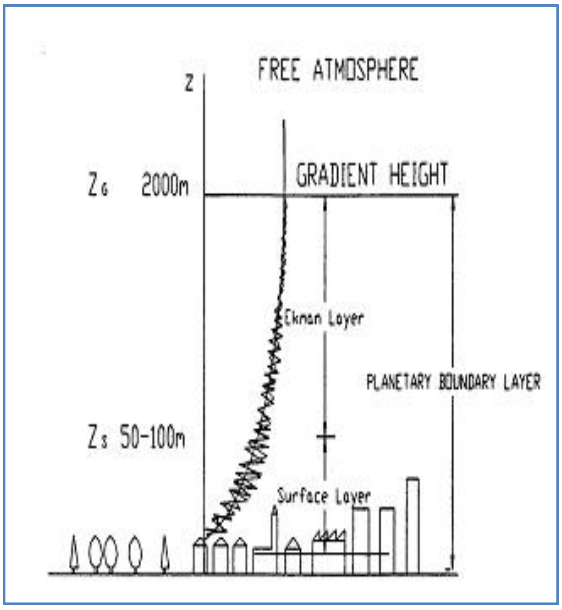

Fig. 2. Atmospheric boundary layer [8]

Fig. 3. Kadugli town at Nuba Mountains location in Sudan

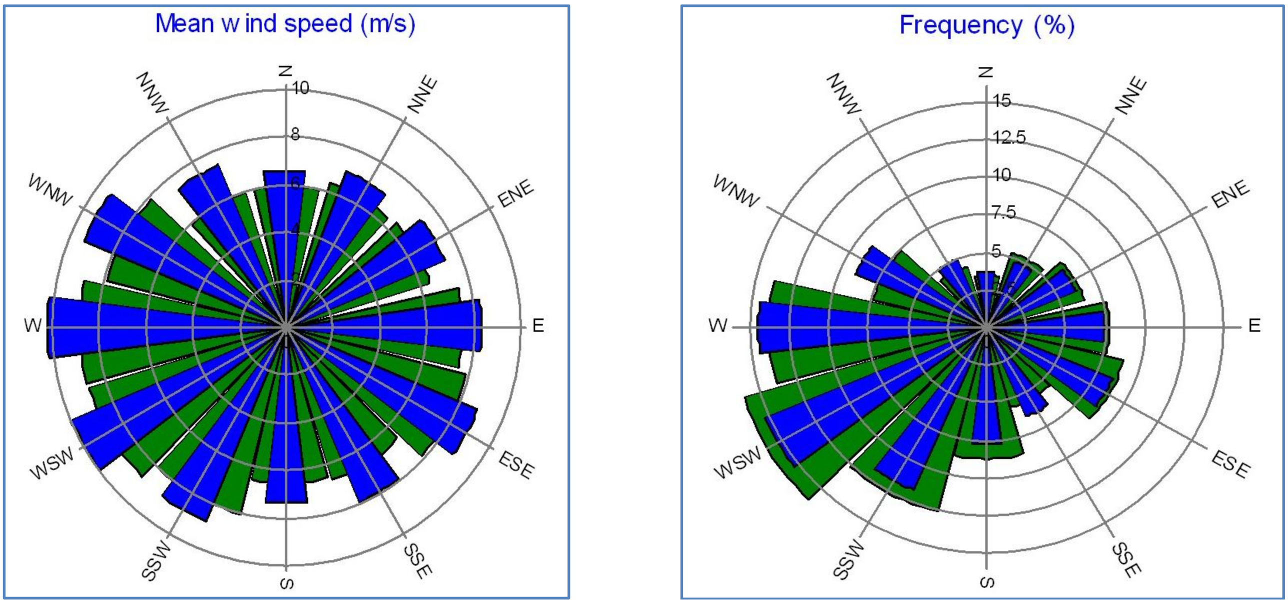

Fig. 4. Wind mean speed and frequency distribution at 90.0 m a.g.l. for Kadugli town in Sudan

Table 2. Weibull Data for Kadugli town in Sudan

Weibull Data

Sector	Current site: A-parameter [m/s]	Current site: Wind speed [m/s]	Current site: k-parameter	Current site: Frequency [%]	Reference: Roughness class 1: A-parameter [m/s]	Reference: Roughness class 1: k-parameter	Reference: Roughness class 1: Frequency [%]
0 N	7.44	6.62	1.769	3.7	6.72	1.884	3.5
1 NNE	7.94	7.06	1.850	4.7	7.16	1.961	5.2
2 ENE	8.16	7.31	1.609	6.1	7.15	1.605	6.4
3 E	9.42	8.35	2.192	7.4	8.49	2.419	7.7
4 ESE	10.03	8.89	2.342	8.6	8.93	2.419	8.9
5 SSE	9.01	7.98	2.092	6.4	7.52	2.082	5.5
6 S	8.36	7.40	2.070	7.7	7.39	2.152	8.7
7 SSW	10.01	8.86	2.138	11.7	9.10	2.276	12.6
8 WSW	11.24	9.97	2.420	15.2	9.89	2.525	16.0
9 W	11.51	10.21	2.448	14.4	9.98	2.513	13.8
10 WNW	10.58	9.37	2.170	9.0	8.93	2.179	7.4
11 NNW	8.34	7.42	1.749	4.9	6.64	1.726	4.2
All	9.86	8.73	2.078	100.0	8.64	2.148	100.0

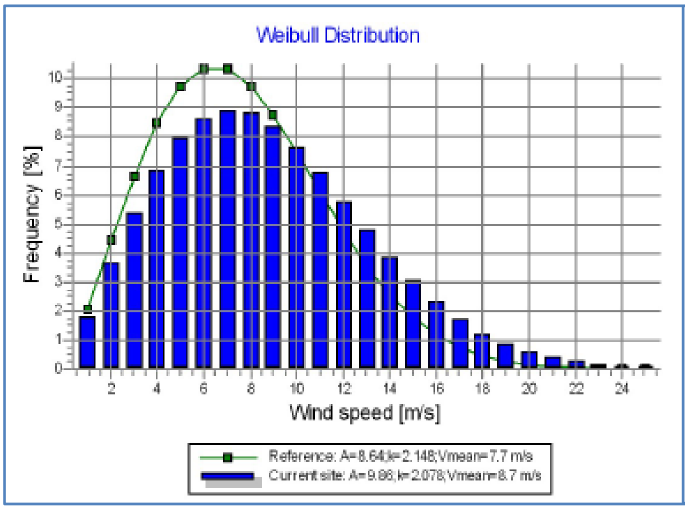

Fig. 5. Weibull data and Weibull distribution curve for Kadugli town in Sudan

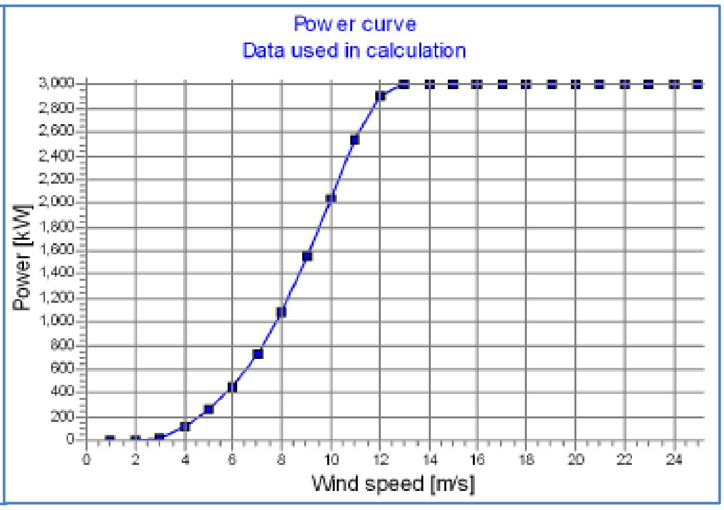

Fig. 6. Power curve data used in calculation for Kadugli town in Sudan

Table 3. Wind Power Analysis for twenty five towns in Sudan. Wind Turbine Generator

	Town	Mean wind speed (at 90m a.g.l) m/s	Annual Energy MWh	Capacity Factor %
1	Wad Madani	8.96	13,083	49.7
2	Al Qadarif	8.96	13,040	49.6
3	Ad Damazin	8.96	13,081	49.7
4	Kurmuk	8.96	13,081	49.7
5	Al Fashir	8.73	12,623	48.0
6	Al Junaynah	8.73	12,591	47.9
7	Nyala	8.96	13,071	49.7
8	Kasala	8.96	13,043	49.6
9	Khartoum	8.96	13,062	49.7
10	Abu Jubayhah	8.73	12,657	48.1
11	Diling	8.73	12,657	48.1
12	El Fula	8.73	12,642	48.1
13	El Obeid	8.73	12,657	48.1
14	En Nohud	8.73	12,642	48.1
15	Kadugli	8.73	12,609	47.9
16	Talody	8.73	12,609	47.9
17	Dongola	8.96	13,121	49.9
18	Wadi Halfa	8.96	13,133	49.9
19	Port Sudan	8.96	13,138	50.0
20	Sawakin	8.96	13,138	50.0
21	Ad Damar	8.96	13,056	49.6
22	Sennar	8.96	13,101	49.8
23	Sinjah	8.96	13,070	49.7
24	Rabak	8.96	13,073	49.7
25	Tandalti	8.96	13,073	49.7

Due to intermittent behavior of wind power, it is often used with other energy sources, such as diesel generators or solar electric panels to make a hybrid system to assure compensation for wind power deficiency.

4. FINANCIAL AND ECONOMIC CONSIDERATIONS

By considering one wind farm consisting of six wind turbines, each unit of 3 MW capacity; the following values are given from Kadugli wind farm:

Total number of wind turbines: 6
Annual Energy of one WT: 11,348
Total Turn-Key price for 6 units: 7,620,000 US$

Cost per 1 MWh = $\frac{7{,}620{,}000\ US\$}{6\ units * 11{,}348\ MWh}$ = 111,913 US$

Table 4 shows the estimated cost amount of a Turn-Key project for a wind turbine farm in Kadugli. The cost estimation includes the unit price, foundation and civil work, road in site, electric works, projecting, and insurance for 5 years. Many assumptions have been applied in this calculation to obtain reasonable values. The following assumptions are used:

- Currency: US$
- Electricity price: US$/kWh
- Energy: kWh
- Installation date: 12/10/2020
- Expected life span: 20 years
- Sales price: 0.03 US$/kWh
- Annual interest rate: 6.0%
- Inflation: 5.0%
- Inflation regulation begins: 1/1/2021
- VAT: 5.0%

Table 4. Turn-Key Budget for Wind Farm in Kadugli. TURN-KEY BUDGET (Amount in US$ excl. VAT)

WTG_price	6,000,000
Foundation	420,000
Road	180,000
Electric Works	480,000
Projecting	240,000
5 year, Insurance	300,000
Net installation price	7,620,000
Cost per 1,000 kWh	111,913

The payback period for this project will be ten years. Simple payback time is the number of years needed to payback the investment plus operation costs within the payback time. Finance costs, tax and inflation are not included. Figure 7 shows the payments, interest, operation, and taxation instalments during a twenty-year life span for the wind farm project in Kadugli town.

The main sources available for financing the renewable energy projects in Africa are multilateral (World Bank Group and regional development banks) and bilateral sources (mainly from members of the Organization for Economic Co-operation and Development (OECD) Development Assistance Committee), sources from governments in developing countries, and private sector sources [10].

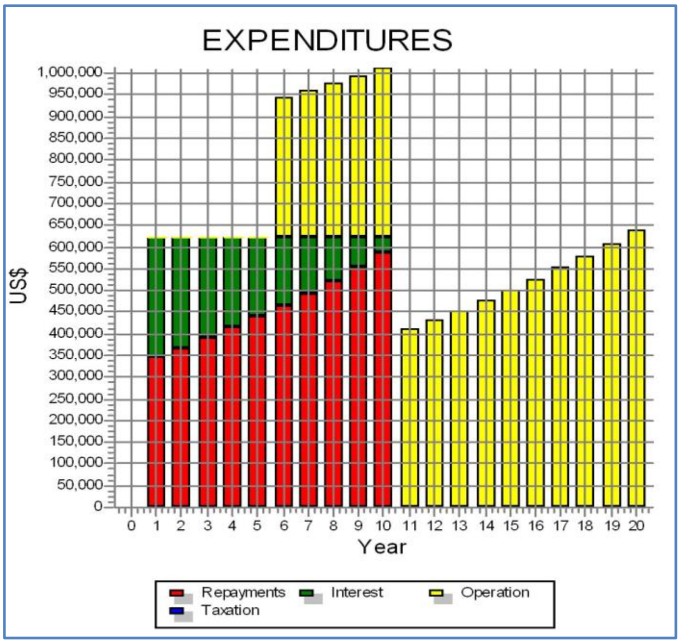

Fig. 7. Wind farm project expenditures during twenty-year life span for Wind Farm in Kadugli.

5. CHALLENGES OF GRID CONNECTED WIND POWER IN SUDAN

Sudan is not yet integrated or interconnected as a very strong network, and still Sudan has small installed capacity, so great efforts should be done to increase the installed capacity. The average of electrification rate in Sudan is only 35% [11]. There shall be a clear strategy for the integration of wind power in the transmission network, however at the same time the increasing of conventional generation shall go in parallel to have such reserve to assure compensation. The challenge is that, efforts are made to maximize the utilization of wind power and at the same time it is intermittent power. It is essential to deal with such condition with smart way to adapt the grid and allow the system to be able to integrate renewable energy in large scales.

The selection of unit size of wind turbine depends on the site and hub height because permission from aviation authorities may be required to assure that does not conflict with flights.

Early wind farms were allowed to connect with little control of voltage and reactive power and no fault ride through capability. This has changed and most countries have now prepared connection requirements and grid codes which takes wind farms into account.

6. GRID CODE REQUIREMENTS FOR WIND POWER

Renewable Grid Code should be implemented to organize the procedures for both planning, connection and operation, constitute a part of the Transmission and Distribution Code and must comply with the technical conditions mentioned in the Grid Code especially Power Quality and the Electrical Standard Rated Values. Some requirements should be fulfilled for wind power integration in transmission network:

- Fault ride through (FRT) requirements
- Transmission system voltage and reactive power capability requirements
- System frequency and frequency response requirements (Active Power Control)
- Wind power forecast requirements
- Power Quality
- Secondary Equipment and Remote operation requirements

7. WIND POWER OPPORTUNITIES IN SUDAN

It is important for the Sudanese government to encourage advancement towards the widespread adoption of clean energy supply on national level through implementing of incentives in regulations and policies besides attracting investments and private sector.

Capital cost of electricity of renewables globally have decreased significantly and continuously over the past decade, driven by combination of learning effects and incentive schemes [12]. Costs are predicted to continue declining in future [13]. The integration of wind generation is likely to increase the commitment of quick-start units to ensure available generation to handle deviations from forecast levels.

8. CONCLUSIONS

Sudan has very good potential and great opportunity to exploit renewable resources especially wind power to supply electricity to remote areas through off-grid systems and wind power integration. This study shows that Red Sea Coast and Northern State have the best resource of wind quality in both mean wind speed and capacity factor among Sudanese regions.

Successful development of renewable energy resources will, however, require the adoption of clear consistent policies, availability of technical skills and institutional capacities and provision of financial incentives.

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