WIND ENERGY IN ETHIOPIA

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INTRODUCTION

Among the renewable energy sources wind energy is the most fascinating one. It has been utilized for thousands of years, it is available everywhere, it seems that one only has to reach out ones hand for it. But one cannot grab it so easily and in spite of its long history and the many experimental approaches it still does not contribute an appreciable part to our present energy production.

Just to mention two main problems:

(a) It is dispersed in the thin air and big or many units are needed for collecting it.

(b) It is changing in time; storage of energy for no wind periods necessitates big investment.

These and all other difficulties can be surmounted but this greatly reduces the economy. Still, there are two fields for economic windmill operation:

(a) Where no other energy source is available.

(b) Where wind is strong and steady, which is the case on the sea shores.

Utilizable Energy

Theoretical maximum power that can be utilized by a windmill of area A m², out of a wind speed of c m/s, with air density of ρ kg/m³ is:

$$P_{id} = \frac{16}{27}\frac{\rho}{2} c^3 A \text{ watt.}$$

Losses on the vanes and in the transmission are usually taken in account by an efficiency of 0.7, which gives a factor of

$$\frac{16}{27} 0.7 = 0.42,$$

and thus

$$P = 0.42 \frac{\rho}{2} c^3 A \text{ watt.}$$

There are three more circumstances which reduce the yearly output energy of a windmill:

(a) Below a minimum wind speed (usually about 4 m/s) the energy cannot be utilized because the wheel does not start. This means a relatively small loss, the energy of this low speed being very low.

(b) Above a maximum wind speed (usually about 12 m/s) the utilized power is limited by the strength of the windmill or by the capacity of the generator or by the maximum permissible speed of the pump, etc. The windmill is intended to be turned out of the wind direction at these speeds so that it should continue to give its maximum power (corresponding to say 12 m/s) even at higher speeds. This can be achieved approximately.

(c) The power utilized from wind must be consumed by the generator or pump. Now, the wind power is proportional to the 3rd power of the velocity, as seen from the formula. But the power consumed by the generator is roughly proportional to the second power of its speed (also depending on control conditions), while the power consumed by a piston or screw pump, pumping to a constant head, is proportional linearly to its speed. Consequently, the windmill does not operate at a constant (its optimum) speed ratio, but its speed ratio will vary in the range of lower efficiences. The amount of this power loss is difficult to estimate, as it depends on the windmill-generator or windmill-pump assembly. We can roughly assume that about 1/3 of the total energy in a year escapes utilization because of this reason.

Harnessable Energies in Ethiopia

Harnessable energies were calculated on the basis of observations of the Meteorological Services of Ethiopia between years 1961-1970. During this 10 year period the wind speeds, recorded at fixed hours (6, 12 and 18 hours) at 12 places, were summarized. The data sheets gave the total number of readings of each particular wind speed range during the 10 year period. The sheets also contain the wind directions which is irrelevant from energy point of view.

As an example a data sheet is shown in Table 1.

Processing of the data can be followed in Table 2. First the number of occasions in all directions were summed up. With the number of calm days added the total number of readings (n) was established, being somewhat less than $10 \times 365 + 2 = 3652$.

Then the daily average of the number of occasions was found for each speed range. These values were multiplied by the cube of each range middle velocity and summed up.

Table 1. Observations based on data from 1971 to 1980

Station: Asmara
Altitude above MSL: 2325m; Lat: 15° 17′; Long: 38° 55′; Height of anemometer:
Type of data: Periodical cumulative wind velocity at fixed hours

Speed Knots	06 00									12 00									18 00								
	N	NE	E	SE	S	SW	W	NW	Calm	N	NE	E	SE	S	SW	W	NW	Calm	N	NE	E	SE	S	SW	W	NW	Calm
1– 3	19	15	55	4	10	2	10	10	1463	10	6	12		8	3	6	2	116	2	3	6	1		4	3	4	96
4– 6	72	130	349	62	57	20	74	155		41	37	89	38	74	39	104	54		53	94	110	6	13	7	56	88	
7–10	21	116	446	24	42	10	92	87		43	128	376	137	107	60	272	152		69	395	548	12	16	18	222	218	
11–15	1	27	123	5	4		24	17		28	131	361	53	55	30	179	125		34	285	401	8	4	10	151	110	
16–20	2	4	27		1		5	4		5	113	309	24	23	16	136	55		12	144	207	6	4	5	121	32	
21–25							1			1	5	25			1	11	1			1	4	1	1		7		
26–30												5				1									1		
31–35																											
> 35																											
Total	115	292	1000	95	114	32	206	273	1463	128	420	1177	252	267	149	709	389	116	170	922	1276	34	38	44	561	452	96
Mean speed	5.4	7.2	7.7	6.2	6.4	5.9	7.8	6.7		8.3	12.2	12.4	9.8	9.1	9.5	11.1	10.8		8.9	11.0	11.2	10.9	9.2	9.5	11.6	9.5	

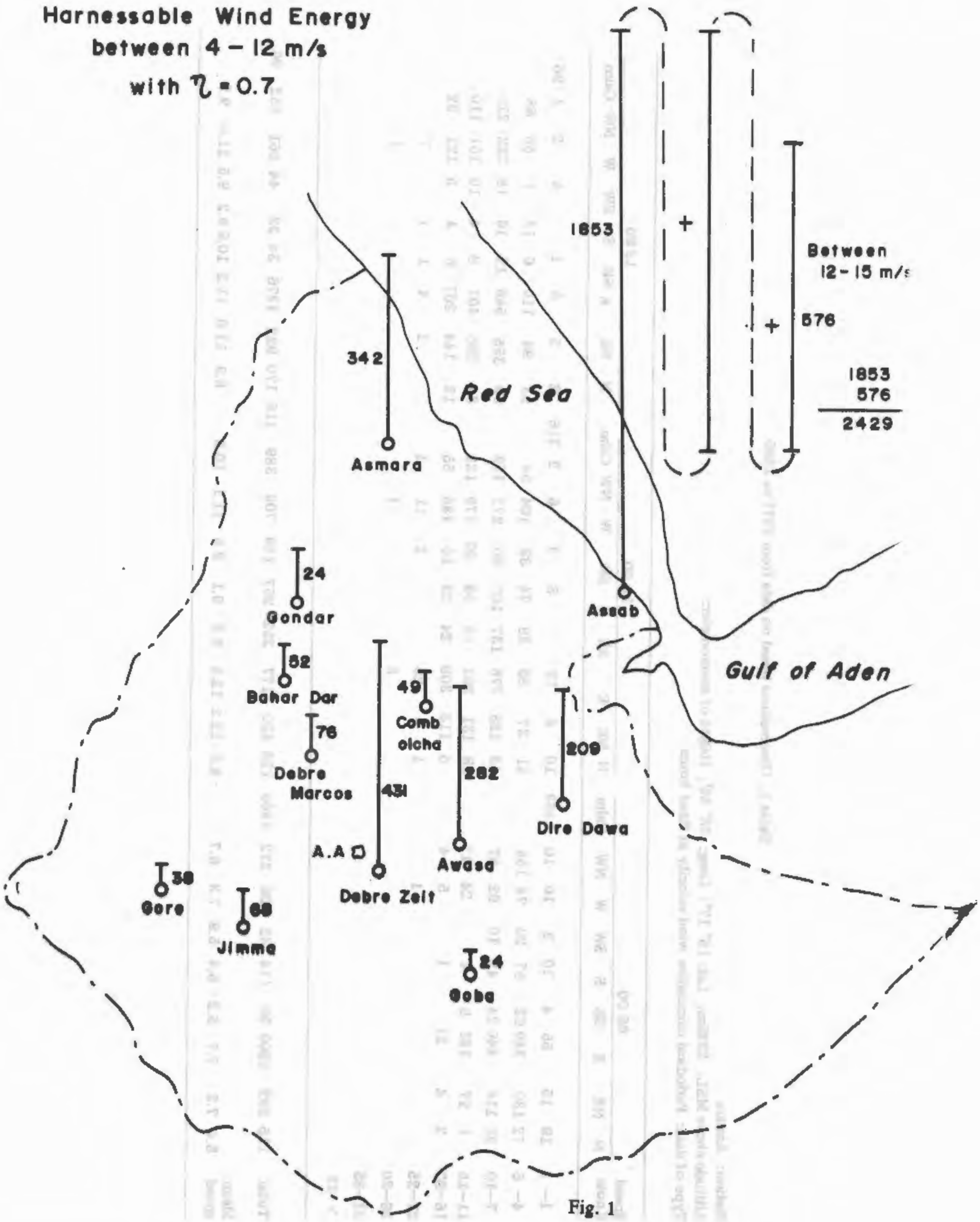

Harnessable Wind Energy
between 4 – 12 m/s
with η = 0.7
1853
+
Between
12 – 15 m/s
+
576
1853
576
2429
342
Red Sea
Asmara
24
Gondar
52
Bahar Dar
49
Comb olcha
76
Debre Marcos
431
282
209
Assab
Gulf of Aden
Dire Dawa
A.A
Debre Zeit
Awasa
38
Gore
68
Jimma
24
Goba

Fig. 1

Values corresponding to less than 4 m/s wind speed were left out and those for wind speeds above 12 m/s were multiplied by the cube of the last middle speed below 12 m/s. This sum (S) was then substituted in the formula

$$E = 0.42\,\frac{\rho}{2}\,\frac{24}{10}\,\frac{1}{1000}\,\frac{3652}{n}\,S \quad \mathrm{kWh/m^2\ year}$$

ρ is the air density at the geodetical height of the particular place as taken from the International Normal Atmosphere, division by 10 reduces the 10 year period to 1 year and 1/1000 stands for kW/W.

Values of harnessable energies, calculated in the above method, are presented on the map in Fig. 1. The map shows clearly that wind energy is considerable on the lowland region starting from the Gulf of Aden and ending at about Debre Zeit. There is practically no wind energy in the mountainous region.

Wind energy is high in Asmara, near the sea shore and very high in Assab, directly on the sea shore. Here it is more than 4 times that in Debre Zeit or Asmara. In Assab the energies between 12 and 15 m/s speeds also can be added because here it would be economical to set up a windmill which utilizes power up to 15 m/s speeds. Beside that wind speed in Assab is fairly steady both, in magnitude and in direction which highly enhances utilization.

Observations in Assab

High wind energy prompted a short time observation in Assab. It was conducted from 2nd to 4th of February 1984.

Wind speed was measured on the roof terrace of the "Guest House" situated on the sea shore beside the harbour, at a height of about 12m above the ground level.

Investigation of the flow pattern around the point of the observation showed that the anemometer was in a slightly increased speed region. On the basis of theoretical analogy, made afterward, the velocities were decreased by 3%. In the last 4 cases the anemometer was fixed 1m higher where correction was negligible.

In two cases pressure differences were taken on a cylindrical probe for monitoring the direction changes, too. Direction change was practically within ± 8° (standard deviation), but inertia effects of the manometer fluid made these velocity readings unreliable.

In all other cases momentary velocities were recorded in each 5th second during 10 minutes. Out of the 120 readings the average wind speed was established and also the average of the cube of the momentary values was calculated for energy purposes (see later).

Measured velocities are plotted in Fig. 2. Out of the 8 points a fairly consequent daily variation can be followed showing lower velocities during the night.

For the two days an average wind speed of 10.9 m/s was found, representing a relatively high power.

Correction for Missing Midnight Readings

As mentioned above, the meteorological charts gave the number of readings at 6, 12 and 18 hours, i.e., out of each 6th hour the midnight reading was missing because of obvious reasons. The suspicion of this giving a positive error was always present but, on the basis of the Assab observations, its magnitude can be estimated.

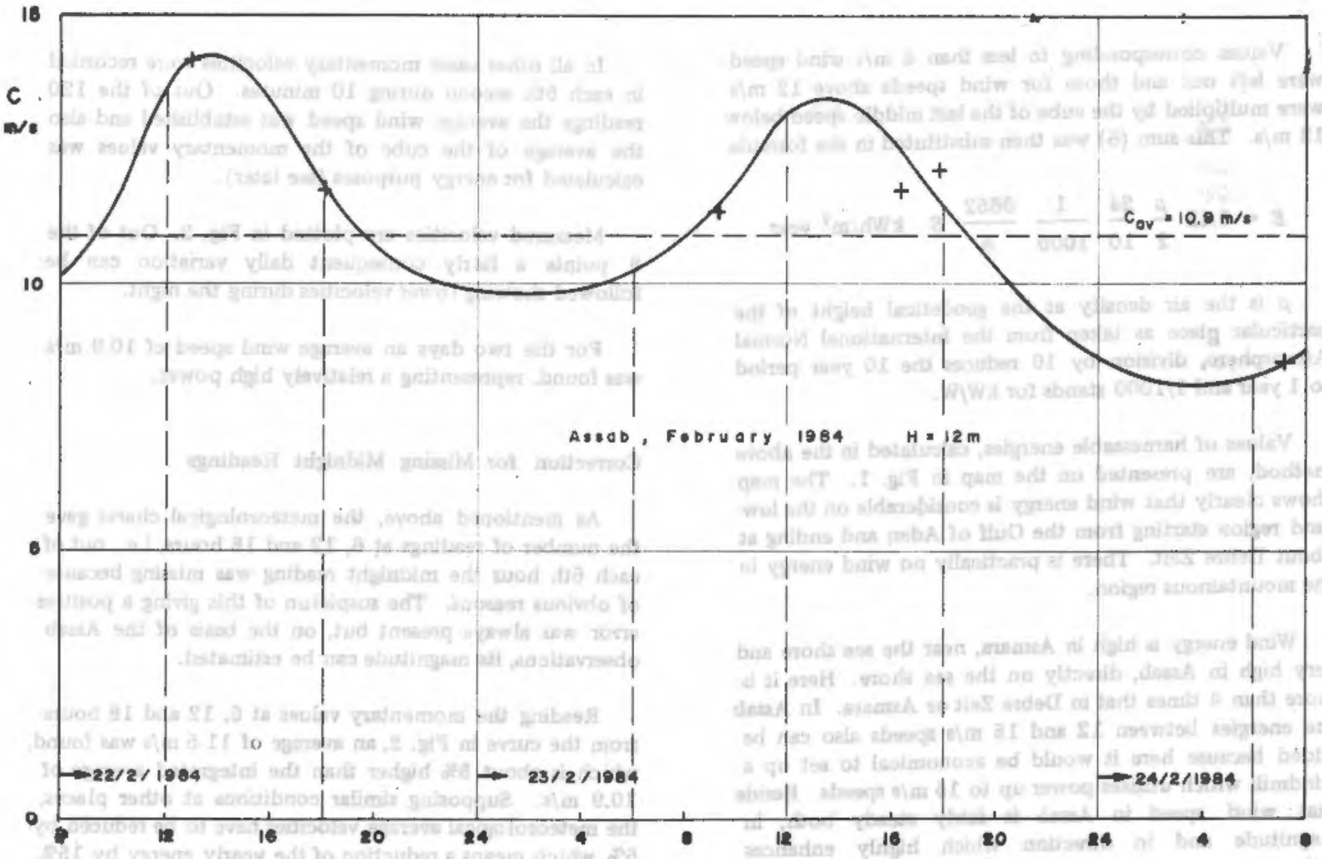
Reading the momentary values at 6, 12 and 18 hours from the curve in Fig. 2, an average of 11.5 m/s was found, which is about 5% higher than the integrated average of 10.9 m/s. Supposing similar conditions at other places, the meteorological average velocities have to be reduced by 5%, which means a reduction of the yearly energy by 15%.

Excess Energy Due to Short Period Fluctuation

The meteorological observations for 10 years, 3 times a day, represented nearly 11 000 data read at regular intervals. This yields a practically perfect average of a random change. The effect of the missing midnight data has been discussed above. Still, there is an excess energy as due to the short period fluctuation because these readings are the average values during 1, 2, or more minutes. Whether a windmill can follow a fluctuation of a period of less than a few minutes, this is another question, but usually it can, and it utilizes the effective value of the changing velocity with some efficiency even if it does not follow it.

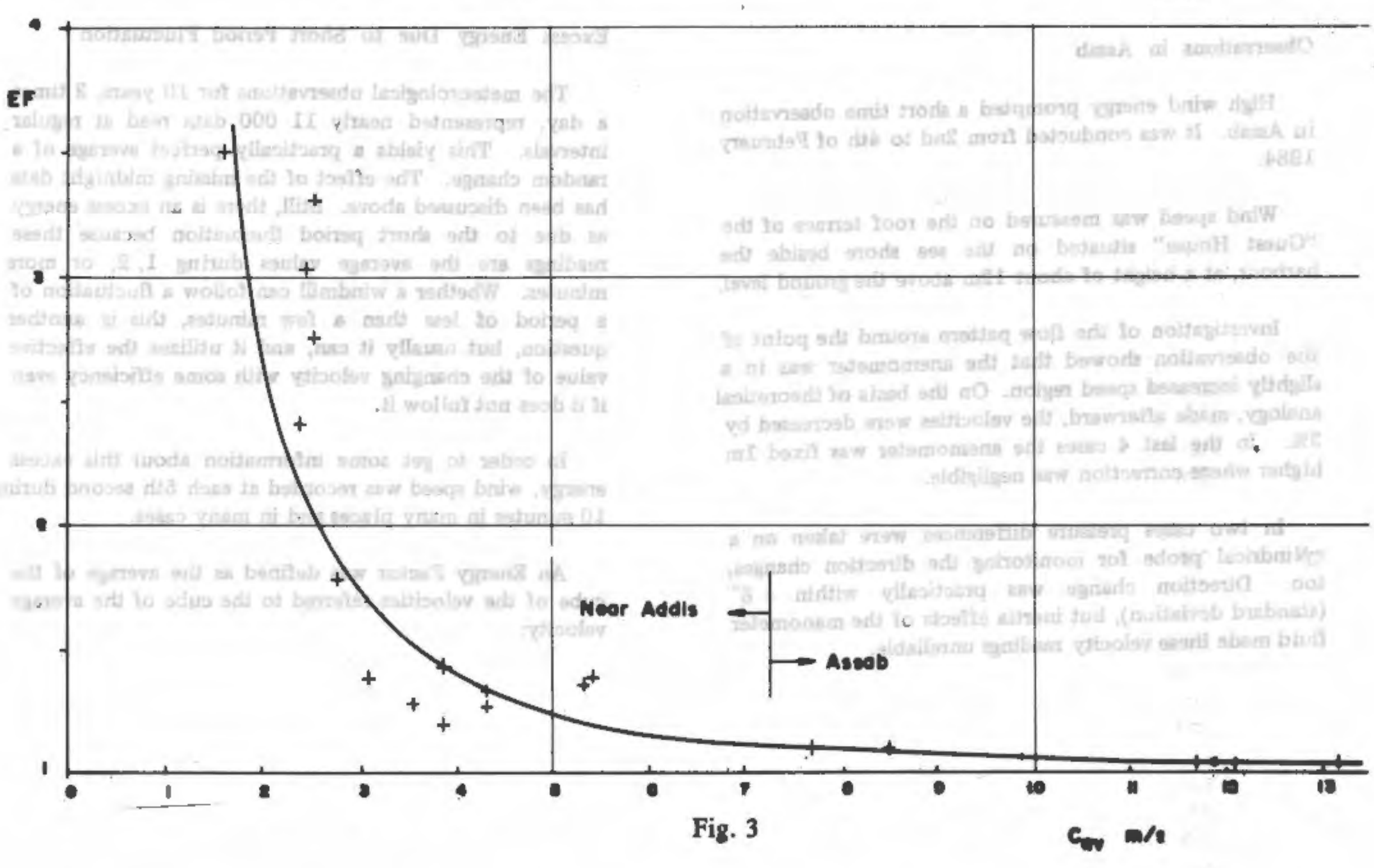
In order to get some information about this excess energy, wind speed was recorded at each 5th second during 10 minutes in many places and in many cases.

An Energy Factor was defined as the average of the cube of the velocities referred to the cube of the average velocity:



15
C
m/s
10
5
0
C_{av} = 10.9 m/s
Assab , February 1984 H = 12 m
22/2/1984
23/2/1984
24/2/1984
8 12 16 20 24 4 8 12 16 20 24 4 8
Hour

Fig. 2



EF
4
3
2
1
Near Addis
Assab
0 1 2 3 4 5 6 7 8 9 10 11 12 13
C_{av} m/s

Fig. 3

Table 2

Station: Asmara $\rho = 0.973$ kg/m^3

Speed range Knots	Mean speed c_m Knots	Mean speed c_m m/s	c_m^3 m^3/s^3	Harnessable c_m^3 m^3/s^3	Number of readings 6 00	Number of readings 12 00	Number of readings 18 00	Mean No. of read. n	nc^3 m^3/s^3
Calm	0	0	0	0	1463	116	96	558	0
1– 3	2	1.03	1	0	125	47	23	65	0
4– 6	5	2.57	17	0	919	476	427	607	0
7–10	8.5	4.38	84	84	838	1275	1498	1204	101 000
11–15	13	6.69	299	299	201	962	1003	722	216 000
16–20	18	9.27	797	797	43	681	531	418	333 000
21–25	23	11.84	1660	1660	1	44	14	20	33 000
26–30	28	14.41	2992	1660	0	6	1	2	3 000
31–35	33	16.99	4904	1660	0	0	0	0	0
> 35	38	19.56	7846	1660	0	0	0	0	0
								3596	686 000

$$E = 0.42 \; \frac{0.973}{2} \; \frac{24}{10} \; \frac{1}{1000} \; \frac{3652}{3596} \; 686\,000 = 342 \text{ kWh/m}^2 \text{ year}$$

$$EF = \frac{\frac{1}{T}\int_0^T c^3\, dt}{\left(\frac{1}{T}\int_0^T c\, dt\right)^3}$$

and its value was found for each case.

These EF values are plotted against the average wind speed values in Fig. 3. Without claiming that it does not depeud on other circumstances, a characteristic drop of EF can be discovered with increasing average wind speed.

It may be of some interest that superimposing a sinusoidal change on a coustant value:

$$c = c_{av} + a \sin \frac{2\pi}{T} t ,$$

the Energy Factor

$$EF = 1 + 1.5 \left(\frac{a}{c_{av}}\right)^2 .$$

This gives a maximum of 2.5 for $a = c_{av}$, which is the maximum amplitude for avoiding negative velocities.

But, supposing a change with high peak values and very low or zero values in between for longer periods, EF can go to infinity. This explains the high EF values at low average wind speeds.

From utilization point of view it can be stated that this excess energy is relatively appreciable only at low wind speeds which hardly can be harnessed. At high wind speeds, which give most part of the utilized energy, it is only a few per cent and thus negligible.

Economy of Utilization

Referring to circumstances in Assab and to the present price system, the following economic calculation can be made.

According to the map in Fig. 1, the harnessable energy in Assab is 2 429 kWh/m^2 year. Because of the missing midnight data this has to be reduced by 15%, which gives 2 112 kWh/m^2 year.

A 10m diameter wheel (with an area of 78m^2) would give 166 000 kWh/year. Assuming 2/3 of it as realized output energy, it is about 110 000 kWh/year. This, multiplied by a minimum price of 0.12 Birr/hWh, amounts to 13 200 Birr/year.

Cost of a 10m diameter windmill was estimated for 10 000 Birr by Mr. K. Jensen, leader of the Rural Water Pumping Project, in 1970.

Even if the cost is more for a windmill generating electricity and has increased since then, it seems that such a windmill would repay its installation costs within about 1 year in Assab. There is no fuel but some maintenance cost in the following years and a well designed and well maintained windmill can work for many decades.

We did not consider storage problem here, which means that it is just a fuel saving generator. As we cannot be sure, there is wind at the time of peak consumption, we have to build heat power plants with the capacity to cover the peak consumption. In other words, building windmills without storage does not save the cost of building heat power plants. Cost of electric energy consists about half of fuel and other half of power plant installation costs. This reduces the economy of the windmill, but full amortization within 2 years is still advantageous.

In other parts of the country, where the yearly energy is less than 1/4 of that in Assab, repaying time would be 4 or 8 years, respecitively without any maintenance cost. Thus, installing a windmill generating electricity is reasonable only on the sea shore.

Circumstances are different for a water pumping windmill. Firstly, it is simpler and thus cheaper, secondly, storage is at hand by a reservoir. Still, it it is for drinking water, storage for an about two months long no wind period in the rainy season is impossible. In this case installation of a Diesel engine and of a fairly complicated driving system is inavoidable.

But, if the water serves for irrigation, no storage is needed and there is no problem if the no wind period coincides with the rainy season.

A 10m diameter wheel in Awash would give

$$282 \times 0.85 \times 78 \times 0.67 = 12\,500 \text{ kwh/year.}$$

Assuming a 50m deep well and a pump efficiency of 0.8 this delivers a water volume of

$$V = \frac{L}{\rho g h}\,\eta = \frac{12\,500 \times 3\,600 \times 1\,000}{1\,000 \times 9.81 \times 50} \times 0.8$$

$$= 7\,350 \text{ m}^3\text{/year}$$

which is a considerable quantity even for irrigation.

Thus, an irrigation project with windmills may be rather advantageous on the low land of the country.