

# Wind Regimes in Africa

## A comparative Evaluation of Wind Data

charged by **InWEnt gGmbH**

Internationale Weiterbildung und Entwicklung

Division "Environment Policy and Environmental Management"

Berlin

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- purpose of this study
- sources of wind data
- aspects of African wind regimes
- example Gao
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- conclusions
- outlook – what strategy for wind in Africa?

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## Who am I?

Benjamin Jargstorf (Dip.-Ing. Equals M.Sc.)

- electrical engineer, sociologist
- studied at
  - Technische Universität Braunschweig (Technical University of Braunschweig, Germany)
  - Free University of Berlin
  - University of Cambridge (King's College, UK)
  - University of Nairobi
- working experience in more than 40 countries
- specialising in RE since 1985

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## Factor 4 - World-wide Experiences



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## **Purpose of this study**

- get a realistic picture of African wind resources
- end the underestimation of African wind regimes
- put Africa on the international wind map
- identify countries and regions for capacity building in the field of wind energy utilization

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## **Sources of wind data**

- meteorological stations (10 m)
- agro-meteorological stations (2 m)
- weather charts (internet)
- installed wind turbines (nacelle anemometer)
- measurements directly at potential sites - explicit wind resource analysis
- bi-lateral and multi-lateral co-operation projects

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## Current situation



- **public perception:** Africa is a continent with low wind resources
- because evaluation of **meteorological data** leads to under-estimation of wind speeds

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## Meteorological stations

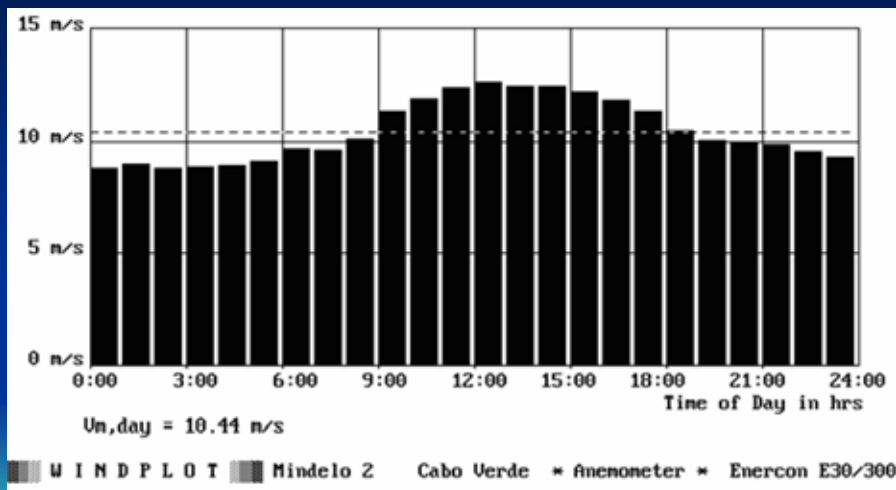
- often surrounded by trees, buildings and other obstacles
- often anemometers not calibrated
- often not measuring at standard height (10 m above ground)
- synoptic wind speed readings at 8.00 h, 12.00 h and 18.00 h
- problematic with marked diurnal patterns

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## Diurnal variation of wind speed



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## Nacelle anemometers

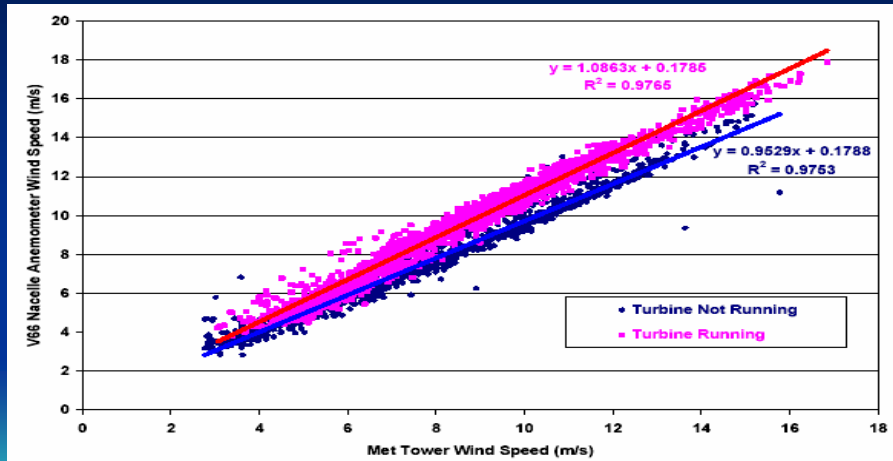
- data from running wind energy projects difficult to get
- often no independent measurements from stand-alone measuring masts
- nacelle anemometers give misleading data (turbulence of rotor)
- normally no frequency distribution recorded – only averages

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# Nacelle anemometer readings

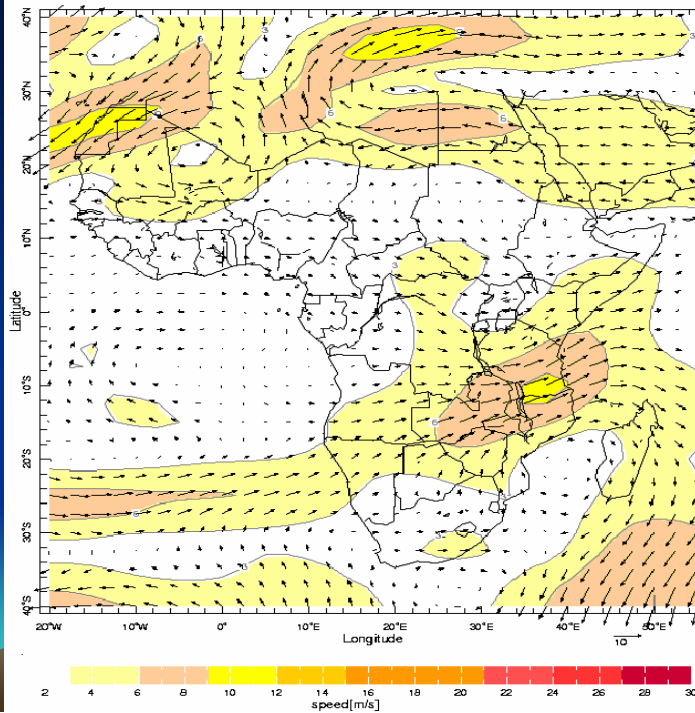


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# Weather Charts



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## **Only one reliable data source:**

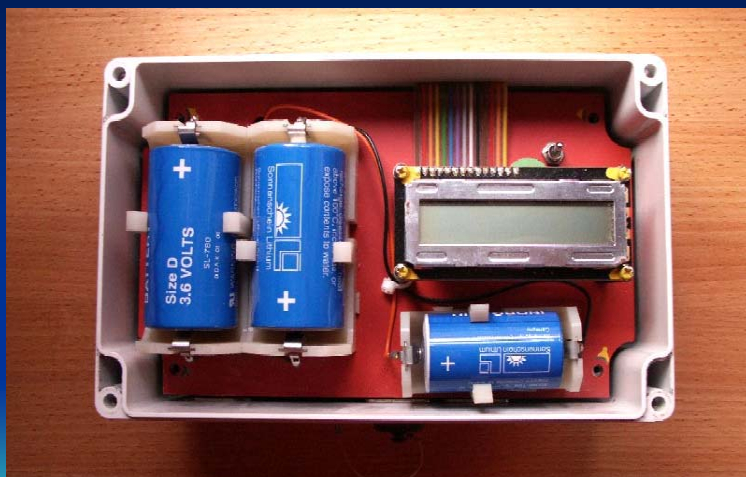
- directly measured at potential wind (park) sites
- best at hub height, but also 10 or 20 m will do for a first assessment
- use locally made towers (utility poles)
- use battery operated data loggers with a memory for one year of data
- use 1 to 10 min averages – not 1hr averages

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## **Battery operated data logger**

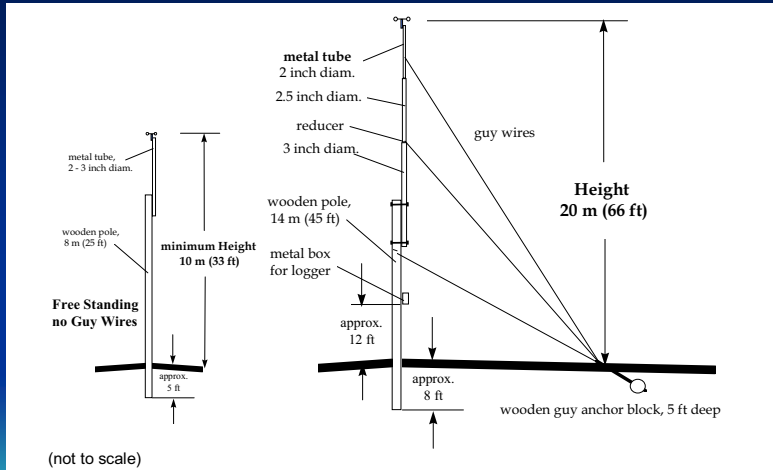


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# Locally made towers



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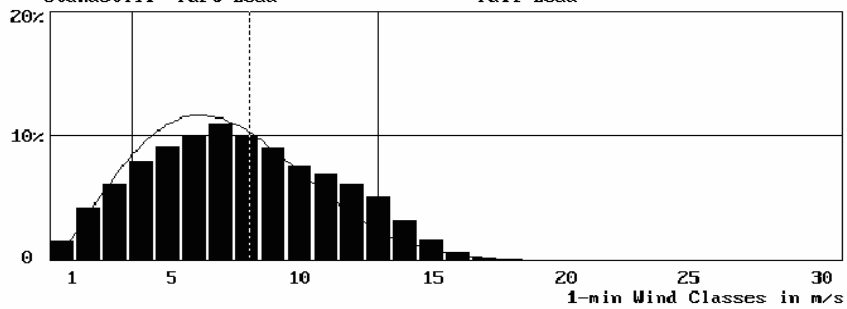
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# Frequency distribution

U-month: 7.27 m/s U-max = 21.60 m/s  
E-month: 69,949.01 kWh; E-year, est.: 839.388 MWh; P-gen, mean: 97.15 kW  
Standstill: 11.7 % \* Part load: 71.4 % \* Full Load: 16.9 % \* CF-gen 27.8 %

FREQUENCY DISTRIBUTION  $f(v)$  in % (k = 2.19; c = 8.20 m/s)  
Standstill Part Load Full Load



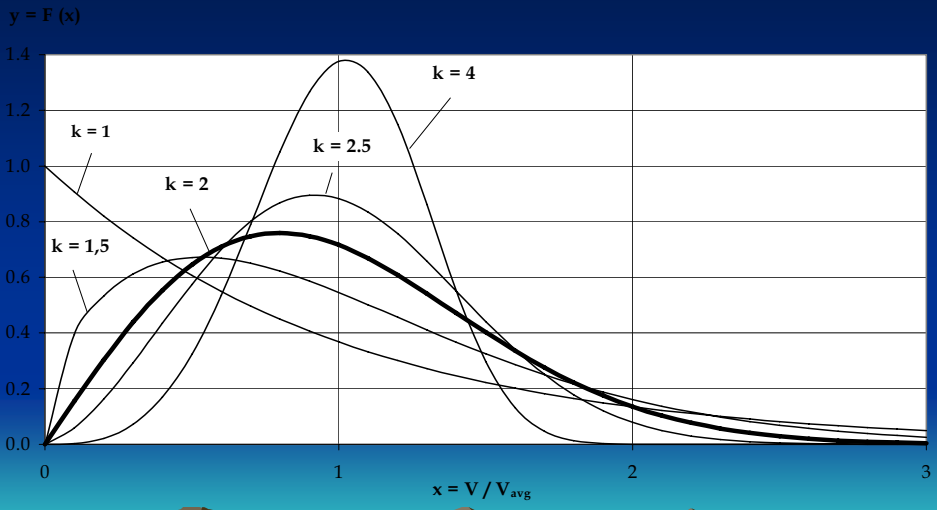
WIND PLOT Hurgada 10 m Egypt \* Anemometer \* Enercon E30/300

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# Weibull parameters k

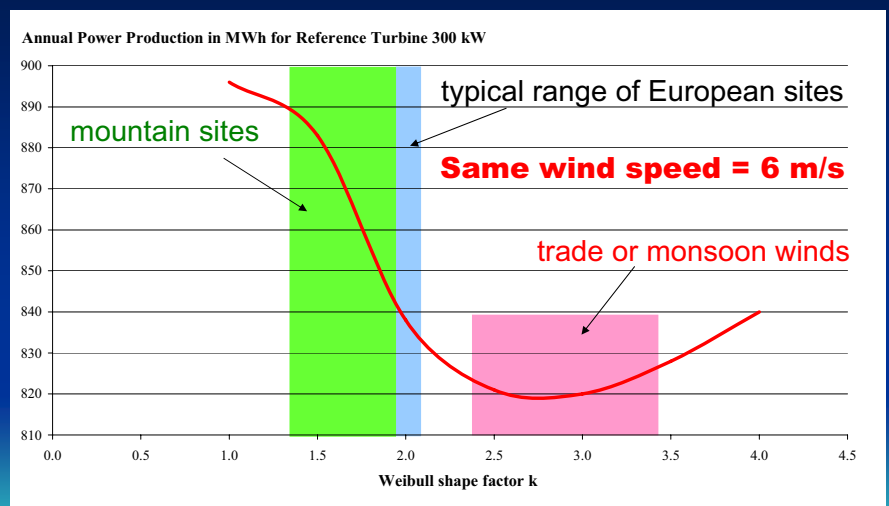


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# Turbine output as function of k

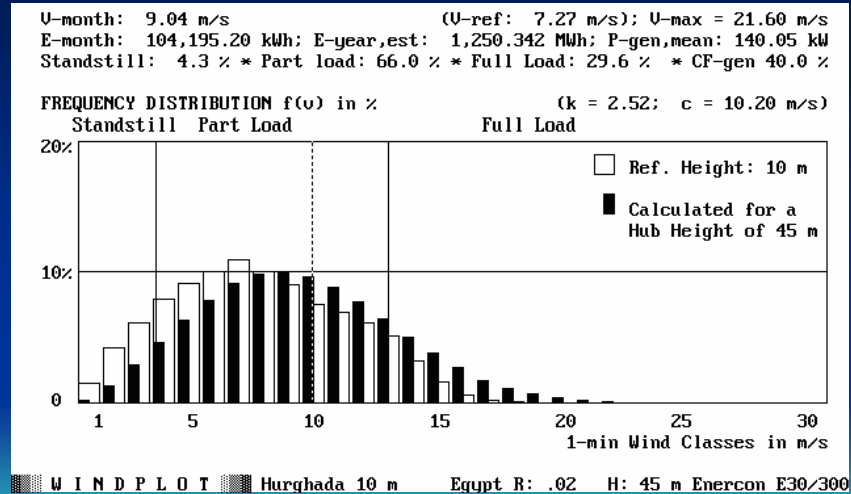


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## Frequency distribution at hub height



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## Morocco

- Special Energy Programme (SEP) of GTZ
- wind measuring campaigns 1992 – 1995
- starting point
  - wind data from Tangers airport (6.2 m/s)
  - 5 stations in North Morocco (Tetouan)
- measuring in 10 m above ground
- 30 wind classes, 1-min averages for frequency distribution, 1-hrs time series

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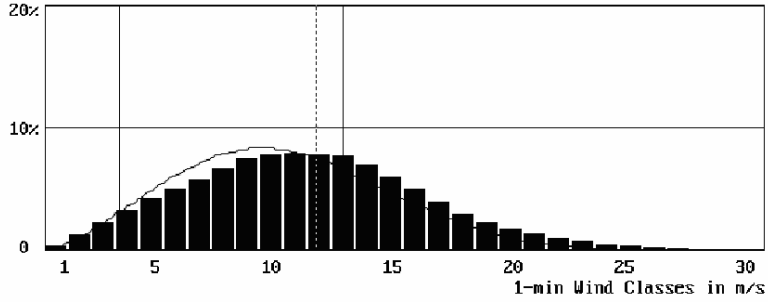
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# Koudia Blanco (Morocco)

U-year: 10.94 m/s  
 E-month: 131,199.16 kWh; E-year,est: 1,574,390 MWh; P-gen,mean: 182.22 kW  
 Standstill: 3.8 % \* Part load: 48.2 % \* Full Load: 48.0 % \* CF-gen 52.1 %

FREQUENCY DISTRIBUTION  $f(u)$  in % (k = 2.42; c = 12.34 m/s)  
 Standstill Part Load Full Load



WIND PLOT K. Blanco 1 (9 m)MOROCCO \* Anemometer \* Enercon E30/300

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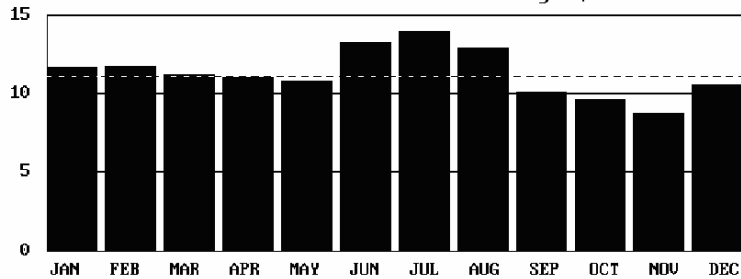
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# Koudia Blanco (Morocco)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average
E-month	143	152	124	134	120	174	154	171	121	105	93	117	131.2 MWh
U-month	11.5	11.5	11.0	10.8	10.6	13.1	13.8	12.7	9.9	9.5	8.6	10.4	10.9 m/s
Weibull	2.9	2.8	2.4	2.6	2.1	3.1	2.5	3.6	2.7	2.1	1.9	2.1	2.42 (k)

MEAN MONTHLY WIND SPEED U<sub>month</sub> in m/s (U<sub>year</sub> = 10.94 m/s)  
 E<sub>year,est</sub> = 1574.4 MWh



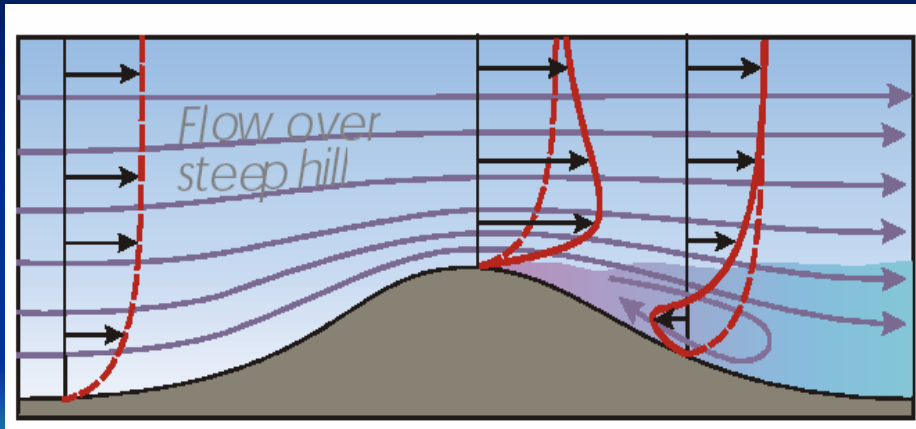
WIND PLOT K. Blanco 1 (9 m)MOROCCO \* Anemometer \* Enercon E30/300

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## Flow over steep hill



Copin, Ayotte, Steggel, "Wind Resource Assessment in Australia – A planners Guide", CSIRO, 2003

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## 84 wind turbines ...



**... now produce 2 %  
of Morocco's electricity needs**

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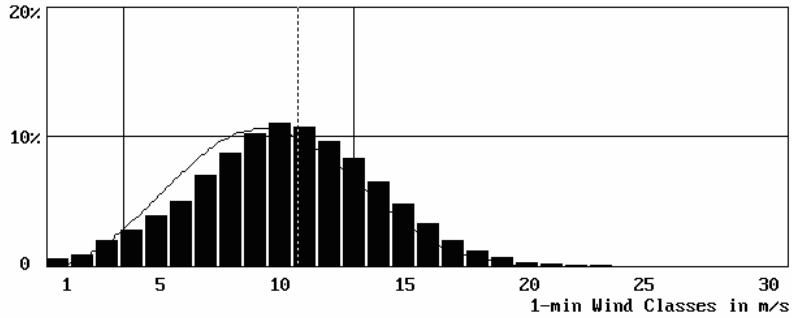
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# Mindelo - Cape Verde Islands

U-year: 9.84 m/s  
 E-month: 118,247.63 kWh; E-year,est: 1,418.972 MWh; P-gen,mean: 164.23 kW  
 Standstill: 3.6 % \* Part load: 59.2 % \* Full Load: 37.3 % \* CF-gen 46.9 %

FREQUENCY DISTRIBUTION  $f(v)$  in % (k = 2.85; c = 11.10 m/s)  
 Standstill Part Load Full Load



WIND PLOT Mindelo 3 Cabo Verde \* Anemometer \* Enercon E30/300

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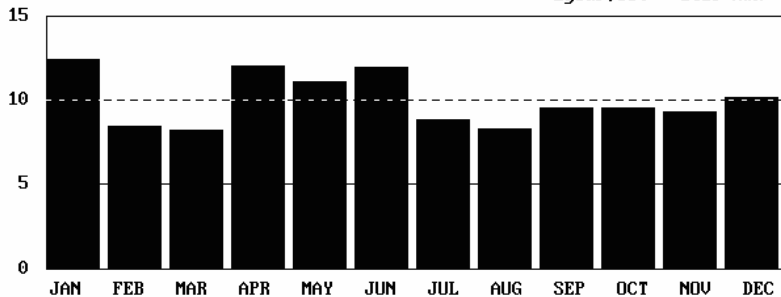
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# Mindelo - Cape Verde Islands

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average
E-month	169	92	80	160	143	165	94	81	107	112	107	123	118.3 MWh
U-month	12.3	8.3	8.1	11.8	11.0	11.8	8.7	8.2	9.4	9.4	9.1	10.0	9.8 m/s
Weibull	4.7	2.4	2.0	3.9	4.3	4.6	2.9	2.3	2.4	3.3	2.9	3.4	2.85 {k}

MEAN MONTHLY WIND SPEED  $U_{month}$  in m/s (Uyear = 9.84 m/s)  
 Eyear,est = 1419 MWh



WIND PLOT Mindelo 3 Cabo Verde \* Anemometer \* Enercon E30/300

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## Wind park Mindelo, Cape Verde



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## Brava – Cape Verde Islands

No	Month	Wind Regime			Production			Operation			
		Vavg (m/s)	Weibull k	Param c (m/s)	Vmax (m/s)	Em (MWh)	P-gen (kW)	Cap-Fac in %	Op.- Stop	time in % Part Full	
1	1/96	11.18	3.39	12.61	19.2	147.9	198.8	56.8	1	48	52
2	2/96	10.30	2.87	11.61	21.3	116.6	173.4	49.6	2	56	42
3	3/96	9.26	5.12	10.45	13.4	110.1	147.9	42.3	0	79	21
4	4/96	9.62	3.61	10.85	17.5	115.0	159.8	45.7	1	66	33
5	5/96	8.88	4.94	10.01	16.5	99.4	133.6	38.2	0	84	15
6	6/96	7.84	3.45	8.84	16.5	73.9	102.6	29.3	2	87	11
7	7/96	8.08	3.38	9.11	16.5	82.4	110.8	31.6	2	84	14
8	8/96	7.79	2.59	8.78	19.8	78.5	105.5	30.1	6	78	16
9	9/96	9.16	3.46	10.34	20.6	104.8	145.6	41.6	1	71	27
10	10/96	9.12	4.17	10.28	14.7	107.0	143.8	41.1	1	76	23
11	11/96	9.96	3.48	11.24	18.8	121.9	169.3	48.4	1	61	38
12	12/96	12.10	3.77	13.64	22.0	164.9	221.7	63.3	0	38	62
Average		9.37	3.25	10.57		109.1	151.5	43.3	2	68	31
Total								1,308.8			

WIND PLOT Brava 10 m Cabo Verde R: .02: 45 m Enercon E30/300

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## for comparison: Bremerhaven Germany

No	Month	Wind Regime			Production			Operation			
		Vavg (m/s)	Weibull k	Param c (m/s)	Vmax (m/s)	Em (MWh)	P-gen (kW)	Cap-Fac in %	Op.- time	in %	Stop Part Full
1	1/93	11.03	2.57	12.44	37.4	137.3	184.5	52.7	3	49	48
2	2/93	6.62	1.65	7.46	25.8	54.6	81.2	23.2	20	65	15
3	3/93	7.00	2.06	7.90	25.0	65.0	87.3	25.0	12	74	14
4	4/93	6.90	3.26	7.79	14.9	53.4	74.2	21.2	4	92	4
5	5/93	6.38	2.67	7.19	19.0	47.7	64.1	18.3	9	87	4
6	6/93	6.40	2.29	7.22	18.3	49.7	69.0	19.7	12	81	7
7	7/93	6.74	2.42	7.61	18.7	57.3	77.0	22.0	10	82	9
8	8/93	6.20	2.16	6.99	18.0	48.4	65.1	18.6	15	79	7
9	9/93	5.67	2.47	6.40	15.0	34.4	47.8	13.6	14	84	2
10	10/93	6.01	2.40	6.78	24.9	42.6	57.2	16.4	13	83	4
11	11/93	5.97	2.44	6.73	17.7	40.0	55.6	15.9	13	84	3
12	12/93	9.19	2.69	10.37	25.4	107.6	144.7	41.3	3	66	31
Average		6.67	2.26	7.52		55.2	76.6	21.9	12	79	9
Total								661.8			

WIND PLOT Bremerhaven 35 m R: .02 H: 45 m Enercon E30/300

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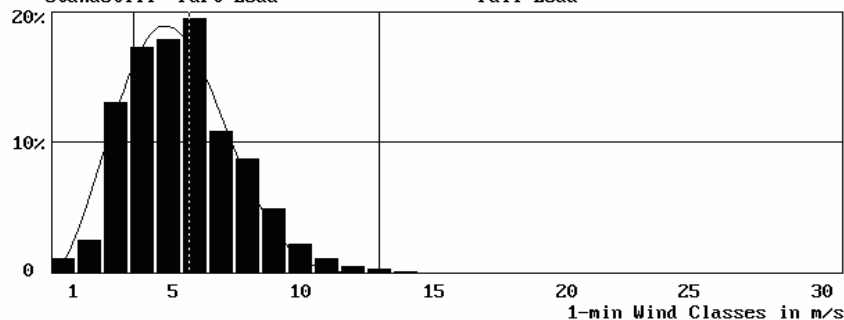
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## Met. station St. Louis, Sénégal

U-month: 5.06 m/s (U-med: 4.00 m/s); U-max = 14.00 m/s  
 E-month: 23,853.81 kWh; E-year,est: 286.246 MWh; P-gen,mean: 33.13 kW  
 Standstill: 16.6 % \* Part load: 82.5 % \* Full Load: 0.9 % \* CF-gen 9.5 %

FREQUENCY DISTRIBUTION  $f(v)$  in % (k = 2.57; c = 5.71 m/s)  
 Standstill Part Load Full Load



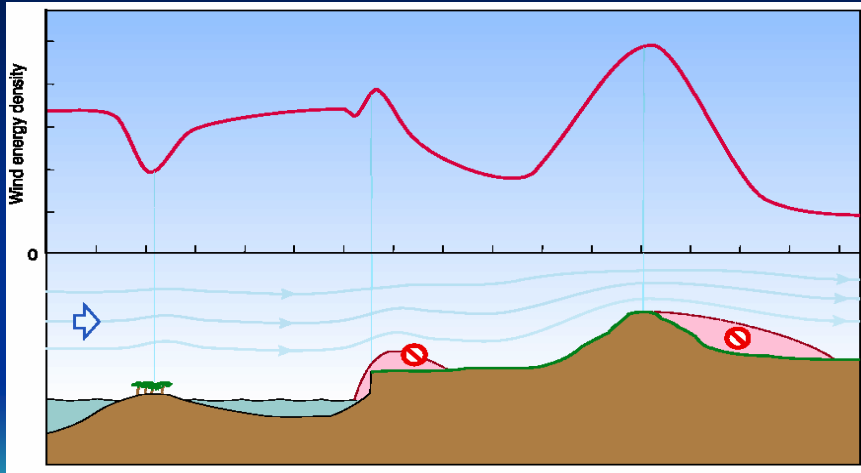
WIND PLOT St. Louis Met.Stat. SEN \* Anemometer \* Enercon E30/300

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## ... but further inland less wind



Copin, Ayotte, Steggel, "Wind Resource Assessment in Australia – A planners Guide", CSIRO, 2003

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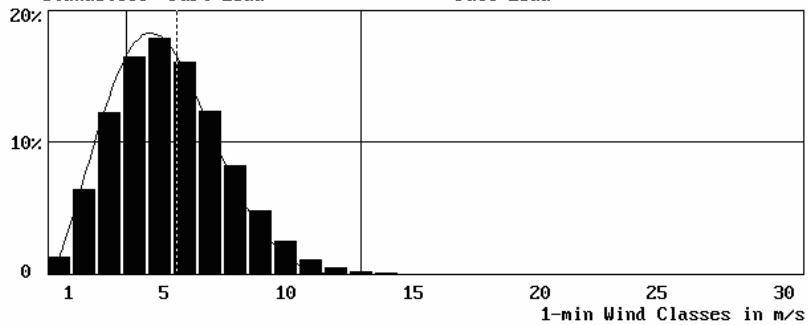
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## Gao 26 m - Mali

U-year: 4.93 m/s  
 E-month: 23,236.60 kWh; E-year, est: 278.839 MWh; P-gen, mean: 32.27 kW  
 Standstill: 19.9 % \* Part load: 79.3 % \* Full Load: 0.8 % \* CF-gen 9.2 %

FREQUENCY DISTRIBUTION  $f(u)$  in % (k = 2.38; c = 5.56 m/s)  
 Standstill Part Load Full Load



WIND PLOT Gao Airport (26 m) MALI \* Anemometer \* Enercon 30/300

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## **TERNA Project Gao**

- measurement campaigns in 26 and 41 m above ground
- wind data evaluation
- feasibility study
- proposal: 3 x 900 kW wind park in grid-parallel operation with existing diesel power station

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## **Wind Shear Assumptions**

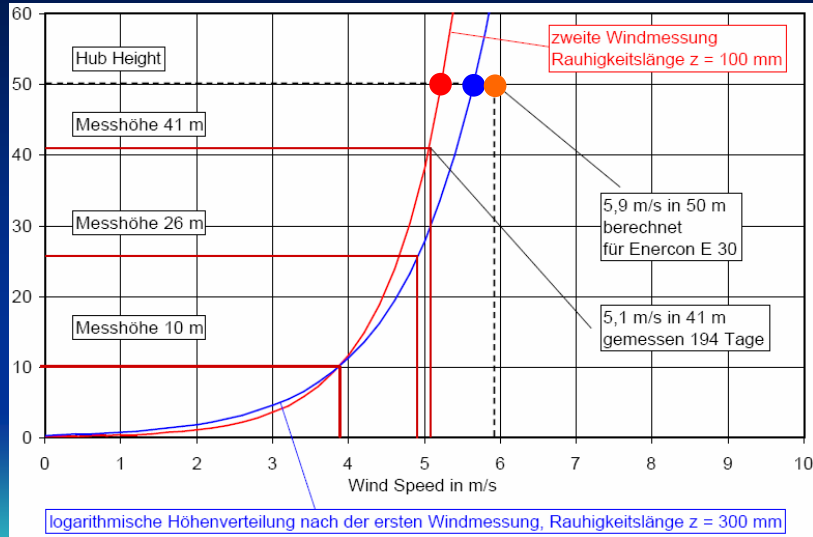
- standard wind mapping and output prediction programmes (WindPro etc.) assume European temperature layers
- under tropical / African condition, the prediction to hub heights can be wrong
- consequence: only measurements in hub height give reliable output estimations

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## Wind Shear Gao

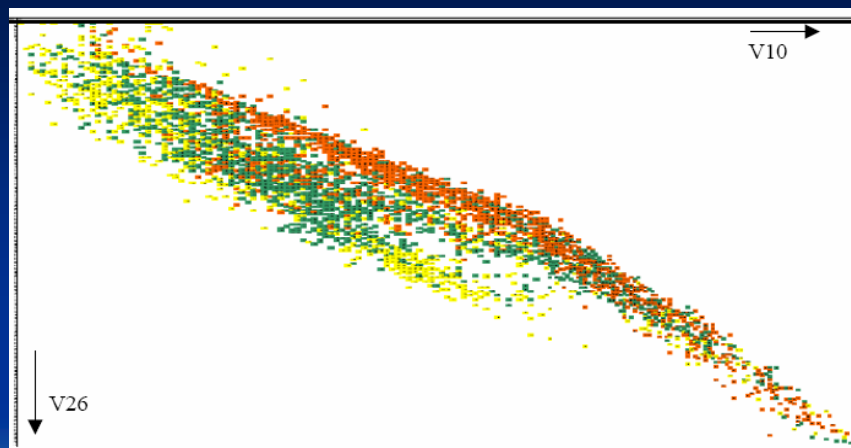


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## Wind Shear Function of Temperature



**yellow:**  $10^{\circ}\text{C} < t < 20^{\circ}\text{C}$ ; **green:**  $20^{\circ}\text{C} < t < 26^{\circ}\text{C}$ ; **red:**  $t > 26^{\circ}\text{C}$

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## Wind Regime Ethiopia

- judging from available wind data from a well exposed airport in the North ...
- ... a prediction of annual wind speed was made in 2003
- from 6.7 m/s in 10 m above ground at hub height of 45 m **8.3 m/s** was estimated for Mekelle

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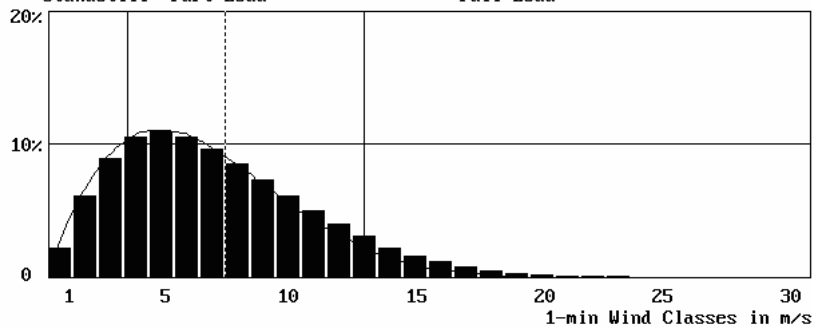
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## Mekelle - Ethiopia

U-year: 6.71 m/s  
 E-month: 59,119.47 kWh; E-year,est: 709.434 MWh; P-gen,mean: 82.11 kW  
 Standstill: 17.2 % \* Part load: 68.5 % \* Full Load: 14.2 % \* CF-gen 23.5 %

FREQUENCY DISTRIBUTION  $f(v)$  in % (k = 1.79; c = 7.57 m/s)  
 Standstill Part Load Full Load



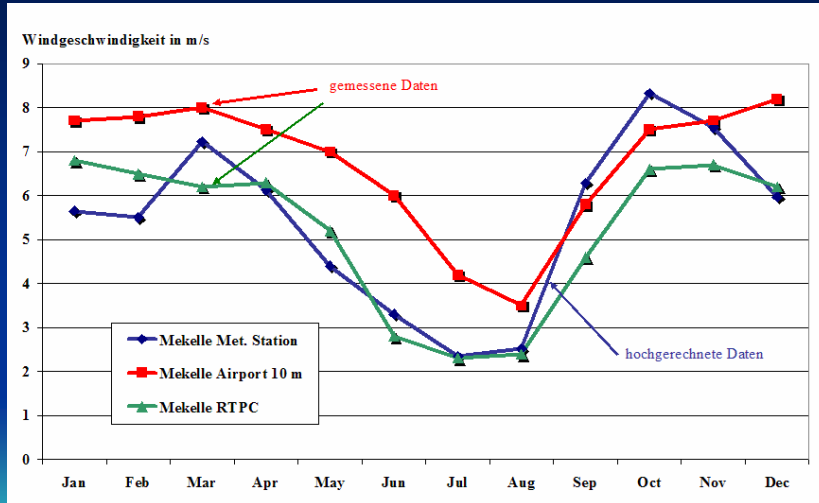
WIND PLOT Mekelle (10 m) ETHIOPIA \* Anemometer \* Enercon E30/300

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# Correlation of 3 stations



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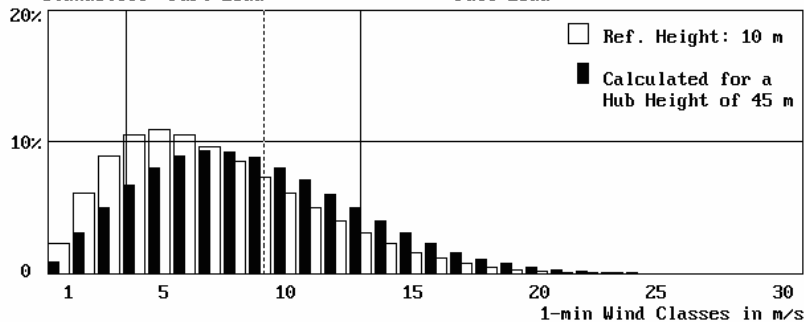
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# Mekelle 45 m - Estimation

U-year: 8.32 m/s  
 E-month: 86,636.80 kWh; E-year,est: 1,039.642 MWh; P-gen,mean: 120.33 kW  
 Standstill: 9.0 % \* Part load: 66.1 % \* Full Load: 24.9 % \* CF-gen 34.4 %

FREQUENCY DISTRIBUTION  $f(u)$  in % (k = 2.06; c = 9.38 m/s)  
 Standstill Part Load Full Load



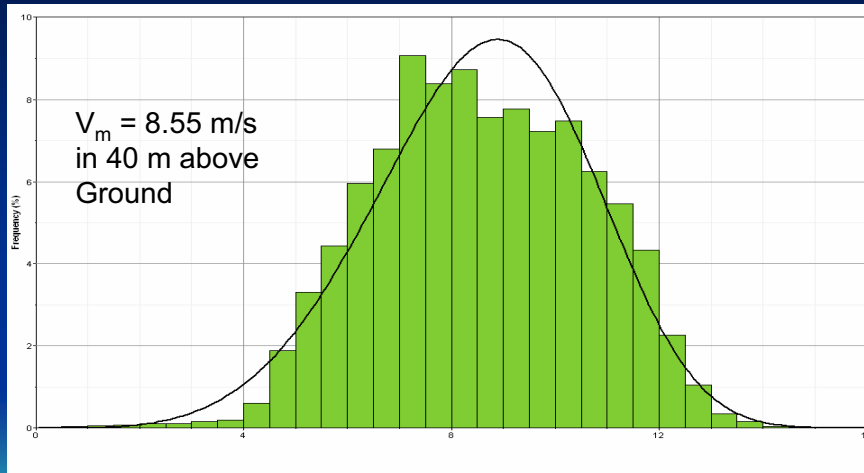
WIND PLOT Mekelle (10 m) ETHIOPIA R: .02 H: 45 m Enercon E30/300

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## Mekelle 45 m – Measured 2005



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## Mekelle 45 m – Measured 2005

	Records	Recovery Rate (%)	Mean (m/s)	Min (m/s)	Max (m/s)	Std. Dev. (m/s)	Weibull k	Weibull c (m/s)
Jan	4,464	100	8.81	0.30	14.30	2.57	4.09	9.68
Feb	4,032	100	9.42	4.01	13.57	1.85	6.23	10.15
Mar	4,464	100	9.29	4.19	13.74	2.03	5.56	10.08
Apr	4,320	100	9.76	4.25	13.92	1.96	6.17	10.53
May	4,464	100	8.15	4.31	12.74	2.00	4.57	8.92
Jun	4,320	100	7.73	4.19	13.39	1.56	5.32	8.37
Jul	4,464	100	7.78	4.25	13.74	1.24	3.82	8.05
Aug	4,464	100	7.18	4.37	14.10	1.20	3.07	7.39
Sep	4,320	100	7.10	4.25	13.15	1.42	5.35	7.68
Oct	4,464	100	8.35	2.80	12.50	1.69	5.71	9.02
Nov	4,320	100	9.27	1.00	15.90	1.95	5.46	10.02
Dec	4,464	100	9.90	2.10	14.50	2.03	6.10	10.67
	52,560	100	8.55	0.30	15.90	2.06	4.70	9.35

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## Wind and Hydro – winning team!

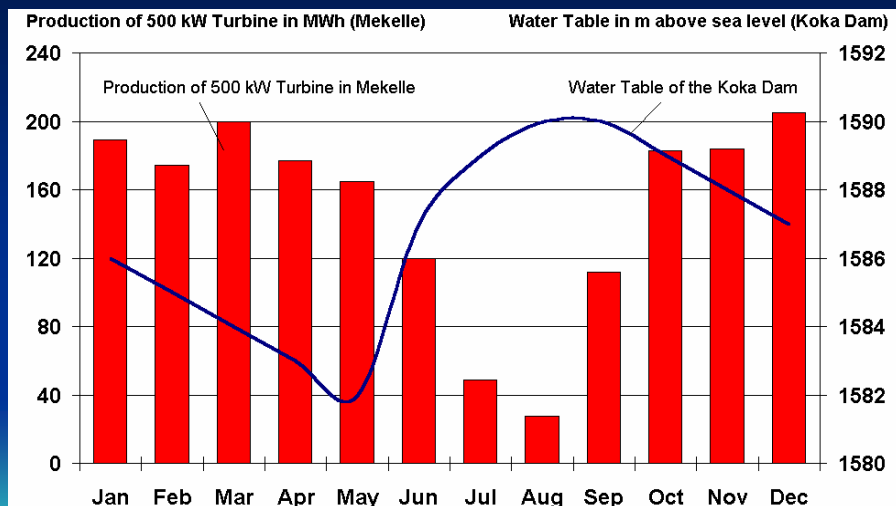
- everywhere in the tropics: wind and rainfall are complementary
- during rainy season less wind speeds
- at the dry season good winds, but no water
- adding wind to a system using primarily hydro power = added value of hydro power!

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## Good Combination: Wind + Water



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## Summary

- many countries in Africa with good wind resources
- some with far better ones than in Europe or the US
- currently most are underestimated, due to lack of data, wrong data etc.
- “Wind Atlas” often not correct, based on meteorological data only

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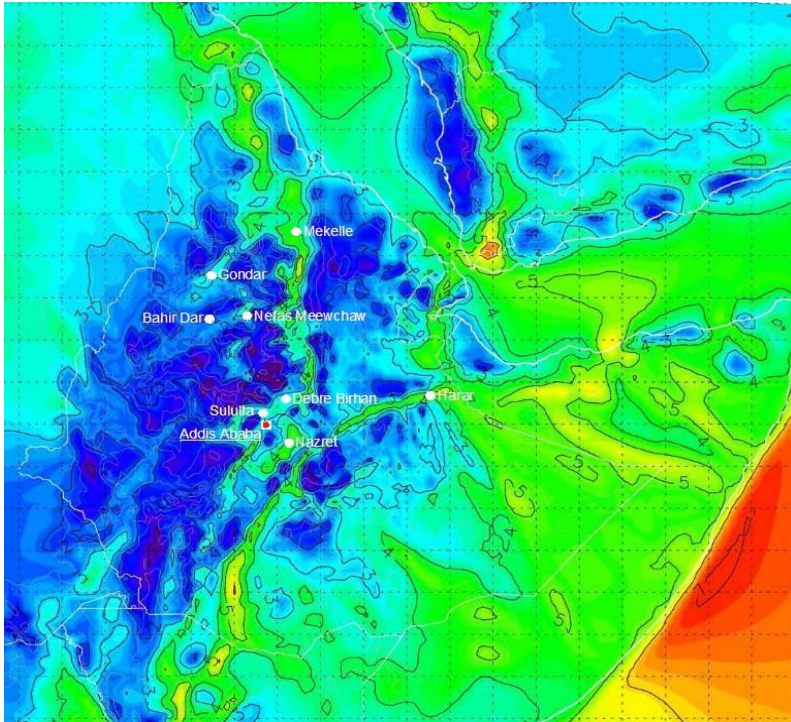
## Wind Mapping

- normally a combination of meso- and micro-scale models can give good results
- however, the validation process is complicated and needs measured frequency distribution from ground stations
- ... not generally available in Africa
- therefore, outcomes of these models may not be very useful in every day practice

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**Example  
Ethiopia**

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**Topographic  
Map Ethiopia**

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## Outlook

- wind resource in Africa much better than anticipated
- lack of data from classifying data loggers
- in the past, wind energy projects in Africa looked often only for water pumping
- today many think, that small stand-alone systems are best for Africa
- not the case: too expensive, too complicated

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## Best wind strategy 1

- large wind parks in grid-parallel operation with interconnected grid
- costs for wind measuring campaign small in relation to investment
- measure several potential sites at 10 or 20 m
- then select the best and measure at hub height (or close to hub height)

Factor 4 Energy Projects GmbH, Wismar (Germany)

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## **Best wind strategy 2**

- after first large wind park is in operation, more and more wind data are collected
- then also smaller systems in stand-alone application might get their chance
- in any case: measure the wind at hill tops, on mountain ridges etc.
- directly where you want to install the turbines

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**... this is not the beginning**



**of wind in Africa ...**

**... but this.**



**Let's have a lot of inaugurations ...**



