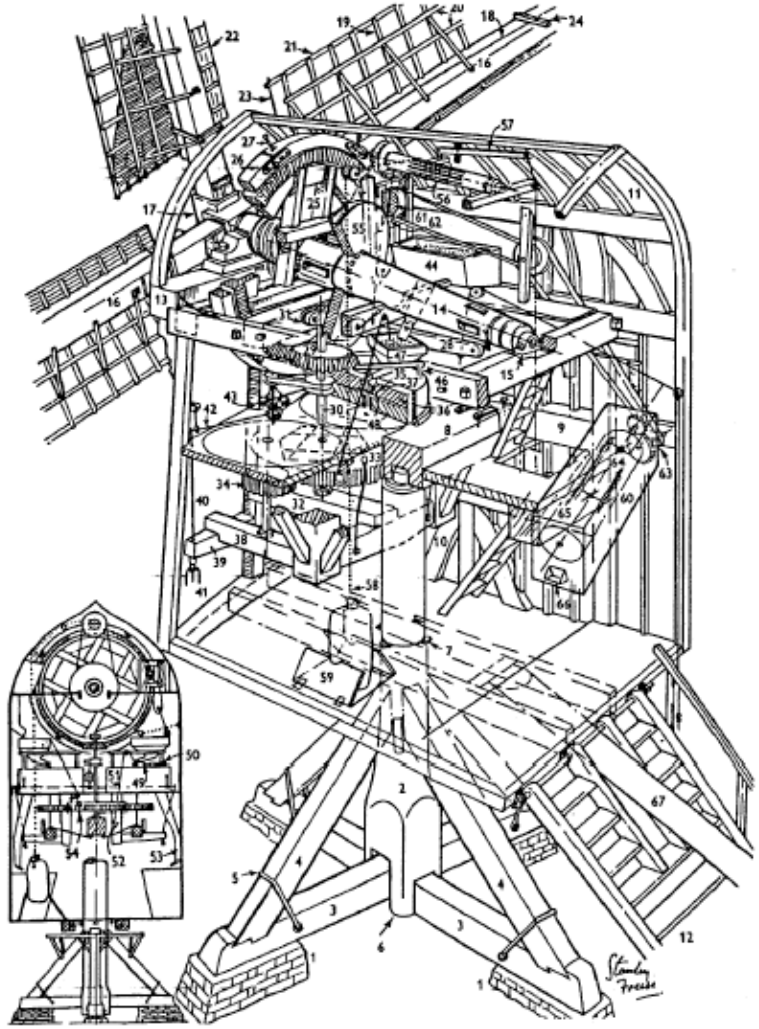
Rüzgar Enerjisi, Rüzgar Türbin Teknolojileri ve ODTÜ-RÜZGEM

Prof. Dr. Oğuz Uzol
ODTÜ Havacılık ve Uzay Mühendisliği Bölümü
Rüzgar Enerjisi Teknolojileri
Araştırma ve Uygulama Merkezi Müdürü

Neden rüzgar enerjisi?

- Yenilenebilir
- Yakıt masrafı yok
- Bol ve yaygın kaynak
- Temiz (CO_2 salınımı yok)
- Fosil yakıtlara bağımlılığı azaltıyor



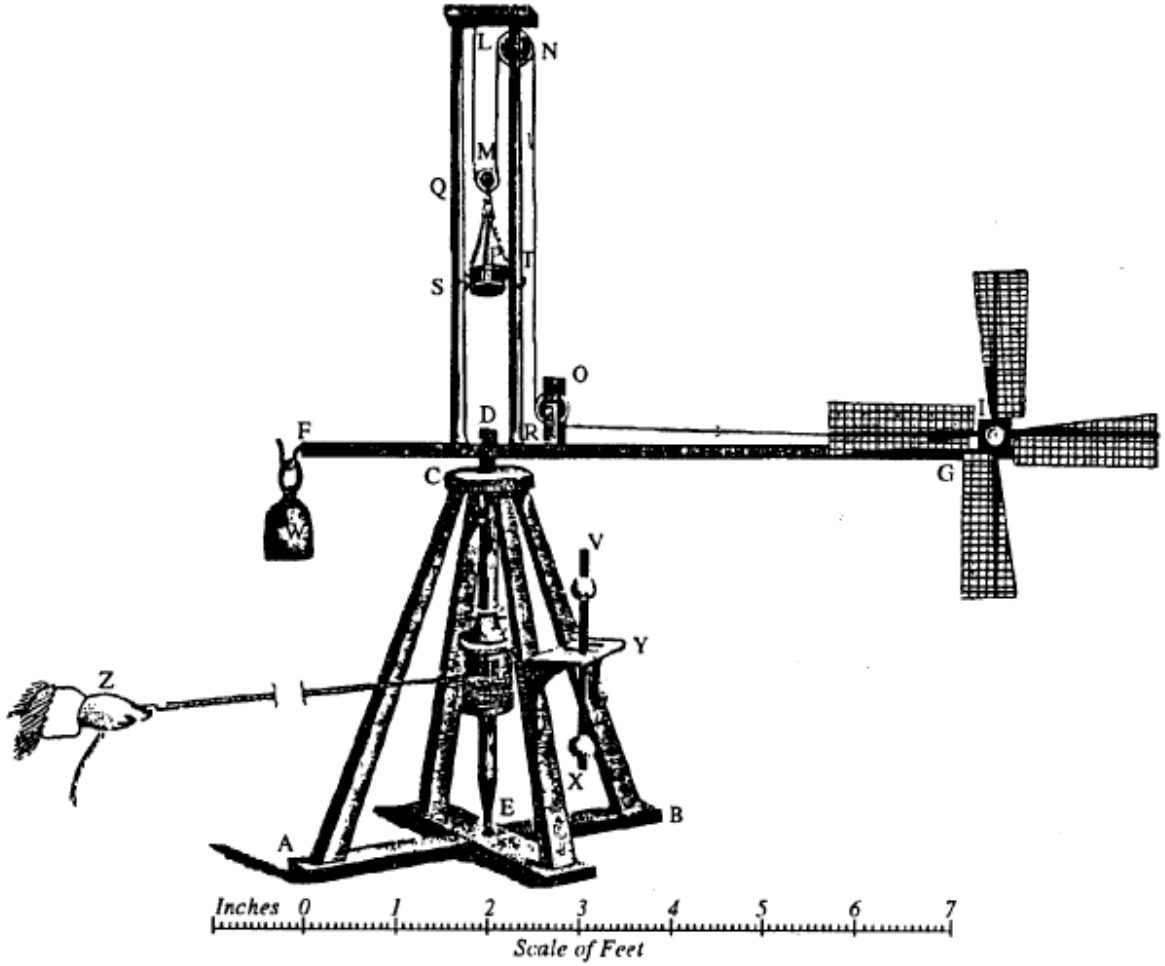


Figure 1-16. Smeaton's laboratory apparatus for testing the performance of model windmill rotors [Smeaton 1759].

Rotor dönüş hızı (Ω) rüzgar hızı ile orantılı

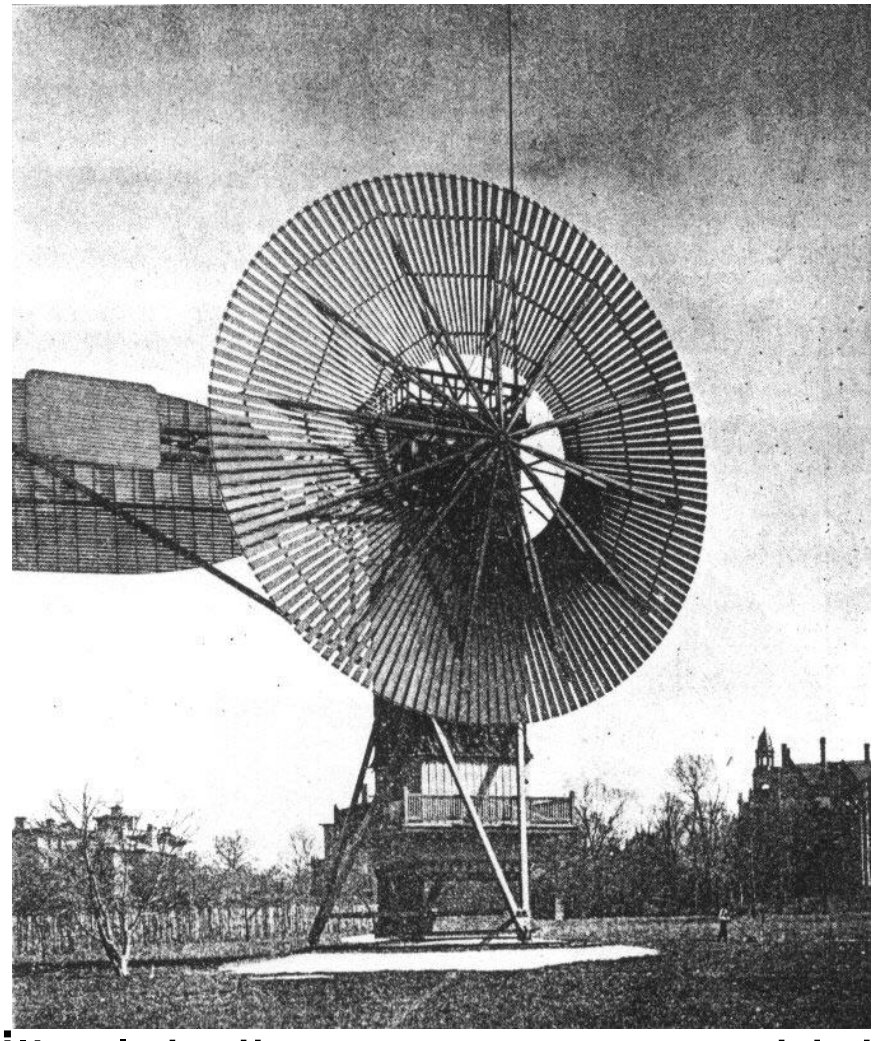
$$W \propto U_{rüzgar}$$

Maksimum tork (T) rüzgar hızının karesi ile orantılı

$$T \propto U^2_{rüzgar}$$

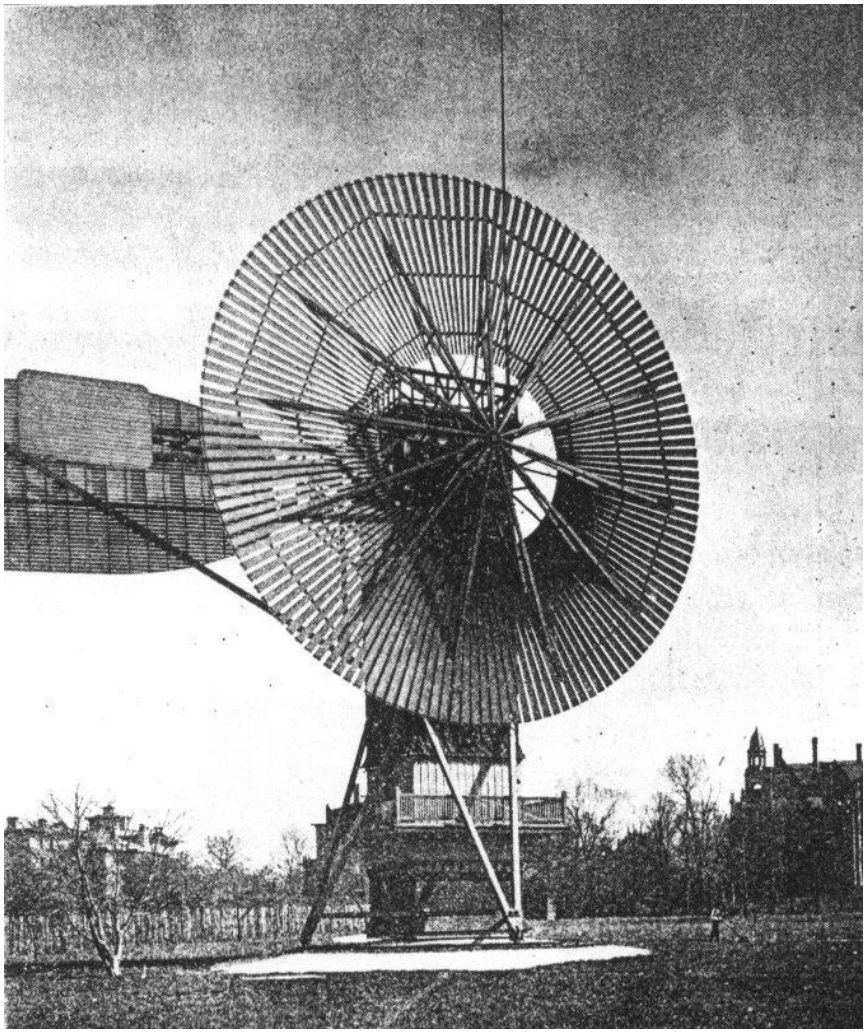
Maksimum güç (P) rüzgar hızının kübü ile orantılı

$$P \propto U^3_{rüzgar}$$



İlk elektrik üreten rüzgar türbini

The Brush Windmill – 1888 Cleveland, Ohio



12 kW DC, 144 kanat, 17 m çaplı rotor, 18 m yüksekliğinde kule

Danimarka'da Paul LaCour tarafından üretilen elektrik üreten rüzgar türbinleri, 1890lar.

5-25 kW, 4-6 adet burgulu dikdörtgen kanat

İlk rüzgar tüneli testleri

Philadelphia North American May 18, 1902

TESLA THINKS WIND POWER SHOULD BE USED MORE NOW

By Nikola Tesla

The power of the wind has been overlooked. Some day it will be forcibly brought to the position it deserves through the need of a substitute for the present method of generating power. Given a good breeze, I have estimated that there is as much as half a horse-power to every square fooot of area exposed. Imagine what energy is left unused with all this force at hand.

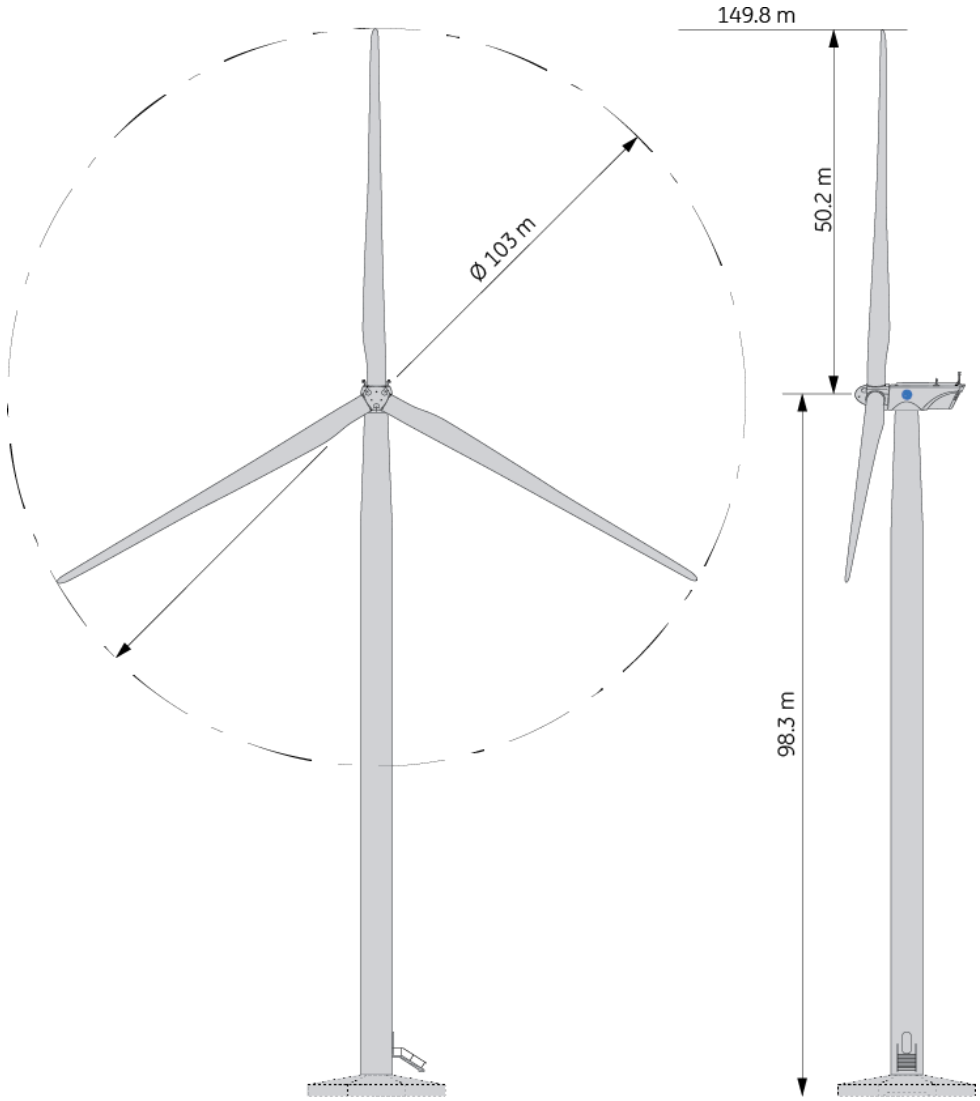
The contrivance that has been at the disposal of mankind from all time, the windmill, is now seen in the rural districts only. The popular mind cannot grasp the power there is in the wind. Many a deluded inventor has spent years of his life in endeavoring to harness the tides, and some have even proposed to compress air by tide or wave power for supplying energy, never understanding the signs of the old windmill on the hill as it sorrowfully waves its arms about and bids them stop.

The fact is that the wave or tide motor would have but small chance of competing commercially with the windmill.

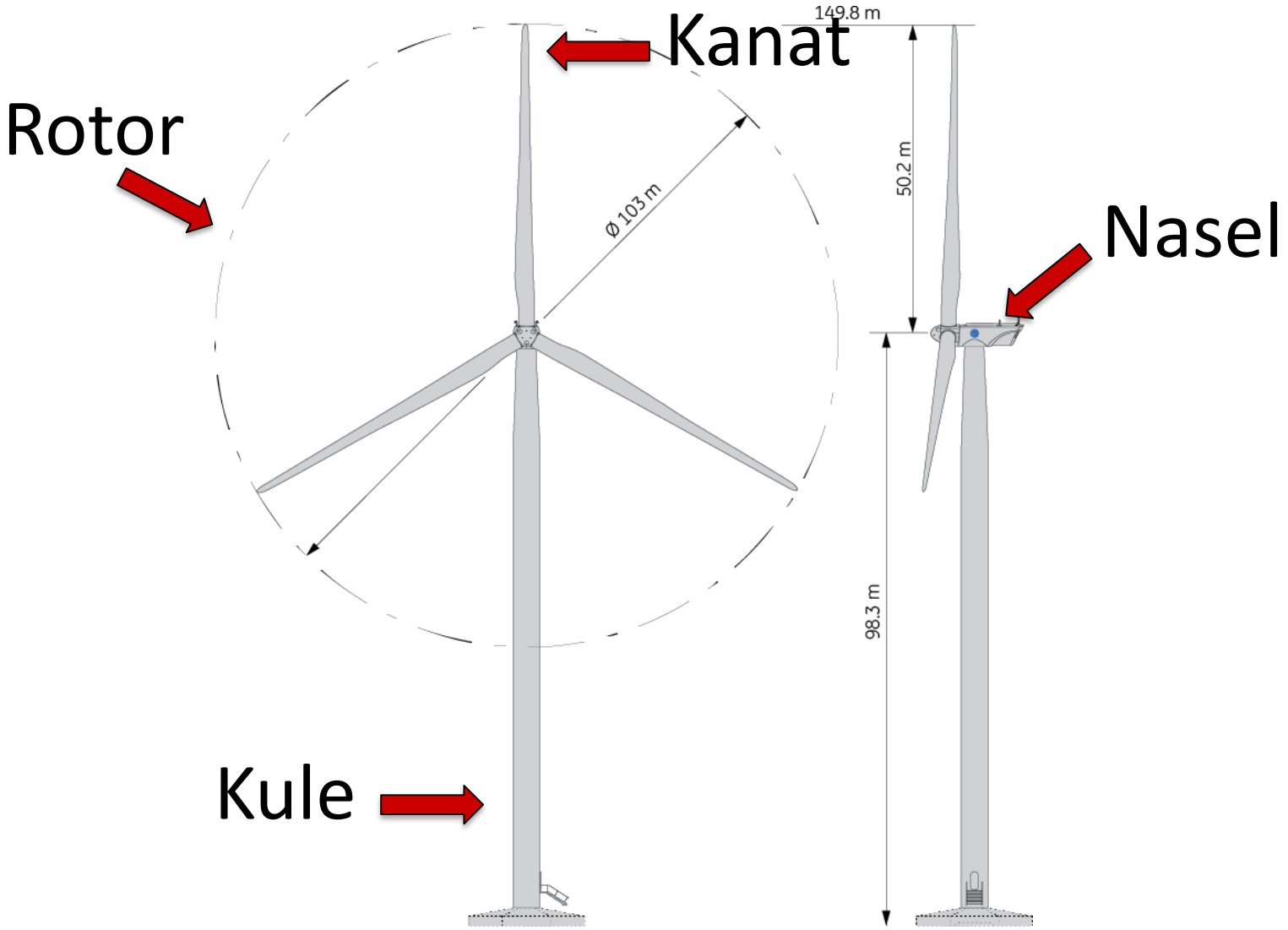
Dünyadaki ilk megawatt üstü rüzgar türbini

The Smith-Putnam turbine, 1941, Vermont, USA

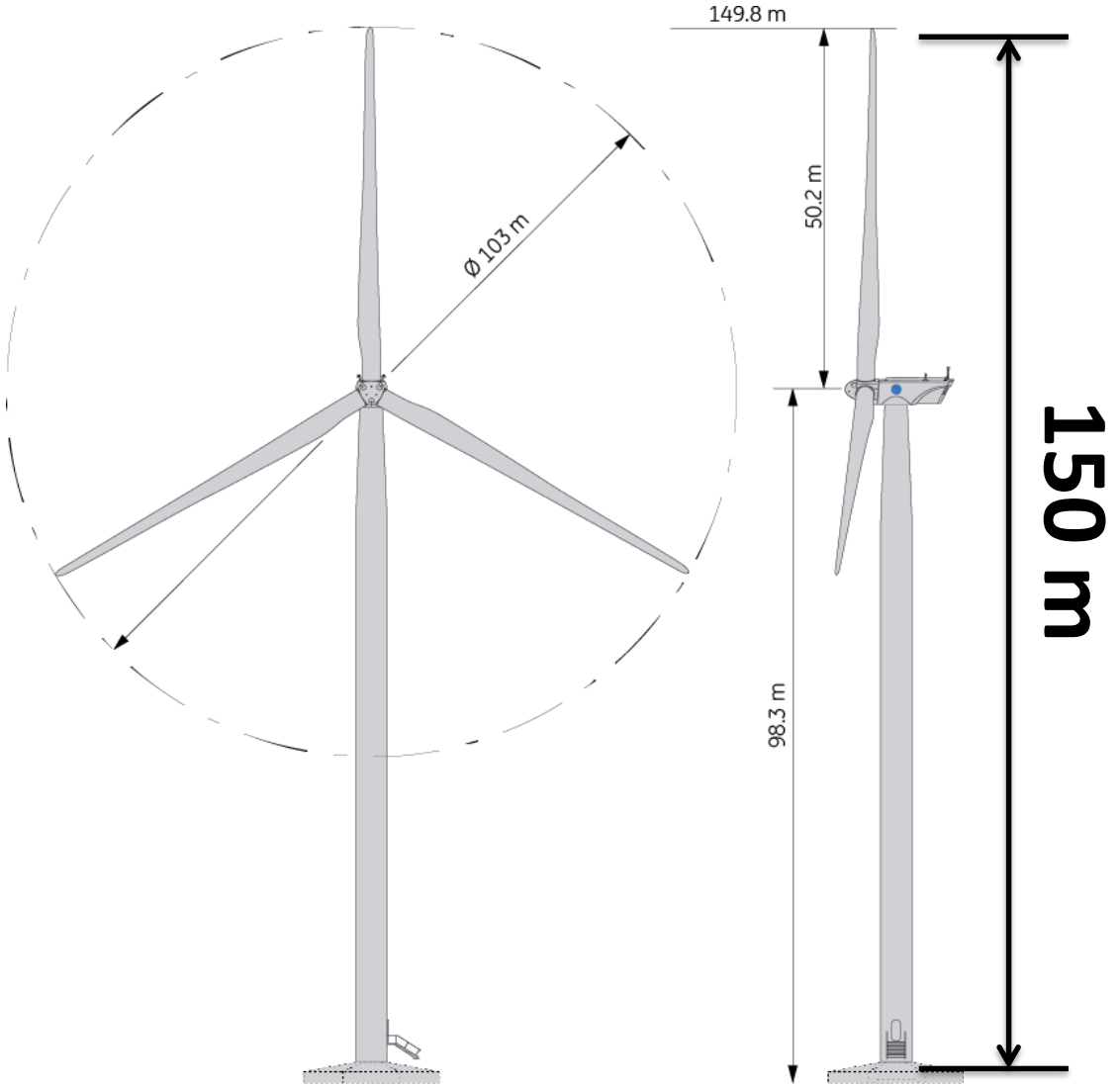
53 m rotor, 1.25 MW



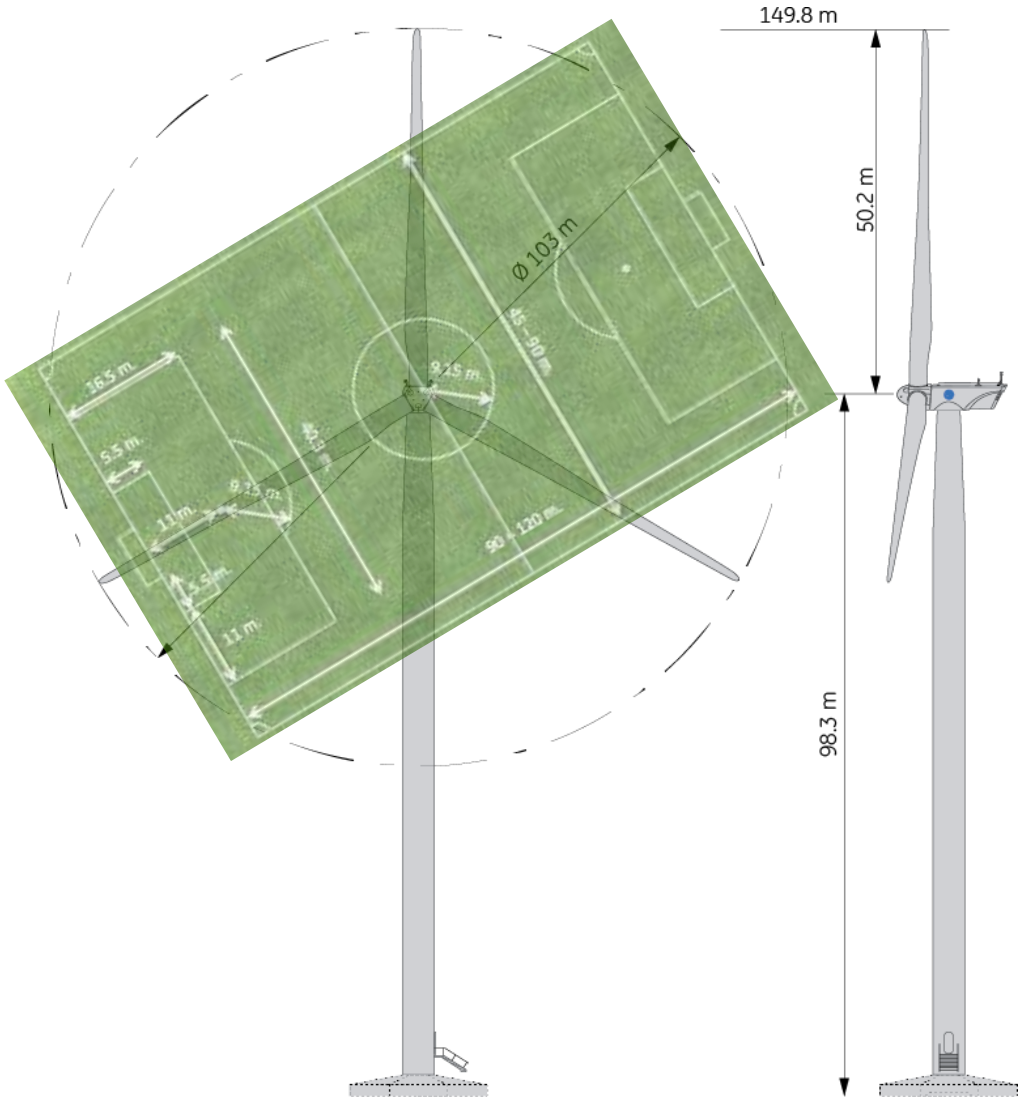
Örnek bir 3 Mega Watt (MW) Türbin (3000 kW)



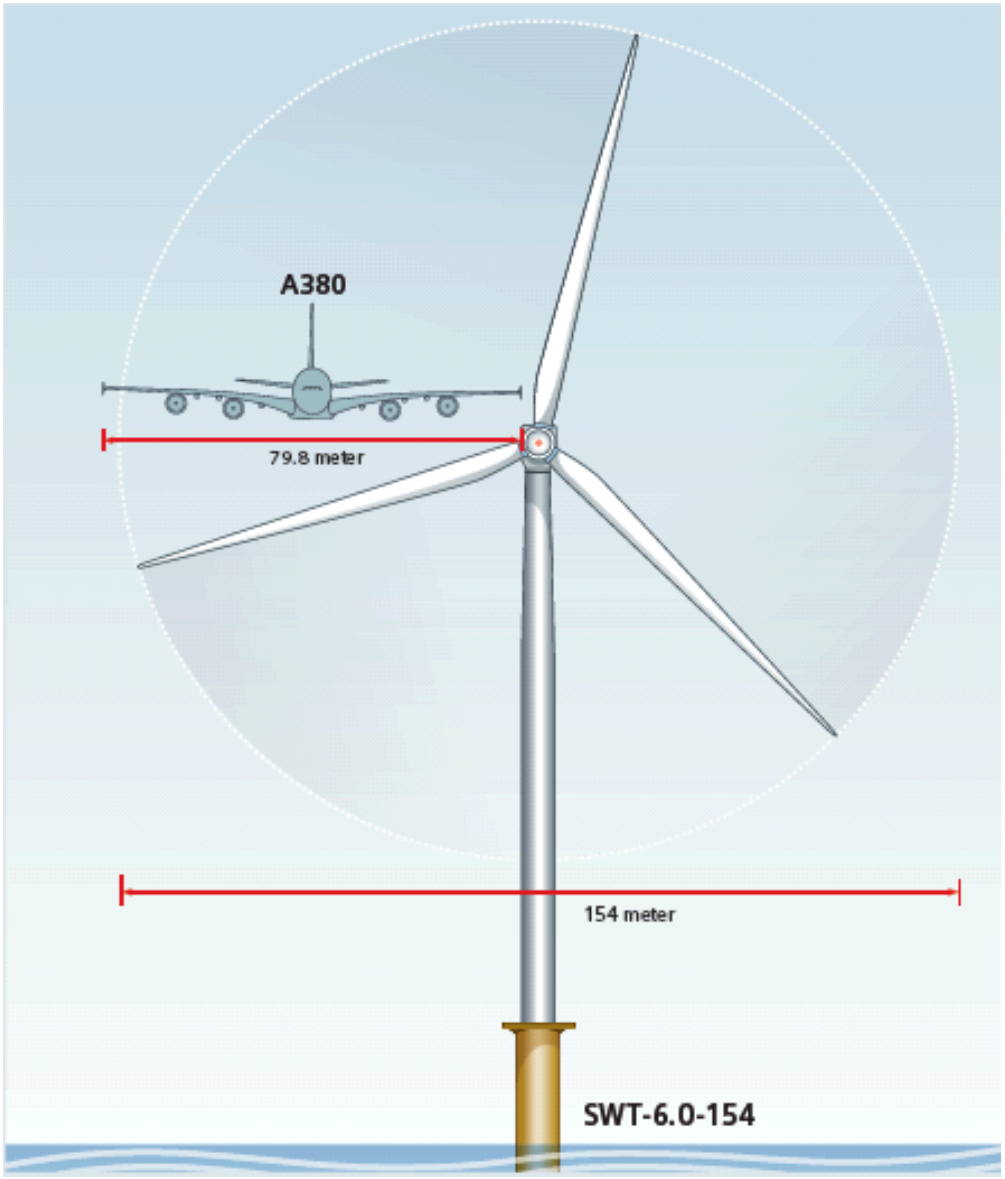
3 Mega Watt (MW) Türbin



3 MW Türbin


149.8 m
50.2 m
98.3 m
Ø 103 m
45 - 90 m
9.15 m
16.5 m
5.5 m
11 m
9.15 m
5.5 m
11 m
90 - 120 m

3 MW Türbin

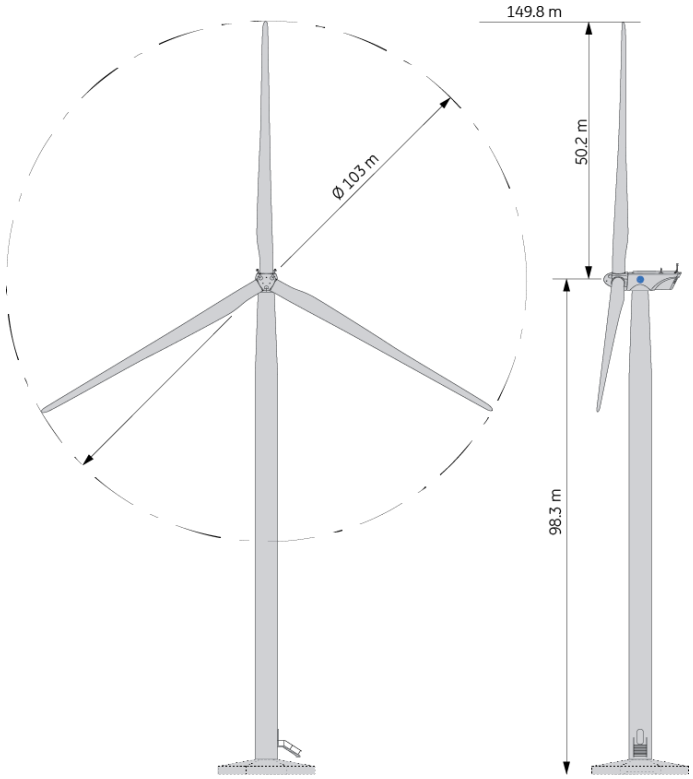

A380
79.8 meter
154 meter
SWT-6.0-154

5MW Offshore Türbin- 126 m kanat uzunluğu

5MW Offshore Türbin- 126 m kanat uzunluğu

340 km/h

3 MW Türbin



Bir Ailenin Ortalama Günlük Tüketimi 4.81 kWh

3 MW Rüzgar Türbini

x 8760 saat/yıl

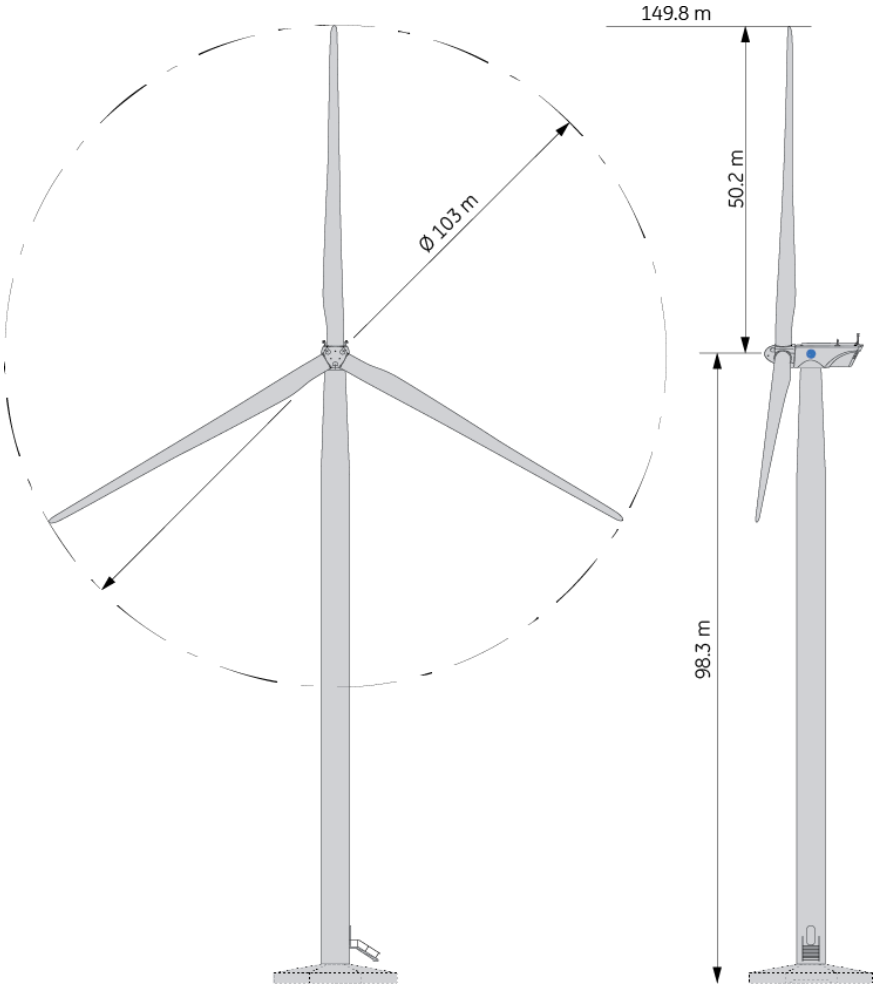
26,280,000 kWh/yıl

x 0.3 (Kapasite Faktörü)

7,884,000 kWh/yıl

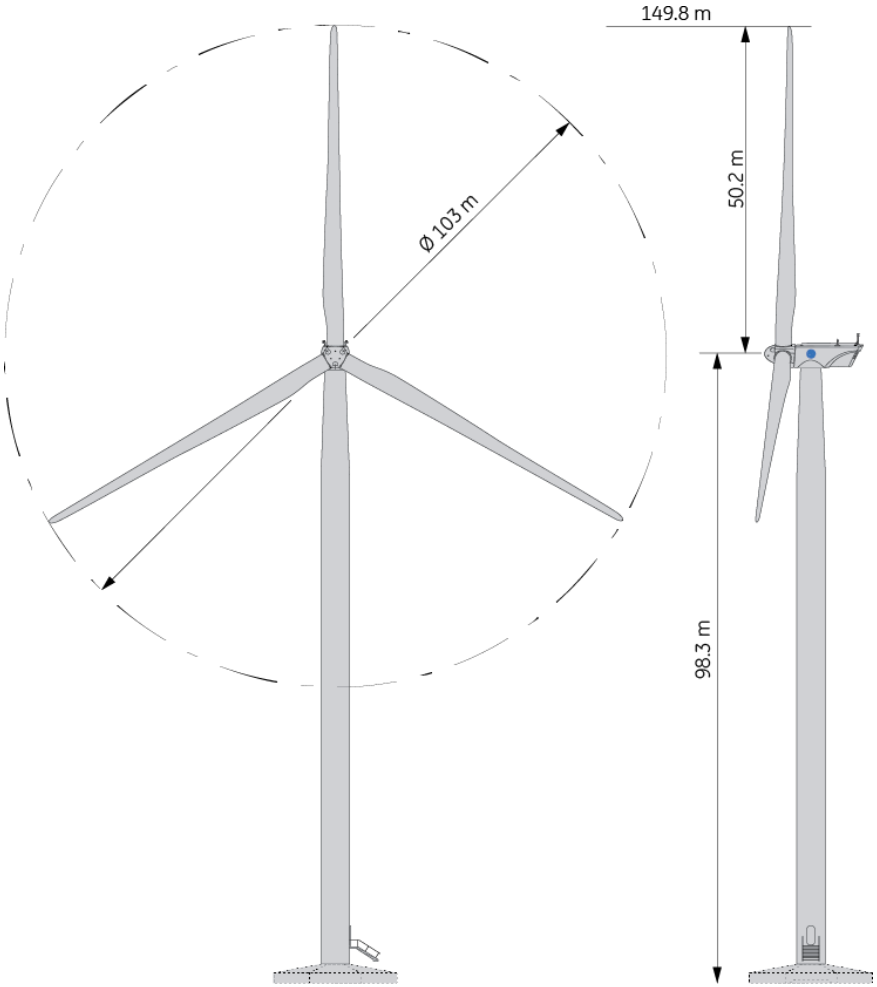
/1800 kwH/hane

~4500 hane



Dünyada kurulu toplam rüzgar türbin gücü:

- ~600 000 MW
- ~876 000 000 hane

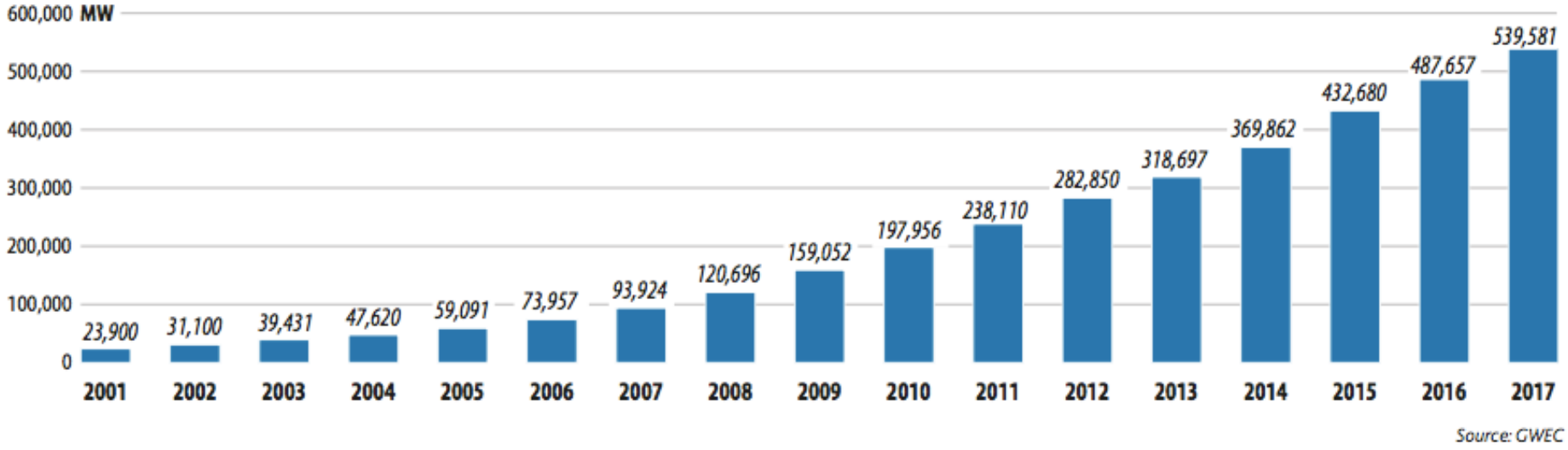


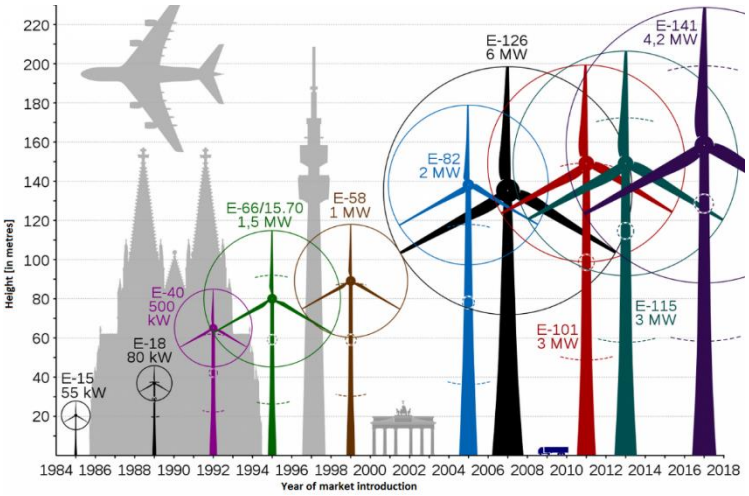
Türkiye'de kurulu toplam rüzgar türbin gücü:

- ~8000 MW
- ~11 680 000 hane

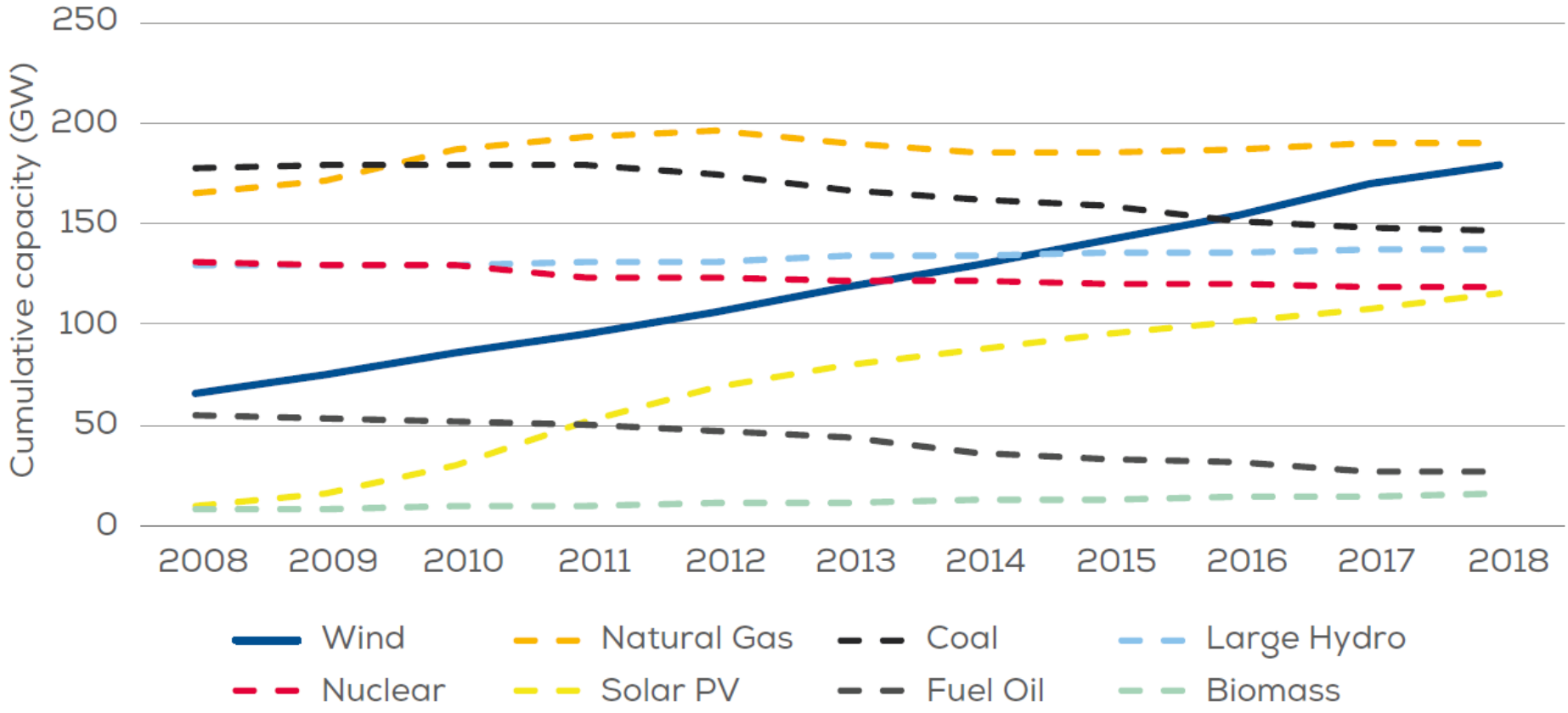
GLOBAL CUMULATIVE INSTALLED WIND CAPACITY 2001-2017

Source: GWEC Statistics Report 2017

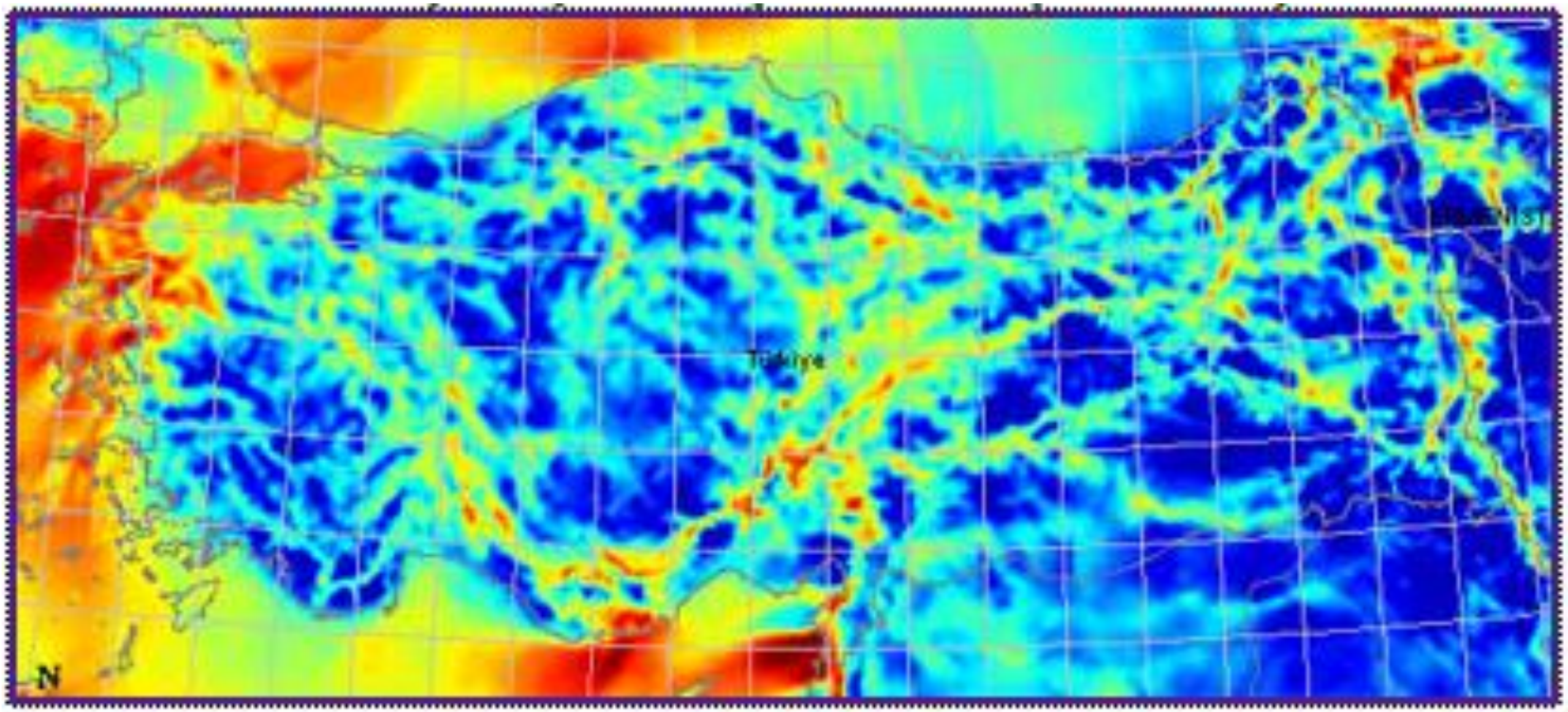




Total power generation capacity in the European Union 2008-2018

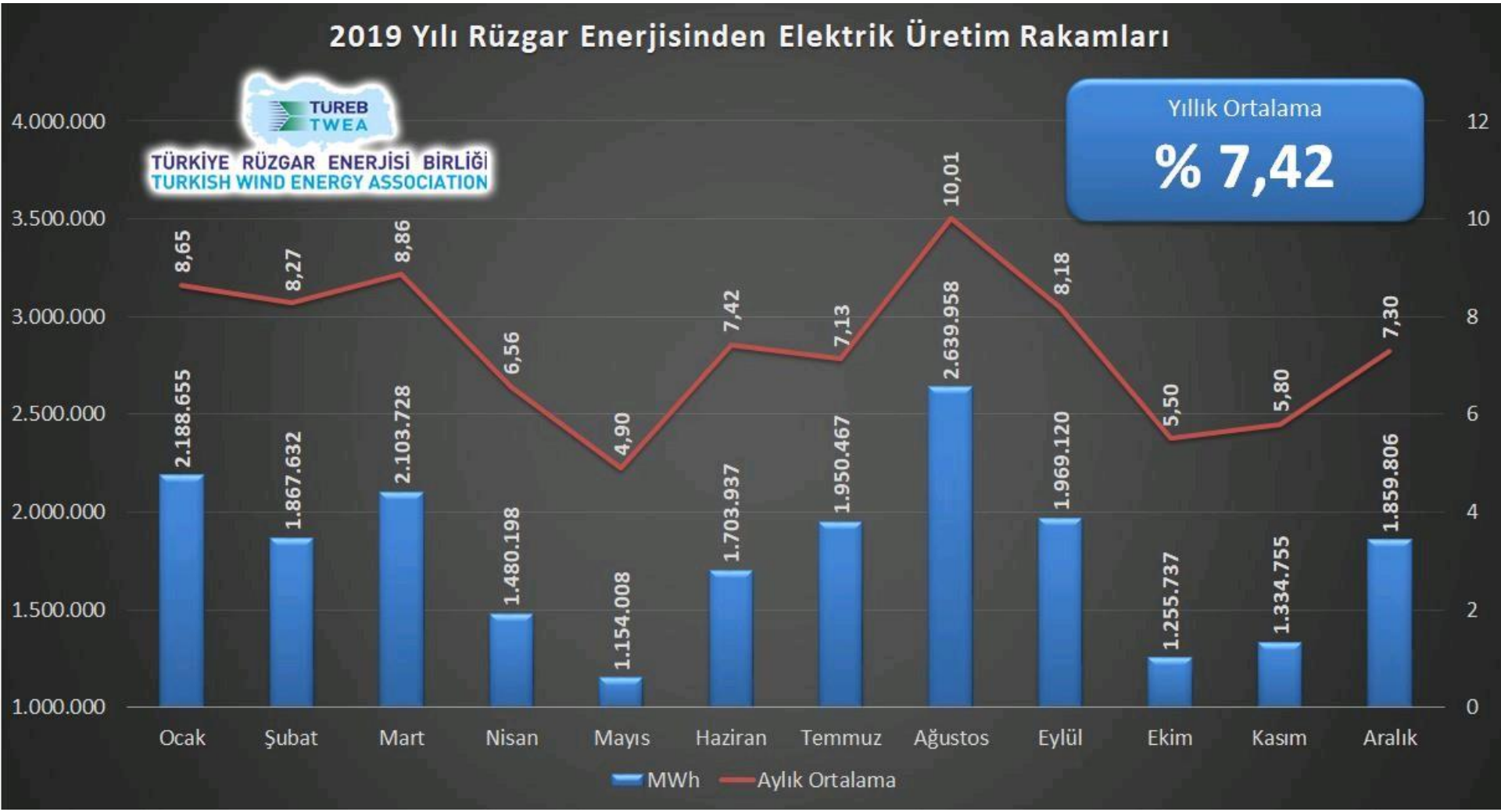


Source: Wind Europe Annual Statistics Report 2018



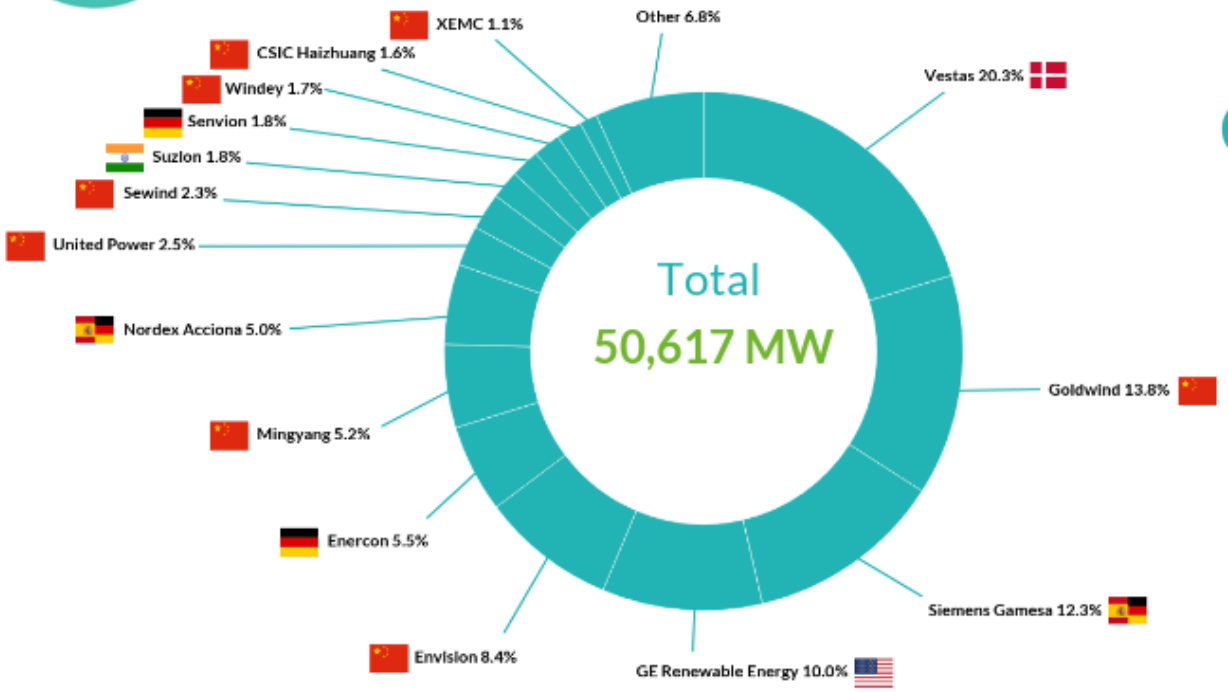
Türkiye Rüzgar Enerjisi Atlası

Türkiye Rüzgar Enerjisi Santralları


2019 Yılı Rüzgar Enerjisinden Elektrik Üretim Rakamları
TÜREB
TWEA
TÜRKİYE RÜZGAR ENERJİSİ BİRLİĞİ
TURKISH WIND ENERGY ASSOCIATION
Yıllık Ortalama
% 7,42
4.000.000
3.500.000
3.000.000
2.500.000
2.000.000
1.500.000
1.000.000
12
10
8
6
4
2
0
2.188.655
1.867.632
2.103.728
1.480.198
1.154.008
1.703.937
1.950.467
2.639.958
1.969.120
1.255.737
1.334.755
1.859.806
8,65
8,27
8,86
6,56
4,90
7,42
7,13
10,01
8,18
5,50
5,80
7,30
Ocak
Şubat
Mart
Nisan
Mayıs
Haziran
Temmuz
Ağustos
Eylül
Ekim
Kasım
Aralık
MWh
Aylık Ortalama

WINDSIGHTS

Top 15 Wind Turbine Supplier in Global Market 2018



"20,641 wind turbines were installed globally in 2018, produced by 37 wind turbine manufacturers."

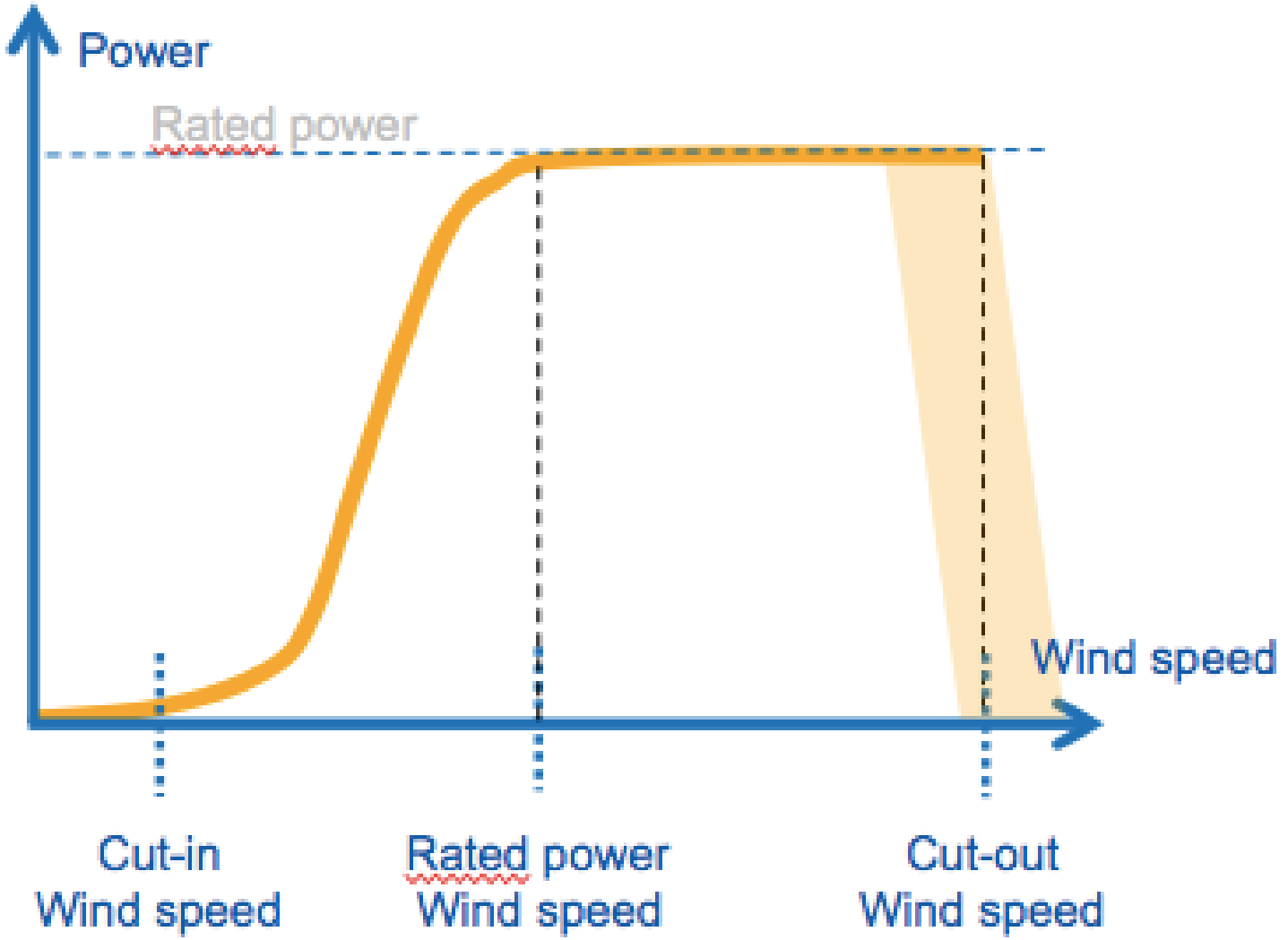
GWEC
GLOBAL WIND ENERGY COUNCIL

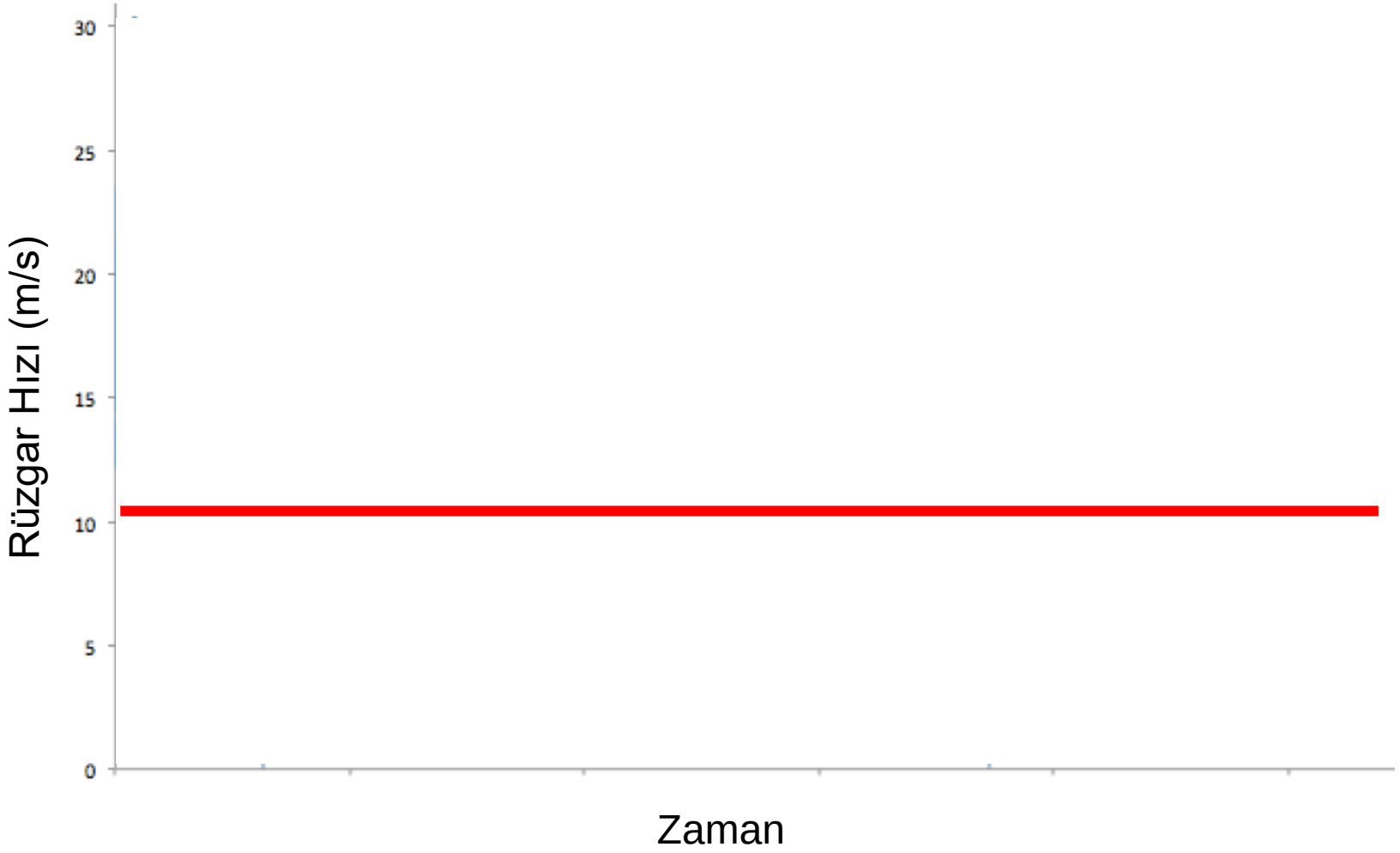
https://gwec.net/gwec-1-in-5-wind-turbines-are-installed-by-vestas-according-to-new-market-intelligence-report/

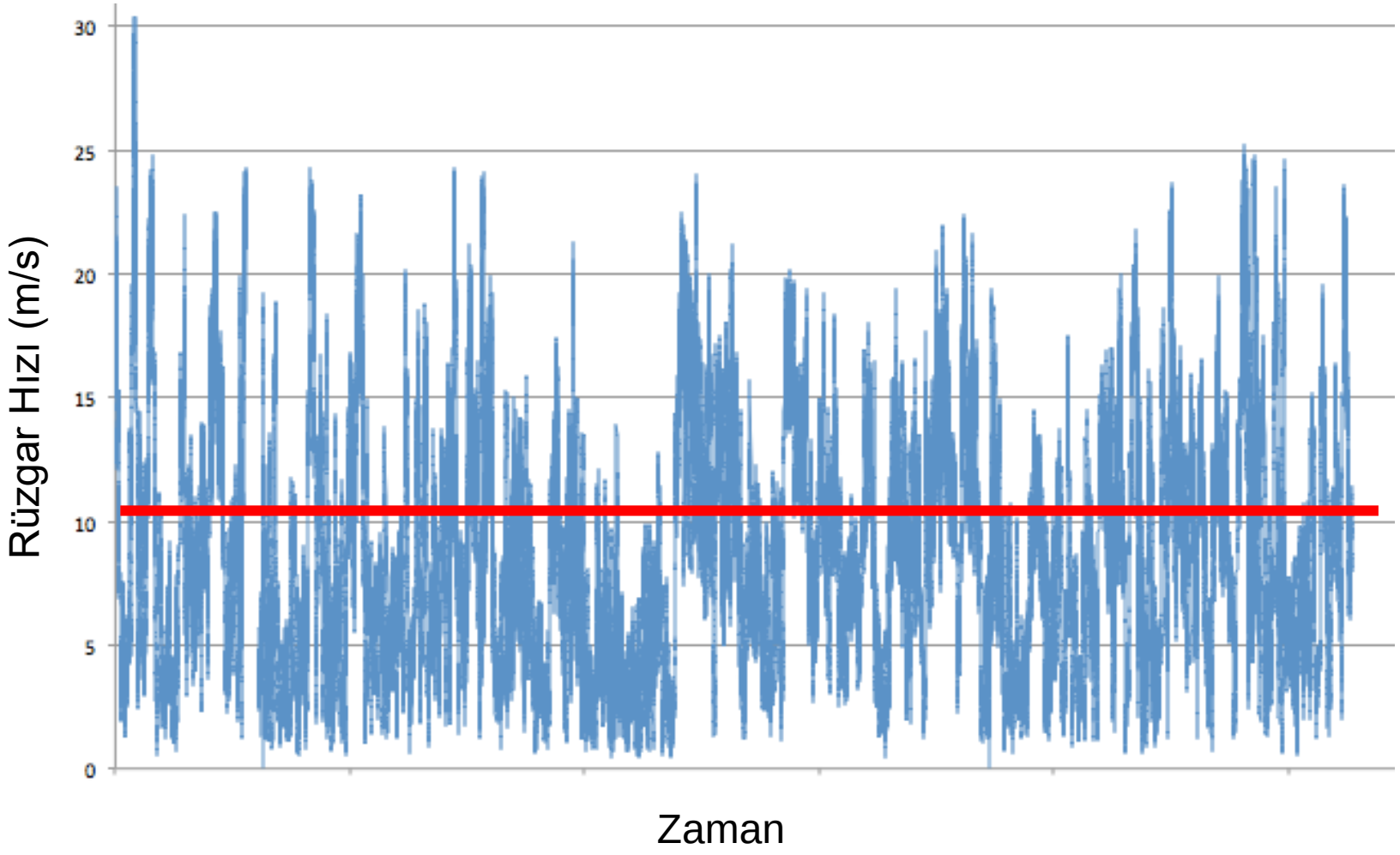
Rüzgar Türbin Güç Hesabı

$$P = \frac{1}{2} r A U_{¥}^{3} C_P$$

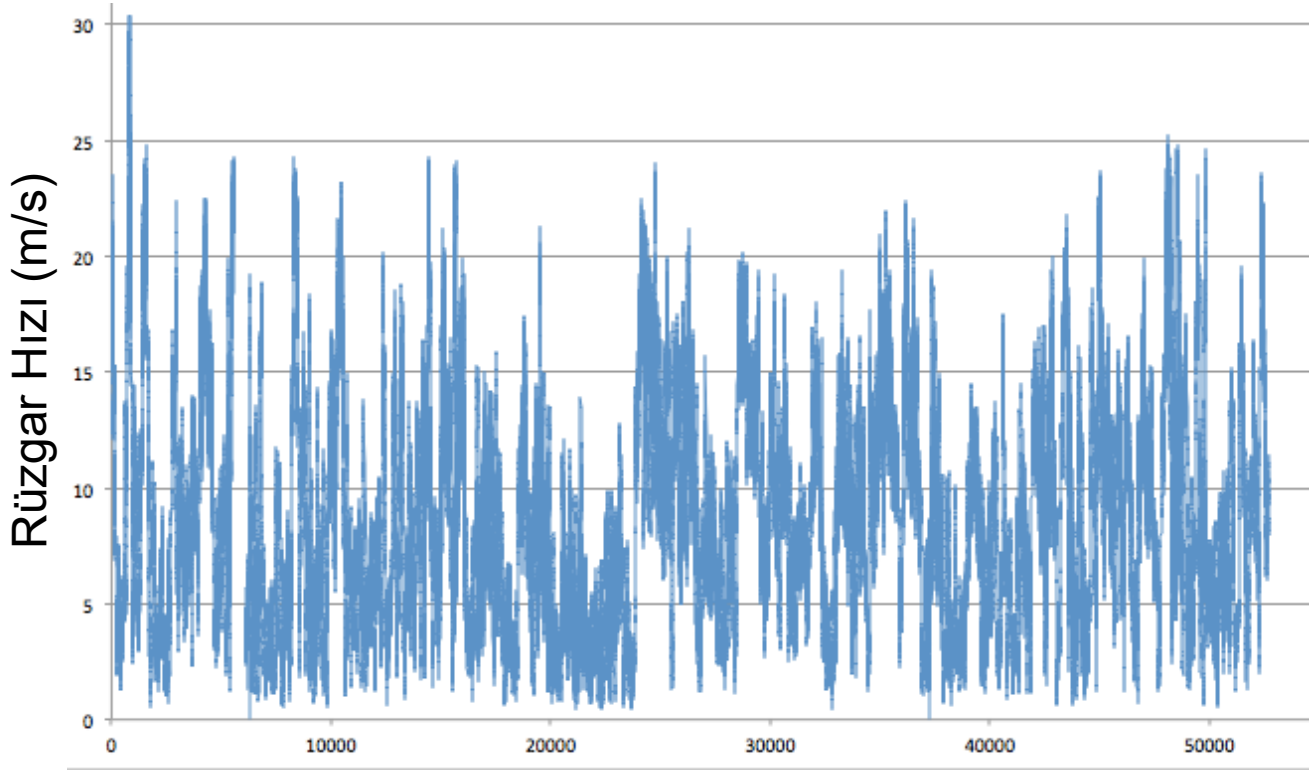
- **ρ** : Hava yoğunluğu (kg/m³)
- **C_P** : Güç Katsayısı (C_P < 0.593, Betz Limit)
- **A** : Rotor disk alanı (m²)
- **U_∞** : Rüzgar Hızı (m/s)


Power
Rated power
Wind speed
Cut-in
Wind speed
Rated power
Wind speed
Cut-out
Wind speed


Rüzgar Hızı (m/s)
30
25
20
15
10
5
0
Zaman



1/1/2012-31/12/2012 arası 10 dakikada bir toplanan örnek rüzgar verisi. Yükseklik 80 m.



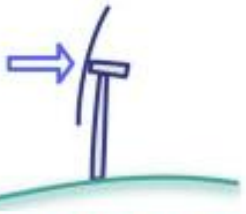
Olasılıksal
Enerji Üretimi

Zamana Bağlı
Değişen Yükler

Zamana Bağlı Değişen Yükler

Extreme wind

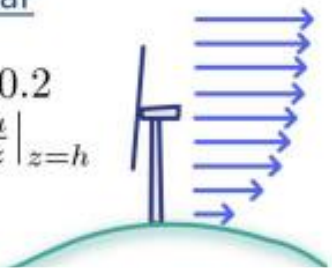
$u_{50} < u_{\text{ref}}$



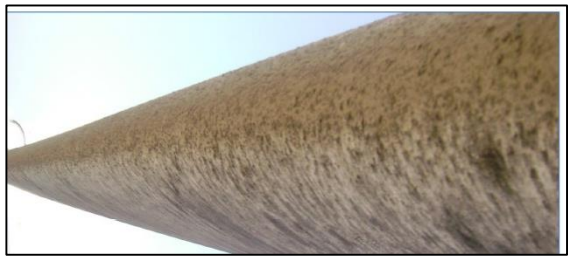
Wind shear

$0 \leq \alpha \leq 0.2$

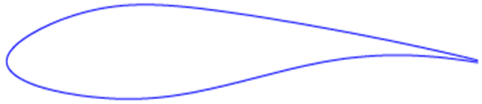
$\alpha = \frac{h}{u} \left. \frac{\partial u}{\partial z} \right|_{z=h}$



Wake turbulence



- Yüksek seviyede optimize edilmiş kanat şekli (veter, burulma açısı, vs) ve kanat profilleri
- Doğruluk seviyesi yüksek ve validasyonu yapılmış aerodinamik ve aeroelastik tasarım araçları
- Cam fiber veya Karbon/Cam fiber hibrit kompozit kanat, esnek çelik kule yapıları
- Rüzgar tüneli testleri, malzeme ve yapısal testler, saha testleri



Türbin Tasarım Optimizasyonu

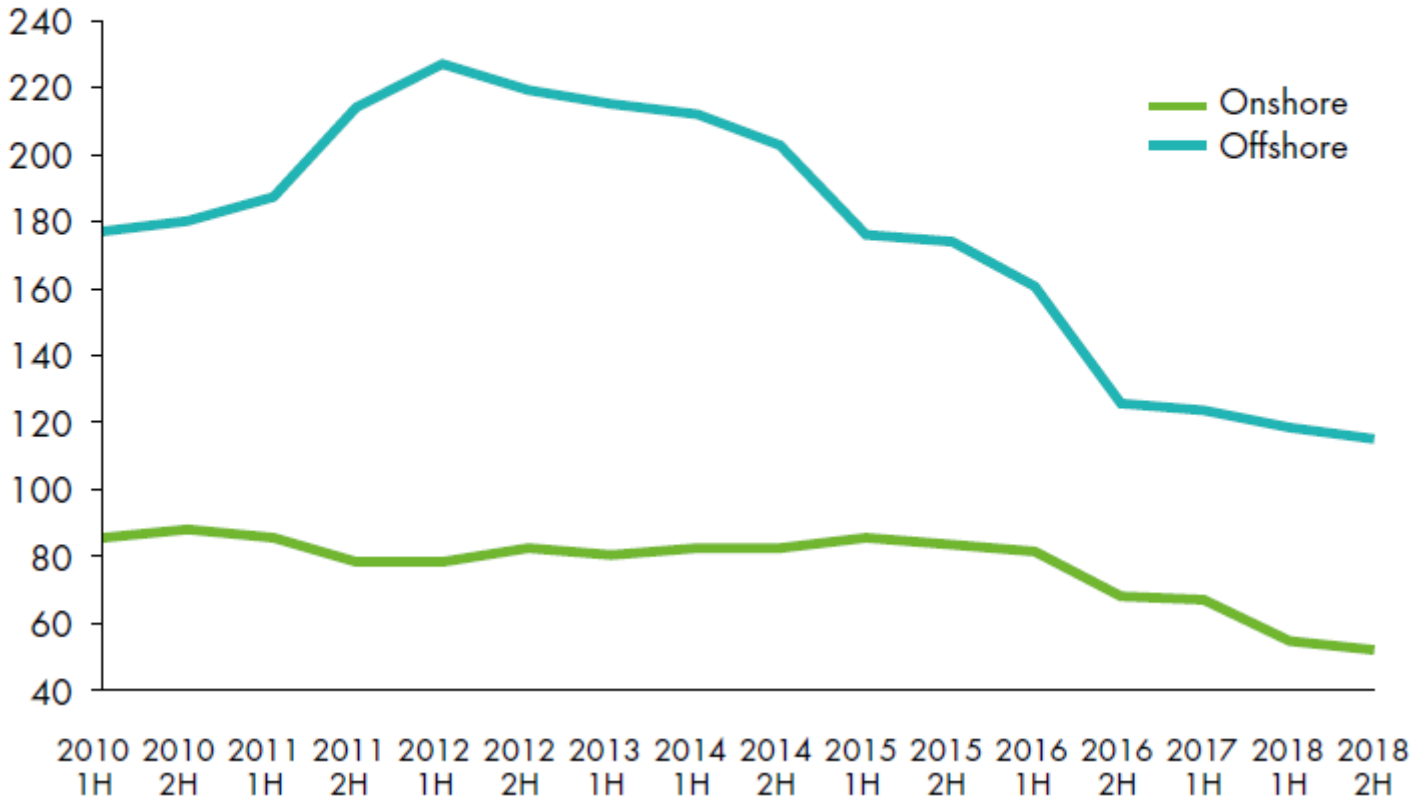
Düzeltilmiş Enerji Maliyeti (Levelized Cost of Energy - LCoE)

$$LCoE = \frac{\sum_{t=1}^{T} \frac{Capex_t}{(1+r)^t} + \sum_{t=1}^{T} \frac{Opex_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{Production_t}{(1+r)^t}}$$

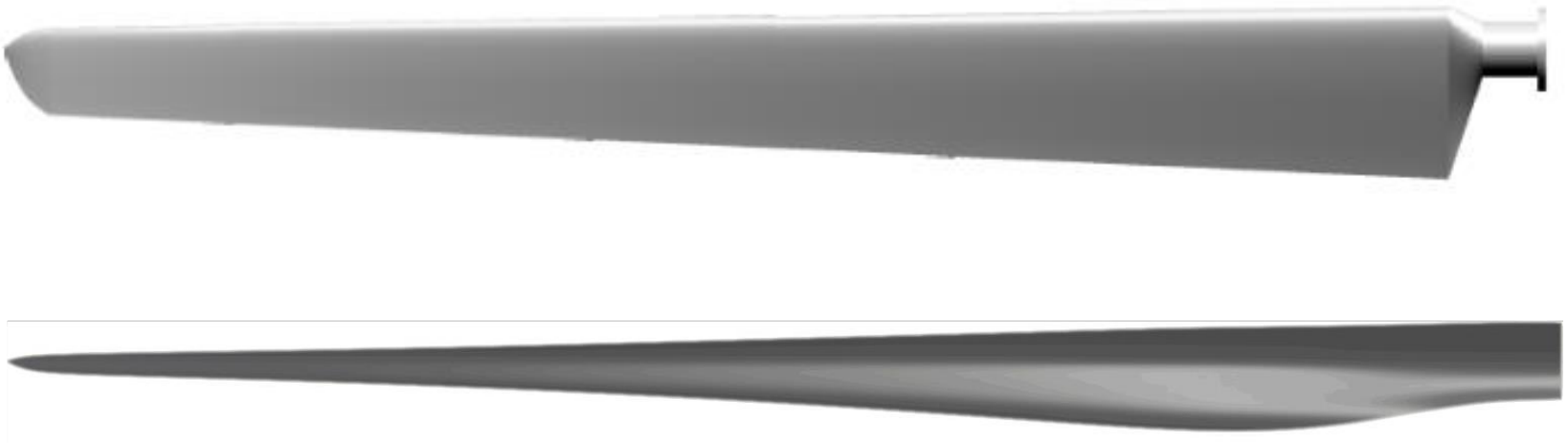
- CAPEX = ön kapital yatırım maliyeti
- OPEX = işletme maliyeti (bakım, onarım, vs)
- T = türbin ömrü, yaklaşık 20-25 sene
- r = indirim oranı

LCOE - Historic development

USD/ MWh



Source: GWEC Statistics Report 2018

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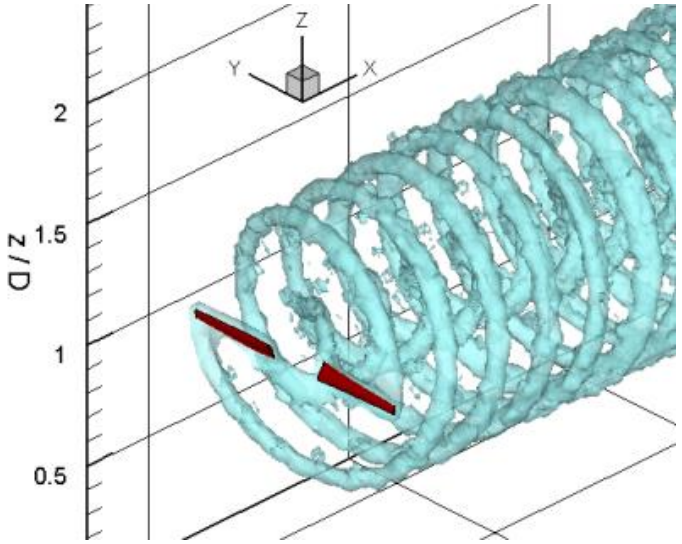
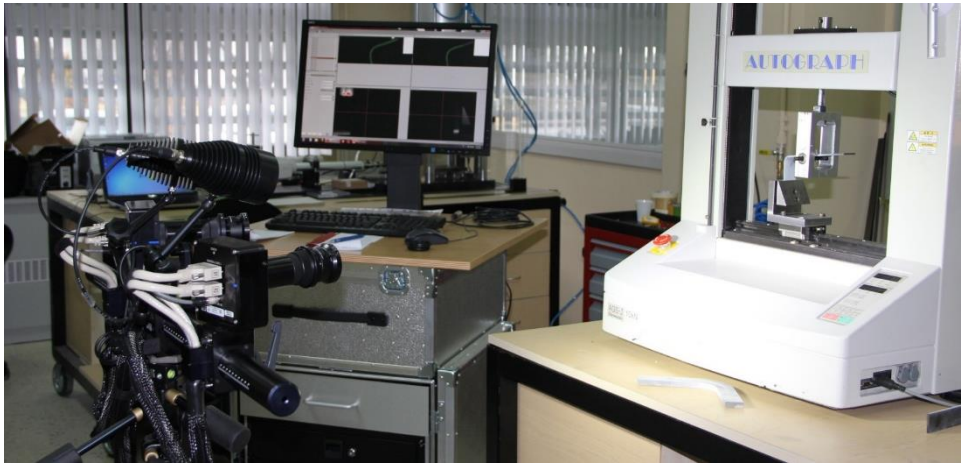
- RÜZGEM 2011 yılında kuruldu
- Kalkınma Bakanlığı destekli altyapı projesi
- ODTÜ'de 9 farklı bölümden 30+ öğretim üyesi katkısı
- European Academy of Wind Energy (EAWE) Asil Üyesi
- Ulusal ve uluslararası araştırma projeleri ve sanayiye test, ölçüm, analiz, tasarım hizmetleri

eawe
european academy of wind energy

- Aerodinamik Laboratuarı
- Yapı ve Malzeme Laboratuarı
- Elektromekanik Laboratuarı
- Yüksek Başarımlı Hesaplama Laboratuarı



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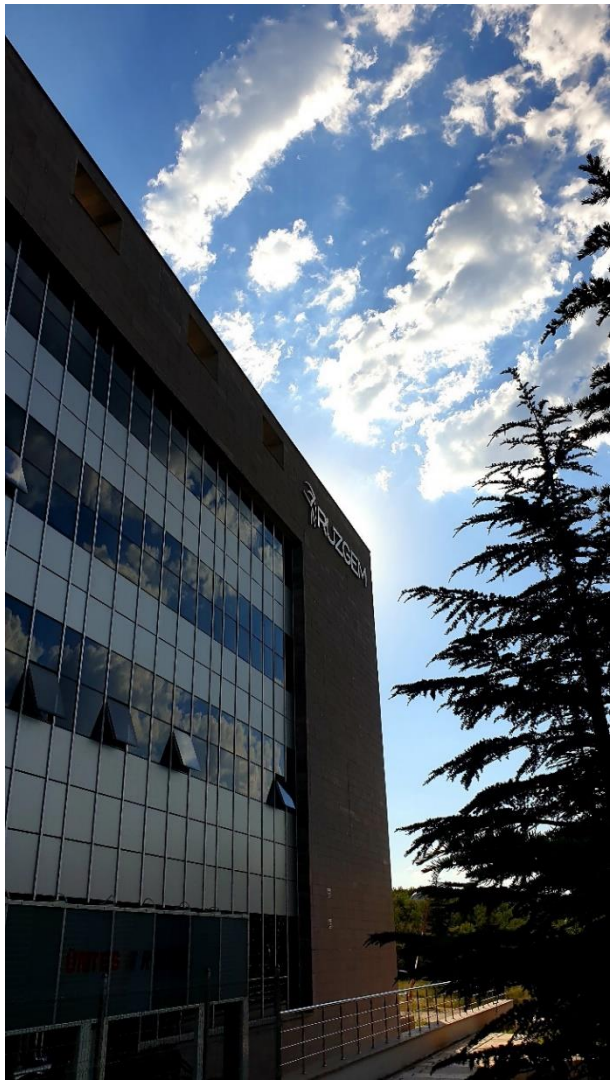
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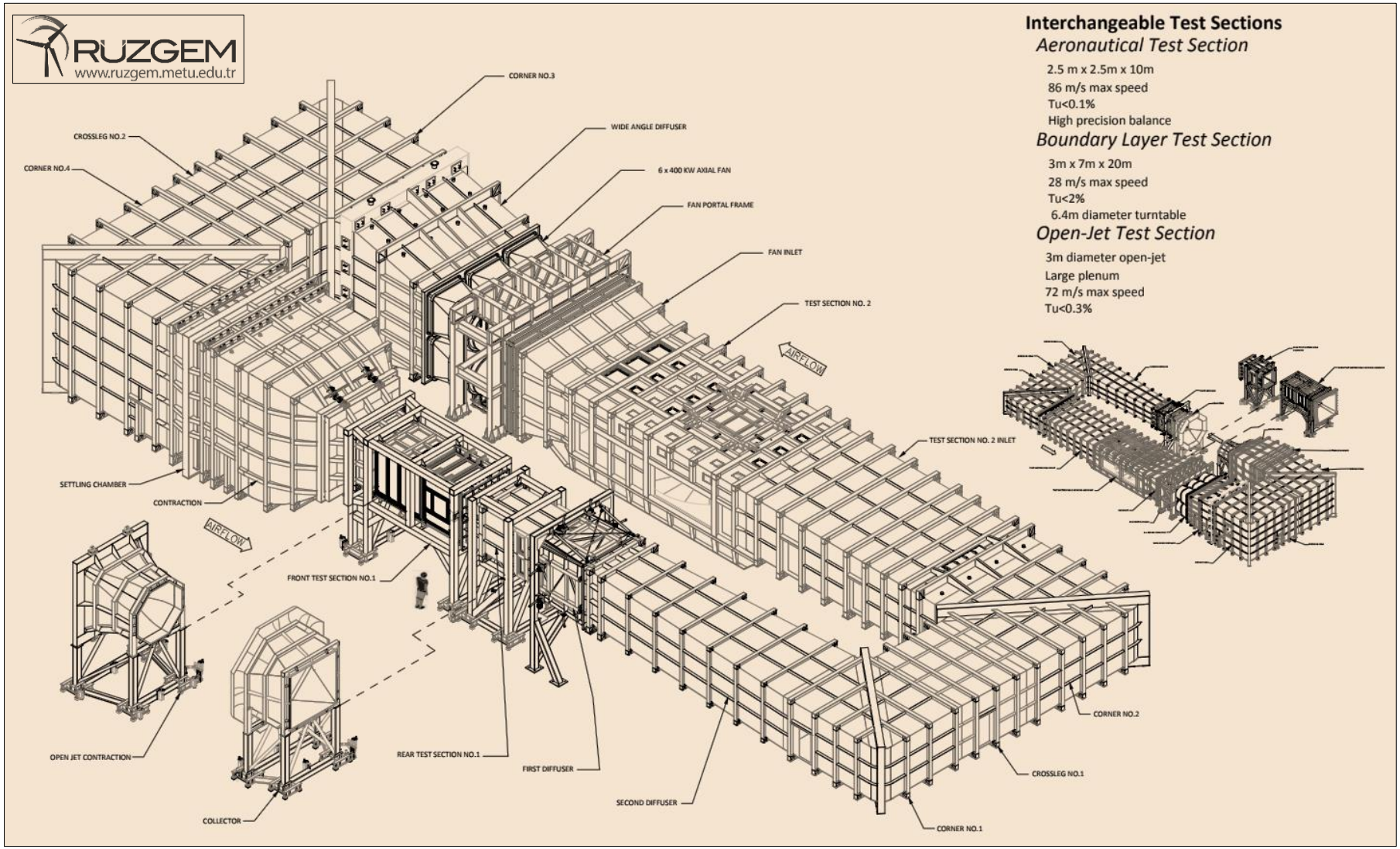
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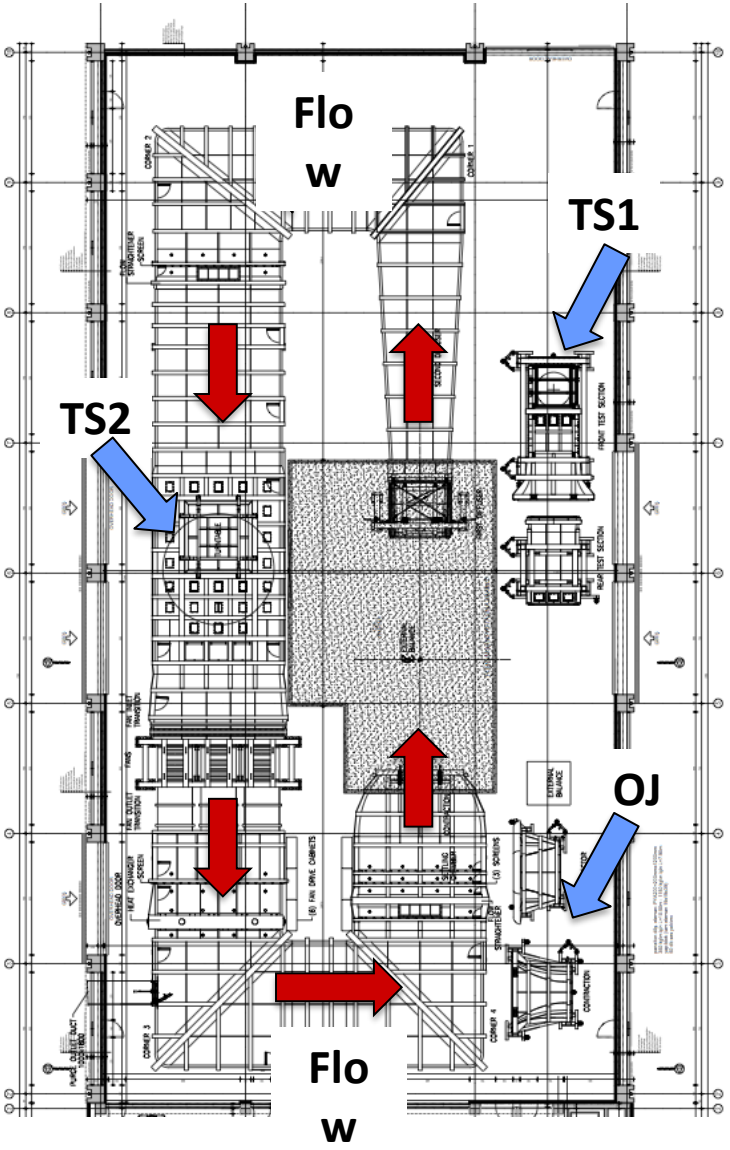
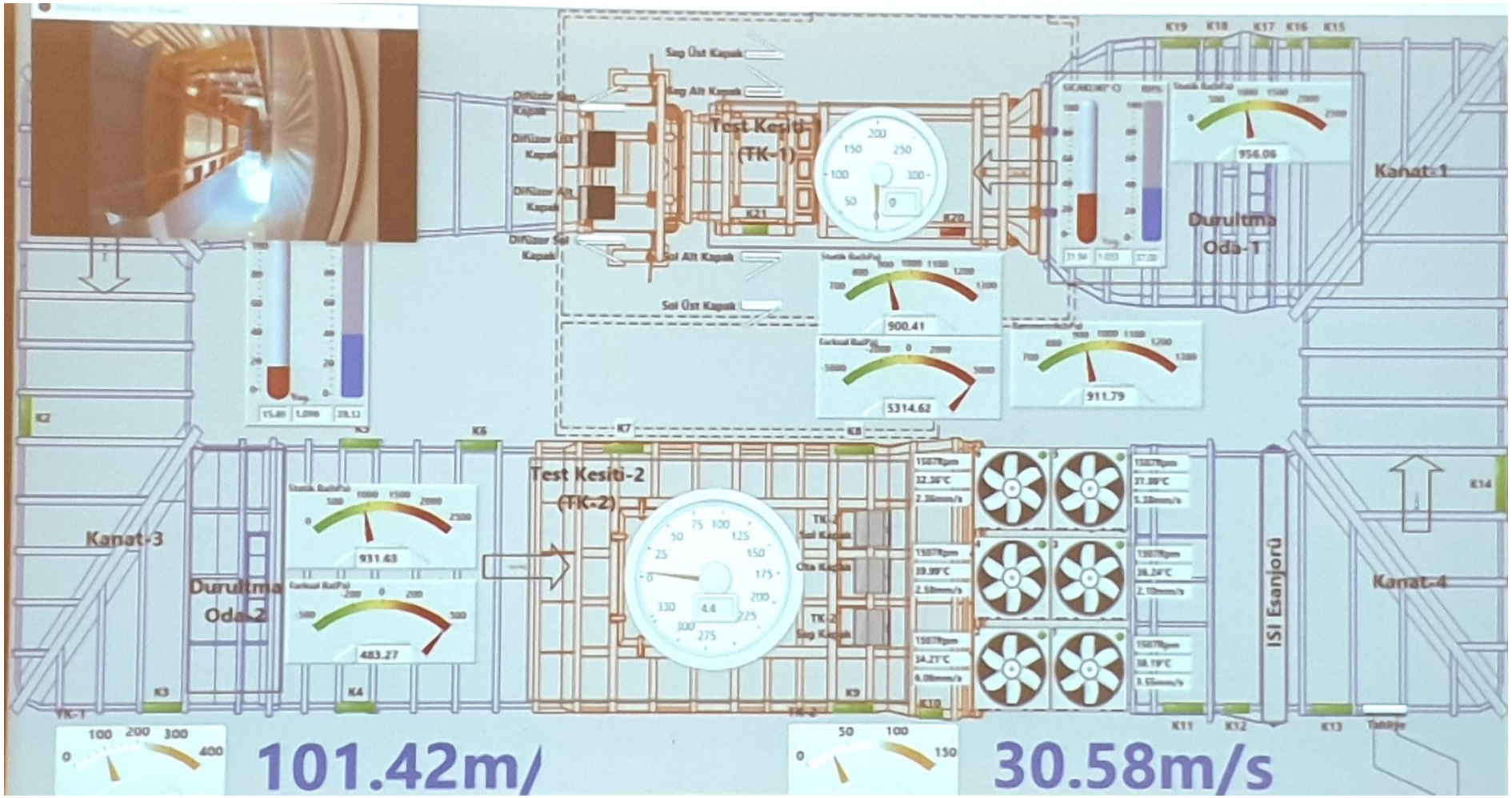
CORNER NO.3
WIDE ANGLE DIFFUSER
CROSSLEG NO.2
CORNER NO.4
6 x 400 KW AXIAL FAN
FAN PORTAL FRAME
FAN INLET
TEST SECTION NO. 2
AIRFLOW
TEST SECTION NO. 2 INLET
SETTLING CHAMBER
CONTRACTION
AIRFLOW
FRONT TEST SECTION NO.1
OPEN JET CONTRACTION
REAR TEST SECTION NO.1
FIRST DIFFUSER
SECOND DIFFUSER
CORNER NO.2
CROSSLEG NO.1
COLLECTOR
CORNER NO.1
Interchangeable Test Sections
Aeronautical Test Section
2.5 m x 2.5m x 10m
86 m/s max speed
Tu<0.1%
High precision balance
Boundary Layer Test Section
3m x 7m x 20m
28 m/s max speed
Tu<2%
6.4m diameter turntable
Open-Jet Test Section
3m diameter open-jet
Large plenum
72 m/s max speed
Tu<0.3%

Tunnel Type	Closed Loop, Atmospheric, Interchangeable Modular Test Sections
Fan Type	6 axial fans, 2 m diameter each
Fan Power	2.4 MW (6x400 kW)
Contraction Ratio	8
Flow Conditioning	2 honeycombs, 5 screens
Test Sections	○ 2.5 m x 2.5 m x 10 m (TS1) ○ 3 m x 7 m x 20 m (TS2) ○ 3 m diameter open-jet (OJ)
Max Speed	○ TS1: 86 m/s. TI < 0.1 % ○ TS2: 28 m/s. TI < 2 % ○ OJ: 72 m/s
Cooling	750 kW heat exchanger




Test Kesiti-1
(TK-1)
Test Kesiti-2
(TK-2)
Durultma
Oda-1
Durultma
Oda-2
Kanat-1
Kanat-3
Kanat-4
ISI Eşanjörü
956.06
900.41
5314.62
911.79
931.63
483.27
101.42m/
30.58m/s

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