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ENVIRONMENTAL ASPECTS OF WIND POWER GENERATION

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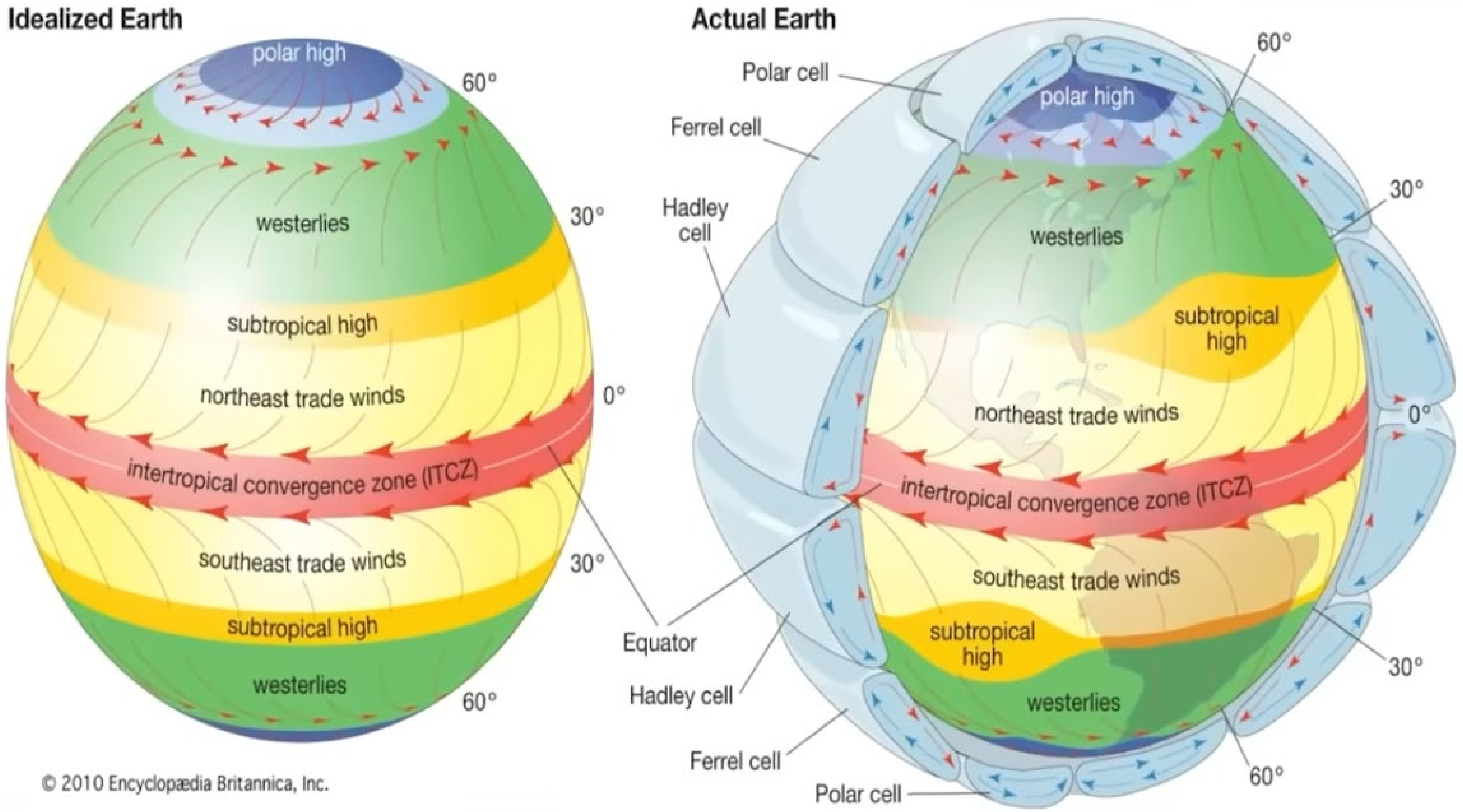
“Blue Pearl” Earth

Thin Earth's Atmosphere


Idealized Earth
polar high
60°
westerlies
30°
subtropical high
northeast trade winds
0°
intertropical convergence zone (ITCZ)
southeast trade winds
30°
subtropical high
westerlies
60°
Actual Earth
Polar cell
Ferrel cell
Hadley cell
60°
polar high
westerlies
30°
subtropical high
northeast trade winds
0°
intertropical convergence zone (ITCZ)
southeast trade winds
subtropical high
30°
westerlies
Equator
Hadley cell
Ferrel cell
Polar cell
60°

PRINCIPLES OF ENERGY CONVERSION

M. Ragheb

A first basic principle of energy conversion or extraction from the environment can be simply enunciated as:

"Energy can only be extracted from a flow system."

A corollary is that:

"The energy flow is from a high energy storage reservoir to a low energy sink."

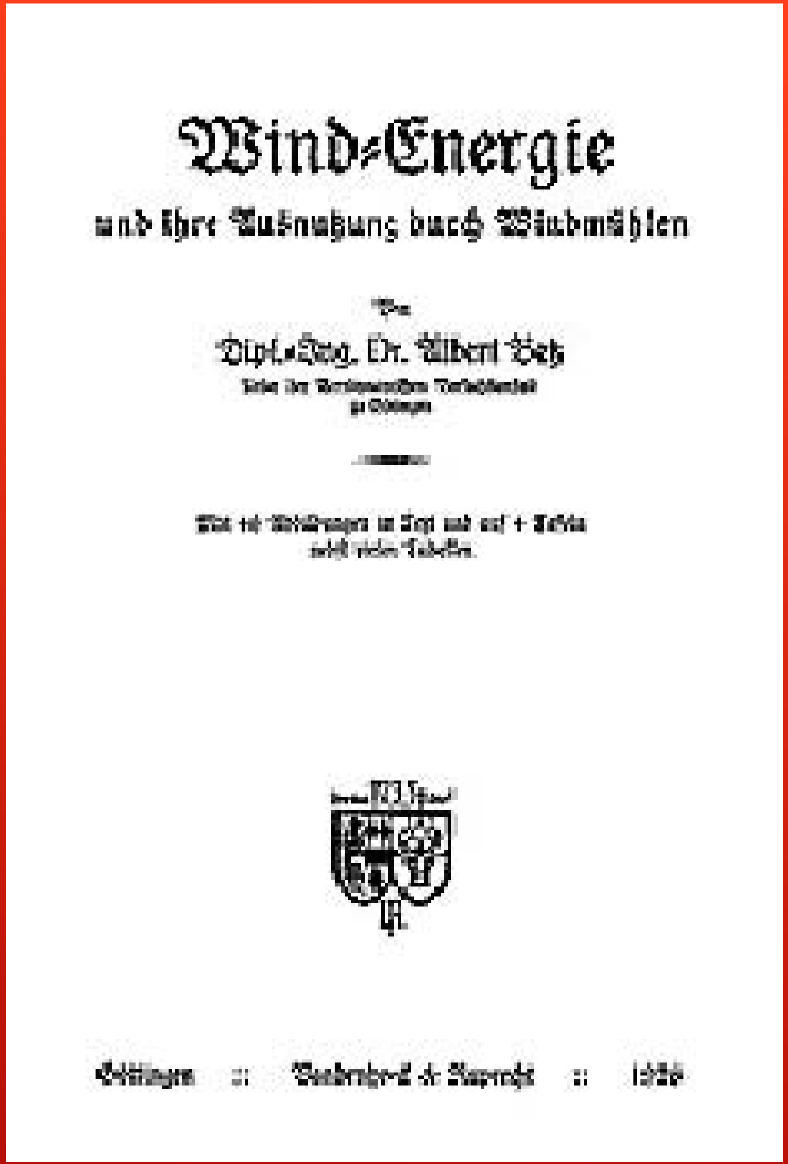
A second principle can be stated as:

"Only asymmetries in a hydraulic, kinetic, thermodynamic or aerodynamic system allow the extraction of a portion of the available energy in the system."

A third principle is that:

"The existence of a flow system necessitates that only a fraction of the available energy can be extracted at an efficiency characteristic of the energy extraction process, with the rest returned back to the environment."

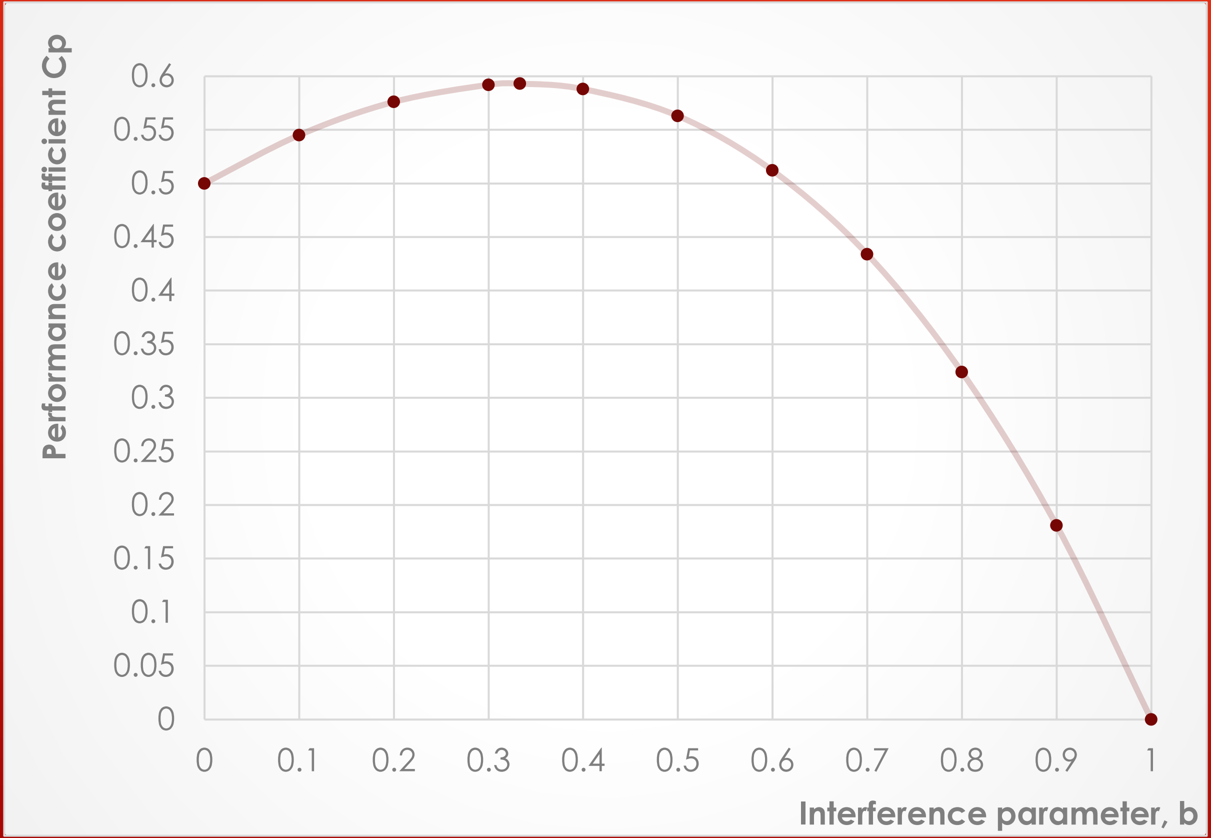
In thermodynamics, the ideal heat cycle efficiency is expressed by the Carnot cycle efficiency. In a wind stream, the ideal aerodynamic cycle efficiency is expressed by Betz's efficiency equation.

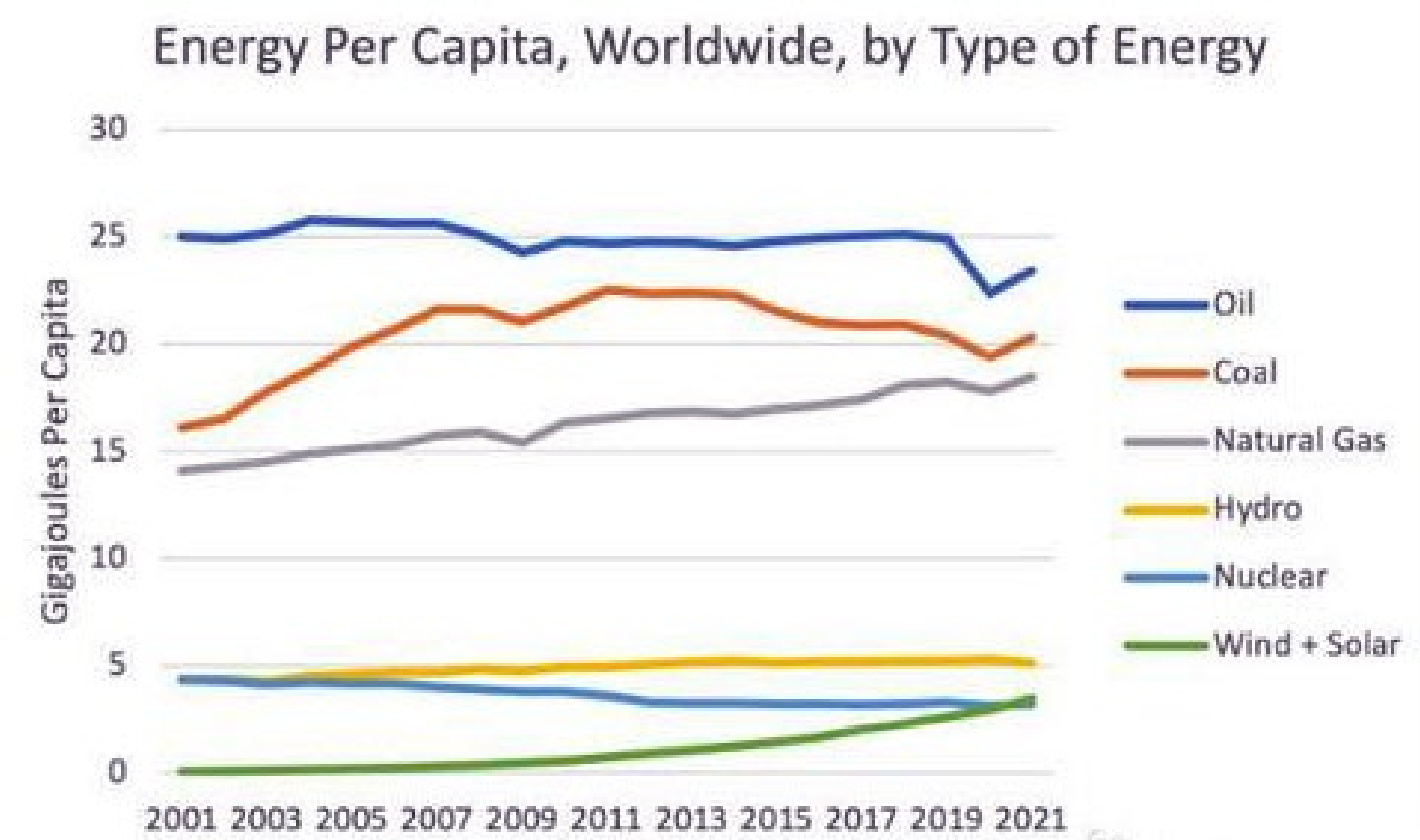

Wind-Energie
und ihre Ausnutzung durch Windmühlen
Dipl.-Ing. Dr. Albert Betz
Göttingen :: Vandenhoeck & Ruprecht :: 1926

"Wind Energie und ihre Ausnutzug durch Windmülen," "Wind Energy and its Extraction through Windmills," book authored by German physicist Albert Betz, 1926.

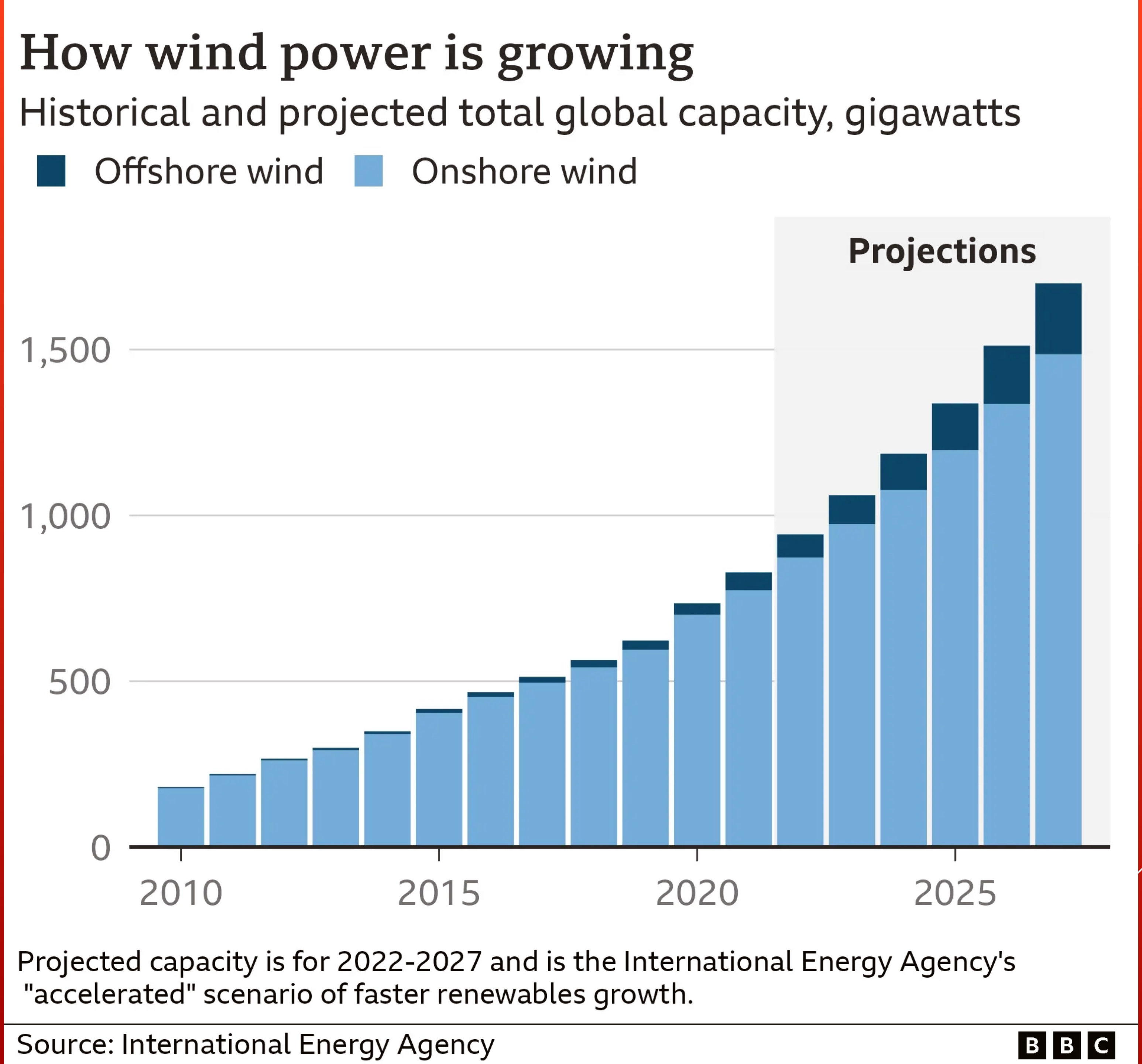
BETZ' EQUATION

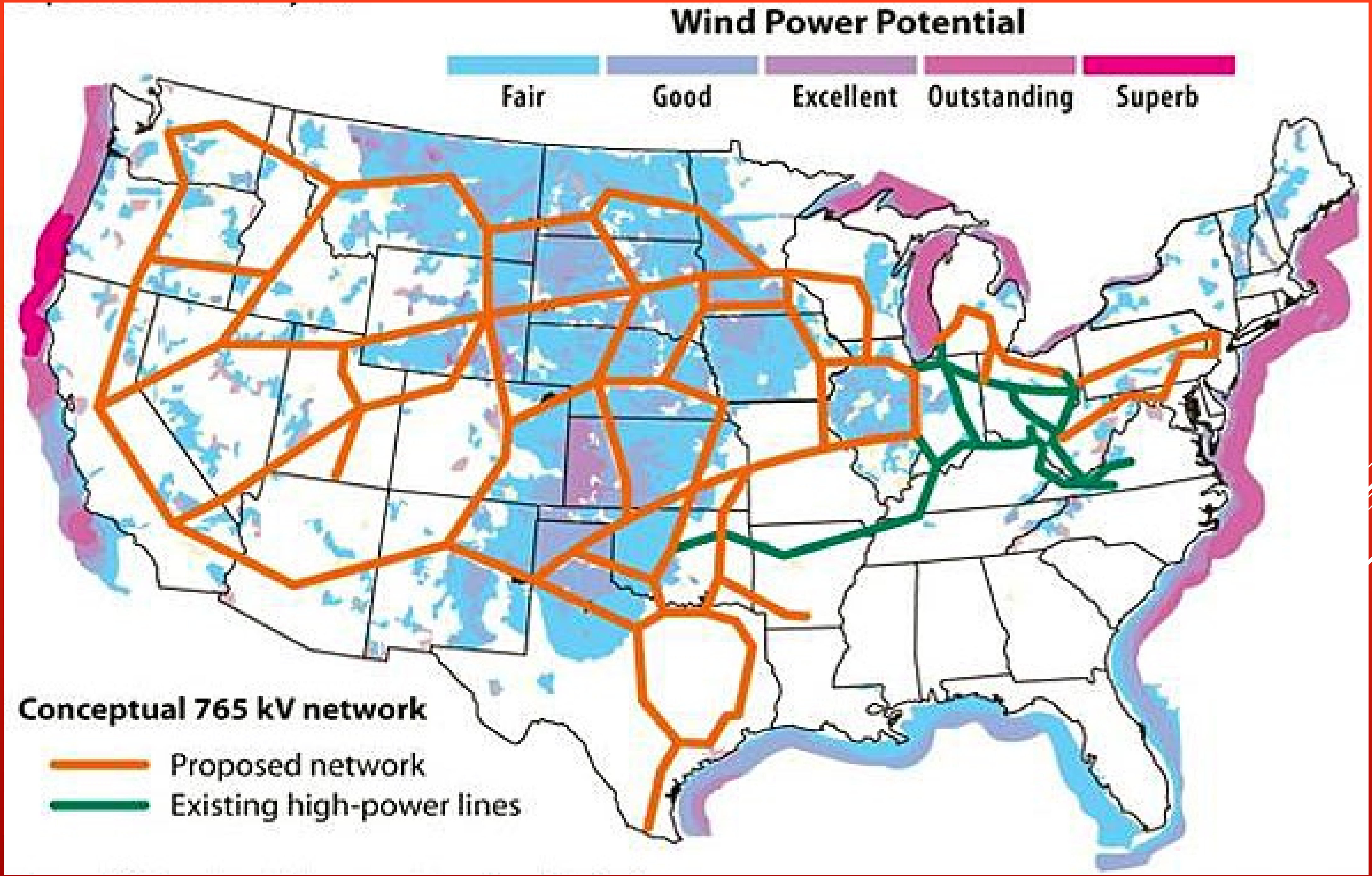
$$P_{\max} = \frac{16}{27}\frac{\rho}{2}V_1^3\frac{\pi D^2}{4} \quad [Watt]$$



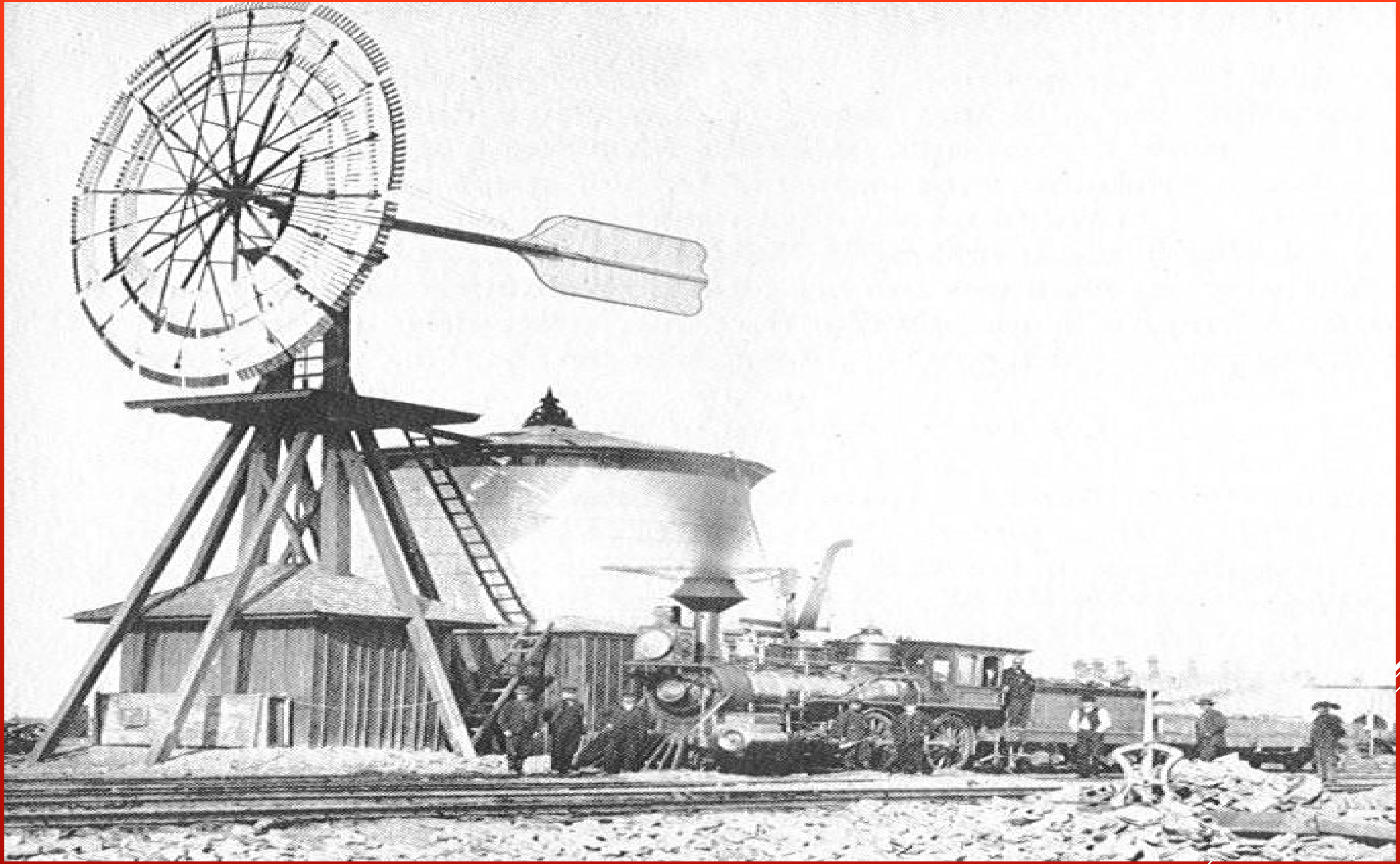


Energy Per Capita, Worldwide, by Type of Energy
Gigajoules Per Capita
30
25
20
15
10
5
0
2001 2003 2005 2007 2009 2011 2013 2015 2017 2019 2021
Oil
Coal
Natural Gas
Hydro
Nuclear
Wind + Solar


How wind power is growing
Historical and projected total global capacity, gigawatts
Offshore wind
Onshore wind
Projections
1,500
1,000
500
0
2010
2015
2020
2025
Projected capacity is for 2022-2027 and is the International Energy Agency's "accelerated" scenario of faster renewables growth.
Source: International Energy Agency
BBC



Wind Power Potential
Fair
Good
Excellent
Outstanding
Superb
Conceptual 765 kV network
Proposed network
Existing high-power lines

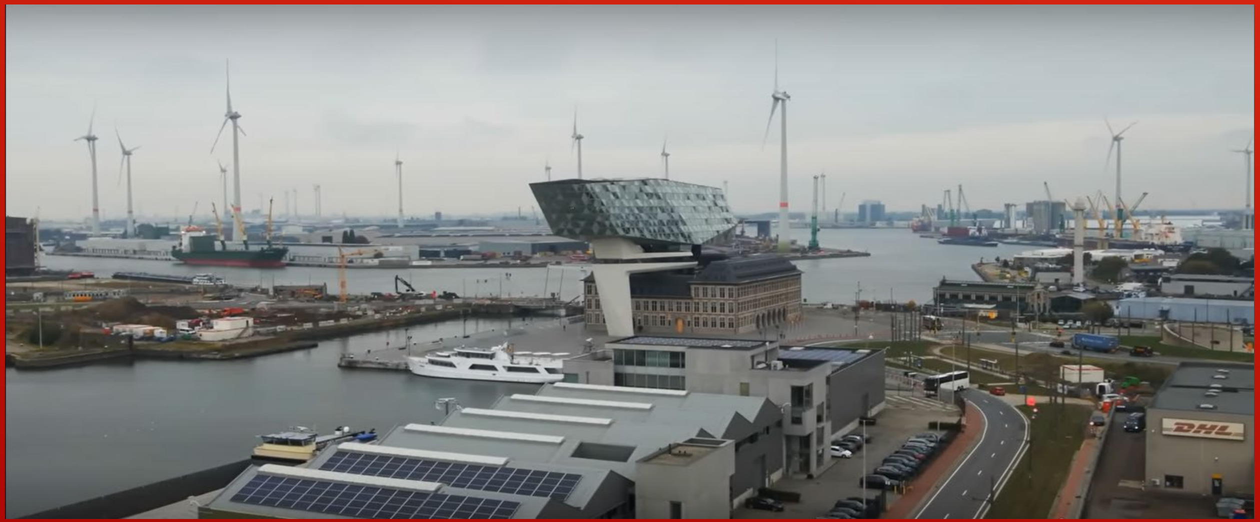


How the West was won. Union Pacific Railroad pumping machine for steam boiler water at Laramie, Wyoming, 1868.

American Wind Mills, 1893 World Fair Chicago 100th year Columbus arrival

Modern and American wind turbines. :Photo: M. Ragheb

The Netherlands, Classical Wind Turbine drained Polters for agricultore



Rotterdam, The Netherland, modern wind turbines

BENEFICIAL AND DETRIMENTAL ASPECTS

Wind farms are not totally devoid of environmental concerns even though they are considered as a green or renewable form of energy.

Their locations and the associated electrical transmission lines corridors must be recognized as primarily industrial production sites with multiple hazards that should be located away from human dwellings.

Their environmental signatures can be either beneficial or detrimental.

Mitigation of the detrimental aspects is the key for humanity to benefit from a carbon-free and abundant source of energy and avoid the emergence of organized resistance to its implementation.

Wind farms and agricultural activities can coexist.

The environmental effects of wind power generation cover two phases.

The first phase includes the fabrication and installation stage.

The second phase includes the operational and maintenance stage.

FABRICATION AND INSTALLATION

Wind machines require fabrication of their components at remote sites and installation and assembly of these components on site.

The environmental impacts from the fabricated components are similar to those encountered in the production of steel, concrete, copper electrical parts, heavy industrial bearings and gears.

An additional impact arises from the fiber glass construction of the rotors similar to helicopter blades manufacture. The non rotor components will add slightly to the polluting residuals of the involved industries. The ensuing pollution is confined to the manufacturing sites as part of their routine operations.

The on-site impacts concerning installation are similar to those encountered in any large scale heavy construction project. These would comprise construction equipment emissions, fugitive dust, heavy equipment noise, soil erosion, streams silting, domestic sewage disposal, and water usage for domestic purposes and dust quelling and solid waste disposal.

OPERATION AND MAINTENANCE

Environmental impacts will arise during the operational lifetime of the machines, and then afterwards after their decommissioning when the system is dismantled and recycled or discarded.

Reclamation of the utilized land by removal of the access roads, concrete and steel foundations and the electrical cabling must also be taken into consideration.

Potential operational problems could include:

1. Electromagnetic interference,
2. Mechanical accidents due to tower collapse,
3. Rotor blades failures and ejection,
4. Lubrication oil spills and fires,
5. Micro climate alterations,
6. Soil and floral effects,
7. Avian, bats and insects mortality,
8. Effects on marine mammals,
9. Aesthetic effects.

Conflicts could arise about the regulatory control of wind resources, the safety of wind machines, the use of private or federal lands, and coastal onshore or offshore placement of wind farms.

The USA Environmental Protection Agency (EPA) has set a zero discharge effluent limitation for the fiber glass industry.

A concern is the water/phenolic resin spray step. The resins are non volatile and few vapors would be entrained to the ambient air. The resins applied during manufacturing are fully reactive and present no emission problem.

Six to eight weeks are required for the erection of the steel tower for a 1.5 MW rated power wind machine.

Wind power generation is a labor-intensive process. Ten to twenty construction workers would be required. This is equivalent to 0.50-1.00 [MW / (person.year)].

This is larger than the 0.12-0.18 [MW / (person.year)] value for a conventional 1,000 MW conventional electric power plant.

Impacts on air emissions, water use, effluents, and solid waste production will arise from the resident construction force and families.

HEATING EFFECTS ON LOCAL AND REGIONAL METEOROLOGY

Wind farms warm up the surface of the land underneath them during the night.

Researchers used satellite data from 2003 to 2011 to examine surface temperatures across as wide swath of west Texas, which is home to four of the world's largest wind farms.

The data showed a positive correlation between night-time temperatures increases of 0.72 ^{o}C or 1.3 ^{o}F and the placement of the farms. The study used satellite data, which can introduce errors from clouds, rather than temperature readings taken at the surface.

According to the present installed capacity and the projected growth in installation of wind farms across the world, if spatially large enough, wind farms might have noticeable impacts on local to regional meteorology

Wind and solar power are good complements to each other.

The wind often blows more strongly at night while solar power is only available during daytime hours.

However, the generated turbulence in the wake behind a wind turbine stirs up a layer of cooler air that usually settles on the ground at night, and mixes in warm air that is on top. This layering effect is usually reversed during the daytime, with warm air on the surface and cooler air higher up.

One possible remediation could be to adopt different sizes and shapes for the turbine blades. Smaller diameter rotor blades turbines may avoid this problem, but this presents a tradeoff, since the wind speed decreases as one moves closer to the ground, hence producing less power. This suggests the need to think carefully about the unintended environmental consequences of any large-scale energy development, including green technologies.

SITE SELECTION

The surrounding ecology to wind machines can be significantly impacted if they are placed in forested areas where the tree tops are high enough to interfere with the wind streams or the blade movements.

If forest clear-cutting is adopted, severe soil erosion, water sediment entrainment and pollution with resultant faunal and floral habitat destruction ensuing. By siting of wind machines on plains or treeless coastal areas, offshore, or in low topped forested areas, the habitat impact would be minimized.

The land usage for a 1.5 MW wind machine is about 1,000-2,000 [m^2 / MW] or ¼ to ½ [acre / MW].

In principle, a 200 MW wind farm would require a land area of about 100 acres. However, electrical transmission lines, access roads, control and power conditioning facilities surrounding each unit could easily double this area to 2,000-4,000 [m^2 / MW] or 1/2 to 1 [acre / MW] leading to a higher figure of 200 acres for a 200 MW wind farm.

The optimal configuration and emplacement of wind machines depends on the distribution of wind directions at a given site. If the wind blows in a fairly constant direction a suggestion for the spacing between wind machines in the direction of the wind is about 30 rotor diameters. Other distributions of wind directions suggest a longitudinal spacing of 12-20 rotor diameters, and lateral spacing of 2-5 rotor diameters.

MICRO CLIMATIC EFFECT

The velocity of the air stream behind the area swept by the rotor blades is attenuated in comparison to the incident stream velocity. This attenuation covers an area behind the rotor that is larger than the area swept by the rotors themselves.

For a 100 kW of rated power wind machine with a maximum of an incoming 29 km/hr (18 mph) wind speed, the reduction amounts to about 10 km/hr (6 mph). For an incoming wind speed exceeding 40 km/hr (25 mph), the reduction is minimal.

The radius of the affected wake area behind the rotors reaches a maximum of 2.3 m (7.5 feet) wider than the rotor radius. If the rotor is at a 30 m (100 ft) tower, the wake would not reach closer than 9 m (30 ft) from the ground.

Small temperatures reductions of 0.02 ^{o}C (0.03 ^{o}F) and pressures reductions of 0.7 mm Hg can be expected at the point of maximum wind velocity reduction. Estimates for larger wind machines have not been attempted and need to be estimated.

CROPPING EFFECTS

Wind turbines create a turbulent wake that is 250 ft high and extending ¼ mile downwind. They help moderate ground level temperatures for the growing crops.

They would blow away excessive moisture that would favor the growth of fungi. No need for fungicides.

By stirring up the air, they expose the plants to photo synthesis growth-promoting CO_2.

Wind turbines would keep the crops warmer in the fall and spring, preventing early and late frosts, and cooler on hot summer nights.

These subtle effects are beneficial in general.

However, under drought conditions, they may have negative effects by drying the surrounding air through excessive air circulation near the ground surface.

FAUNAL EFFECTS

Problems arose at some early wind farms that were sited in locations where large numbers of birds congregate, especially on night migration routes. Such problems are now rare, and it must be remembered that many other activities cause far more casualties to birds, such as the motor vehicle collisions with flying birds and feral cat and animal predation.

Investigations are carried out to ensure that wind installations are not sited too close to large concentrations of birds nesting sites. Most birds are capable of avoiding obstacles and very low collision rates are reported.

Large scale use of wind machines increases the probability of fatal collisions involving insects, bats, birds and flying species in general. Large bodies like birds will be virtually unaffected by the drag forces generated by the airfoils, whereas small size organisms such as butterflies and moths and other flying insects will probably be affected.

The size and high altitude of wind machines makes them potential obstacles to birds' migration paths, particularly under adverse weather conditions such as fog, poor visibility or darkness. Without evasive action, 8 percent of the birds flying through the blades rotation area will be struck. Machines sited out of the migratory bird paths of lower flying song birds will present minor hazard. Wind machines with maximum vertical blade tip extension of 91 meters (300 ft) above ground should present little hazard to flying waterfowl.

A suggestion can be advanced to reduce the rotational speed as well as the number of rotor blades from three to two in areas of large birds congregations. Markings on the rotors have been used as a visual warning to flying species.

AVIAN MORTALITY

In the USA in 2003, wind generators accounted for only 3/1000 of 1 percent of bird killings, which amounts to about 37,000 birds.

That same year, as many as a billion birds died in collisions with tall buildings, and electrical power lines may have accounted for more than a billion more deaths.

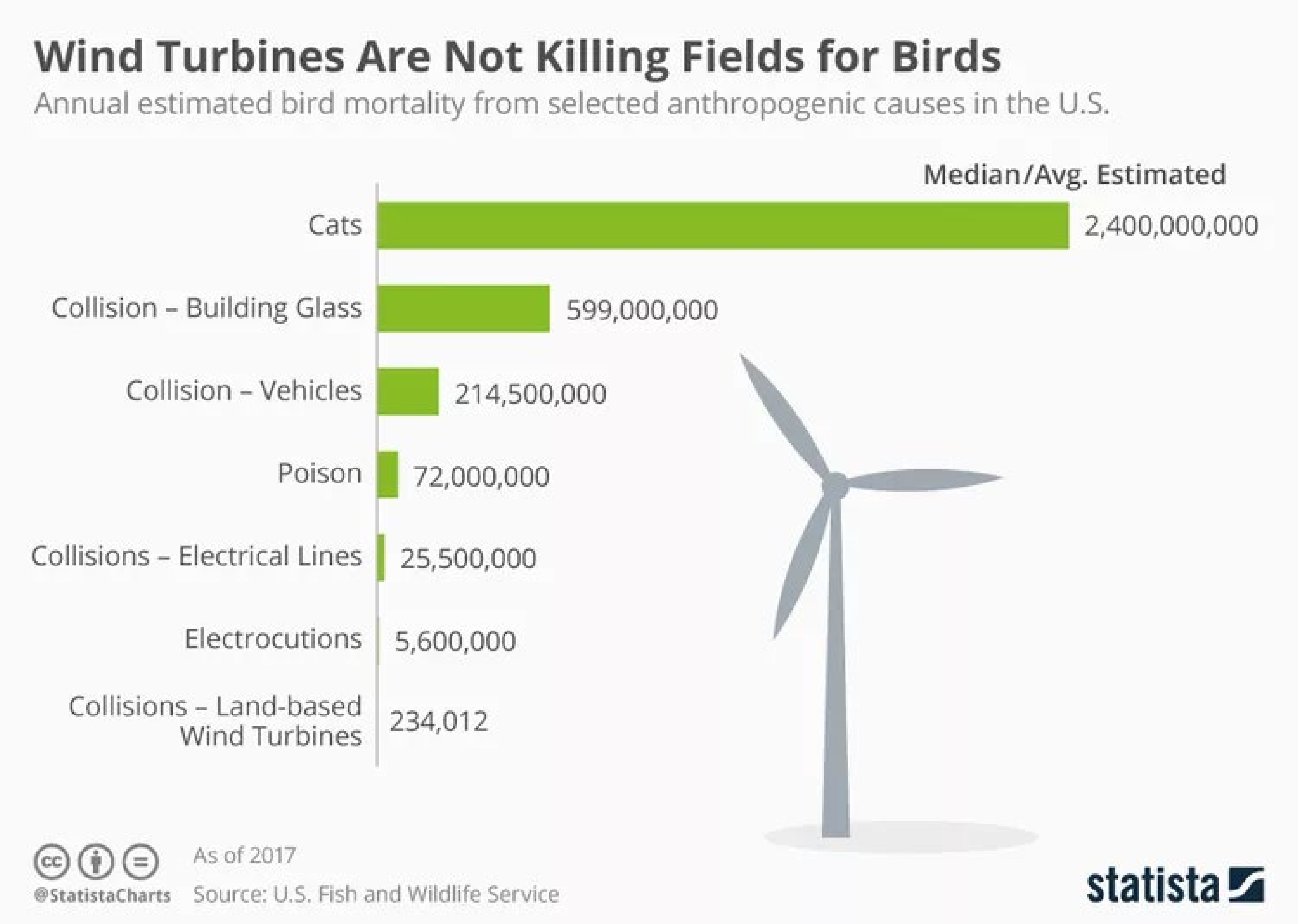
Domestic and feral cats were responsible for the demise of estimated hundreds of millions of song birds and other species every year.

Utility-scale wind turbines have raised concerns about their noise and their effect on wildlife and the environment.

With their large rotor blades spinning at high speeds, wind turbines can cause wildlife, such as birds, bats and flying insects’ mortality.

A study of wind turbines in West Virginia and Pennsylvania found that the 66 turbines at two wind turbines sites caused the death of up to 2,900 bats within a six week period.

Avian raptors mortality from wind turbines, Spain.



Wind Turbines Are Not Killing Fields for Birds
Annual estimated bird mortality from selected anthropogenic causes in the U.S.
Median/Avg. Estimated
Cats
2,400,000,000
Collision – Building Glass
599,000,000
Collision – Vehicles
214,500,000
Poison
72,000,000
Collisions – Electrical Lines
25,500,000
Electrocutions
5,600,000
Collisions – Land-based Wind Turbines
234,012
@StatistaCharts
As of 2017
Source: U.S. Fish and Wildlife Service
statista

BAT MORTALITY

A report by the National Research Council, the research arm of the USA National Academy of Sciences on the environmental impact of wind power suggests birds have far more to fear from high-rise buildings, power lines and feral wild cats than they do from the rotating blades of wind generators.

However, North America's bats might face another hazard. Bats might be at risk in the southwestern USA and elsewhere, where reliance on wind power has been growing.

The wind power turbines generate sounds and, possibly, electromagnetic fields that lure the acoustically sensitive creatures into the spinning blades.

FLICKER EFFECT

A potential environmental nuisance consideration of wind farms in flicker generation.

Two types of flicker are encountered: reflection and shadow flickers:

1. The Reflection Flicker effect arises by the reflection of the solar radiation by the polished surface of the rotating blades, and can be noticed at a distance.

2. The Shadow Flicker effect can occur as the rising or setting sun shines through the rotating blades of a wind turbine casting intermittent local shadows on area homes.

FLORAL EFFECTS

Plants are not much affected by the presence of wind machines since they are already conditioned to survive in an active wind environment.

In a wind farm, in between the structural towers and the access roads, agricultural practices of planting, harvesting or grazing can be pursued unaffected, albeit at a higher degree of complexity.

A possible impact on plant life is the change of moisture deposition patterns downwind from the machines. This would translate into increased moisture in the warm weather period and increased insulation of winter growing crops such as wheat by snow drift deposition. These are both beneficial effects.

Clear cutting of trees may be required in forested areas.

The blade tips would reach 15-23 meters (50-75 feet) from the ground.

Shrubs and trees below that level can still be left requiring only clearing for the structural towers, power lines and the access roads. In forested areas with tall trees full clearing or at least a minimum clearing area must be adopted equal to the area swept by the blades to avoid undesirable wind blockage.

ELECTROMAGNETIC INTERFERENCE

Wind turbines, like other metallic structures, can scatter electromagnetic communication signals, including television signals.

Careful siting can avoid such difficulties, which may arise in some situations if the signal is weak.

It is usually possible to introduce low-cost technical measures for compensation. Metallic and conducting materials reflect electromagnetic radiation falling upon them such as radio, radar, or microwaves.

Clusters of more than one wind machine in a given location may increase the severity of the problem.

The reflected radiation may interact with the incident radiation leading to interference. This interference affects the amplitude or intensity of the original signal.

NOISE GENERATION, WIND TURBINE SYNDROME

Noise produced by wind blowing through trees and brush is noticeable on windy days.

The sound produced by operating wind turbines consists of a whooshing sound as the turbine blades move through the air.

Most mechanical noise produced within the turbine from the transmission and generator is muted by the design of the turbine enclosure.

The only audible noise produced during turbine operation is similar in frequency to natural wind noise.

Planting trees as wind breaks to mask the turbines noise may not be a solution.

The trees, if planted close enough, will block the noise from the wind which could be the only factor masking the noise from the turbine.

Thus trees planting as a wind break may actually make the noise from the wind turbine more discernible.

It must thus be recognized that wind farms are industrial projects to be located away from human dwellings.

"Wind Turbine Syndrome" has been discussed by environmentalists. It is alleged that people with inner ear problems, children with autism, people with epilepsy-type illnesses are more prone to be at risk from living in too close of a proximity to turbines.

Low-frequency vibrations in basements which cannot be insulated out were reported. In the UK and other countries people have been driven from their homes by the continuous, maddening sound of turbines.

Sleep deprivation was reported as a cause of diminished health.

Source	Distance (ft)	Sound Pressure Level dB(A)
Threshold of Pain	-	140
Jet engine	200	120
Freight Train	100	70
Vacuum Cleaner	10	70
Truck at 30 mph	300	65
Busy general office	-	60
Urban residential area	-	58-62
Large Transformer	200	55
Wind in trees	40	55
Normal suburban residential area	-	53-57
Light traffic	100	50
Average home	-	50
Wind turbine, 660 kW	650	47
Air rotor system, 400 kW	800	<40
Soft whisper	5	30
Quiet bedroom	-	20
Threshold of hearing	-	0

The aerodynamic design of the rotor blades tip can reduce the rotor blades generated sound.

Ailerons have been used at the rotor tips as well as tapering that eliminates the noise causing vortices, flutter and vibrations at the wind tips.

VISUAL AESTHETIC CONSIDERATIONS

There is no effective measurable way of assessing the visual effect of large wind farms, which is essentially subjective.

Experience has shown that good design fitting the visual background and the use of subdued off white neutral colors is popular.

The subjective nature of the question often means that extraneous factors come into play when acceptability is under discussion.

The identified public perceptions include:

1. Sentimental acceptance and preference to the post card Old Dutch design.
2. Preference of the three blade rotors design to the twin blades or single blade.
3. Favoritism to the cylindrical towers design compared with the truss design.
4. An acceptance to pay up to 25 percent more for the electricity generated from windmill compared with other sources.

Avedøre wind farm visual signature compared with coal fired power station, 5 kilometers from Copenhagen, Denmark.

Louis Guarnaccias painting of Nantucket Sound

DECOMMISSIONING ISSUES

The expected operational lifetime for wind machines is 20-30 years.

It can be assumed that the tower can remain longer in place with the rotor, transmission and electrical components replaced by more modern components.

These would constitute solid waste, even though some parts can be recyclable such as the copper wiring.

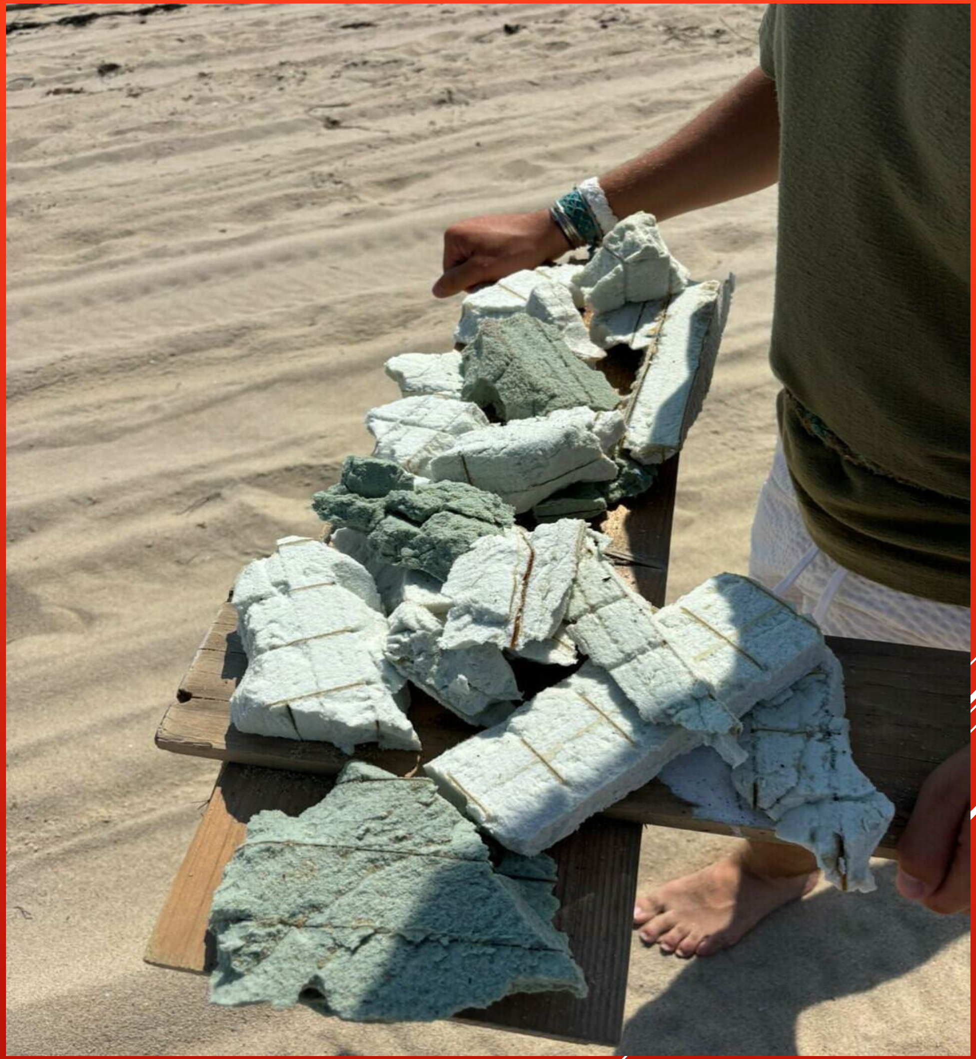
The tower itself is recyclable into steel. The rotor, steel and composites parts, concrete, asphalt in access roads would be treated as solid waste.


Turbine collapses, Germany

Source	Distance [ft]
Manufacturer’s recommendation	1,300
General Electric (GE) Energy Company	1.5 H, from property lines, H = turbine nacelle height
Cleveland, Ohio	1.1 H, from nearest property line, H = turbine nacelle height
Protection from ice shedding and blade throw	1,750
USA National Research Council	2,500
Shadow and strobe flicker effect	3,300-5,000
Germany	1 mile
France	1 mile
French Academy of Science	1.5 km, from residences
Canada, rural Manitoba	6,500
Riverside County, California, USA	2 miles
Michigan, USA	1,000
Wisconsin, USA	1,000
Illinois, USA	1,500
Ontario, Canada	550 m, residences, 120 m, roads, railway, property lot lines.
Conservation, planning and zoning commission, Woodford County, near Eureka, Illinois, USA	1,800 from residences

Offset distance of commercial and utility scale wind turbines from human structures. 1 mile = 1.609 kilometer = 5,280 feet

Judicious warning about ice shedding and limited access at a wind turbine site, USA.



Foam poly and perfluoroalkyl substances, perfluorooctanoic acid and perfluorooctane sulfonates from offshore wind turbine on beach

Wind Turbine oil spill

Wind turbine fire

Lightning fire, Texas

Wind damage, Oklahoma



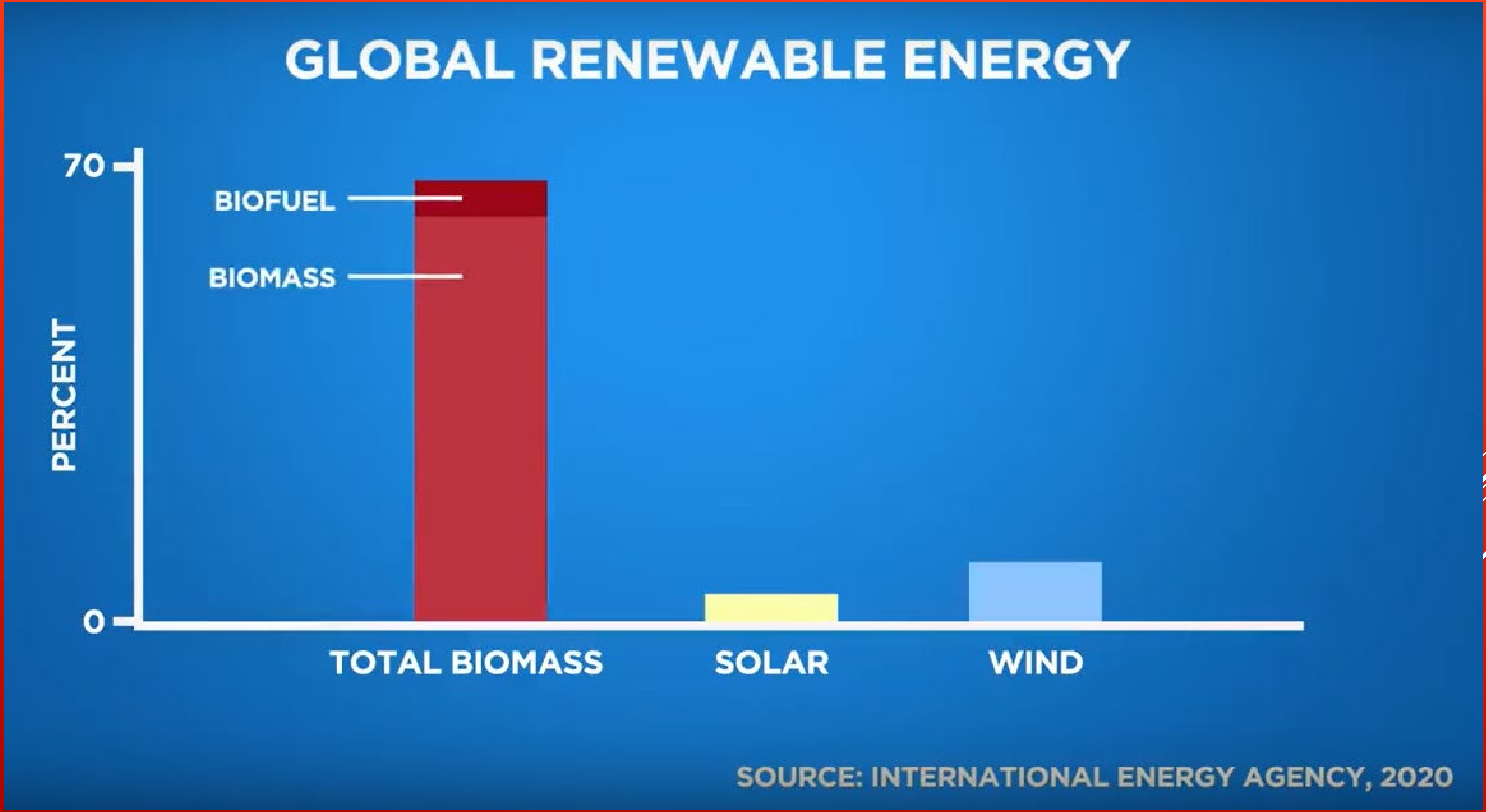






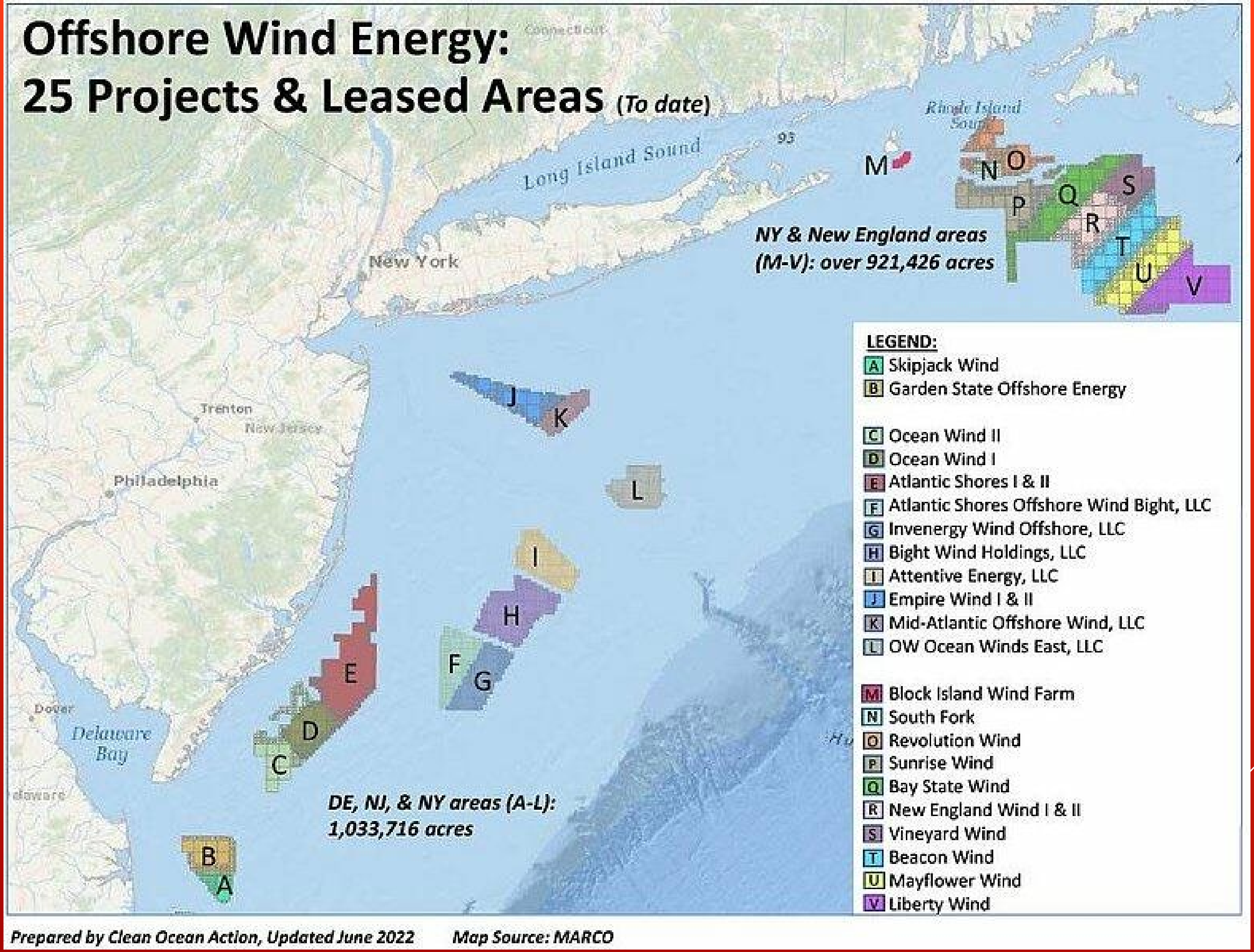

Tornado damage Greenfileld, Iowa, May 21, 2024

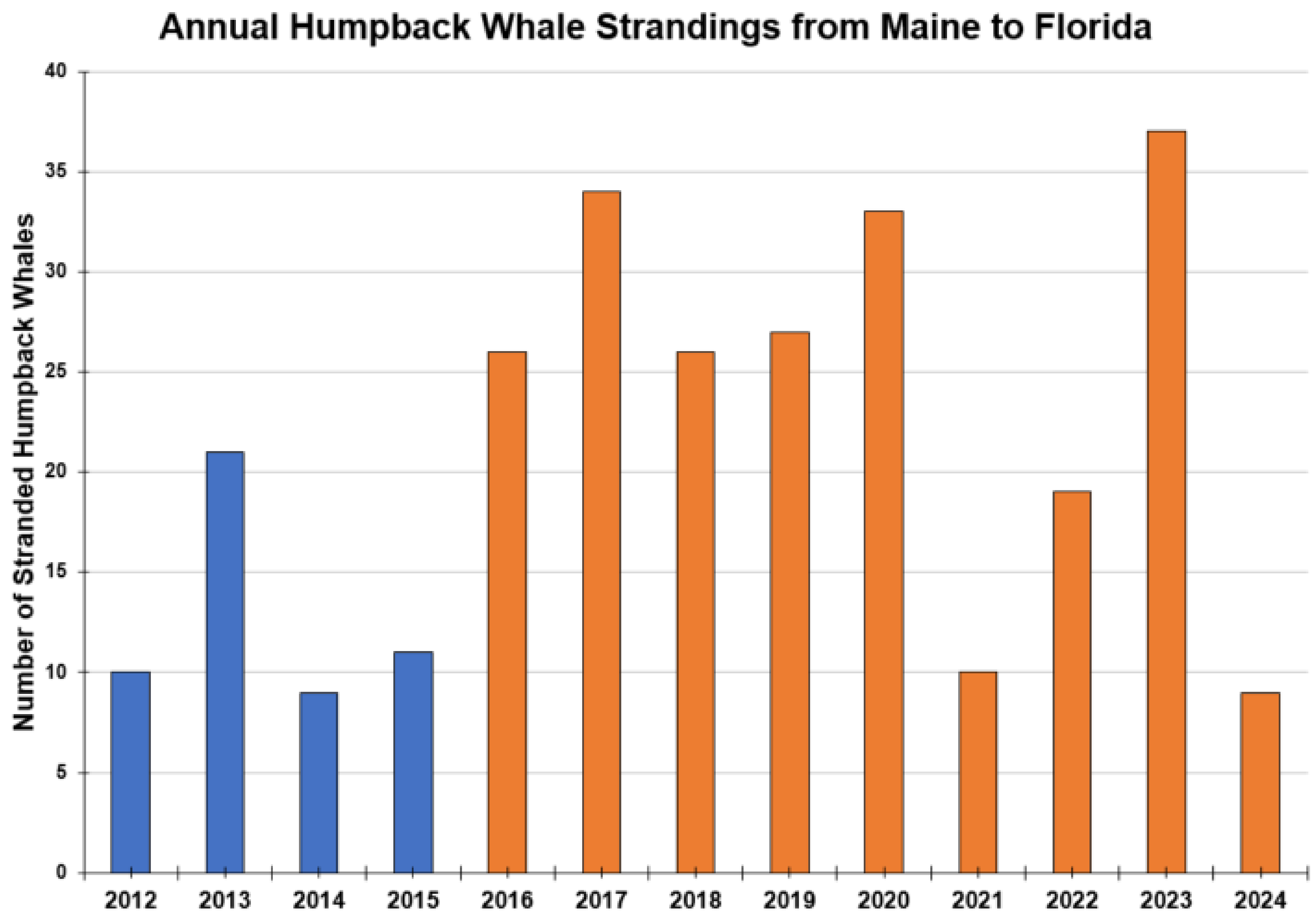
Rotor blades disposal by burial


GLOBAL RENEWABLE ENERGY
70
0
PERCENT
BIOFUEL
BIOMASS
TOTAL BIOMASS
SOLAR
WIND
SOURCE: INTERNATIONAL ENERGY AGENCY, 2020

Biomass exports to European Union, EU

Skara, Sweden 150 m wood tower turbine construction

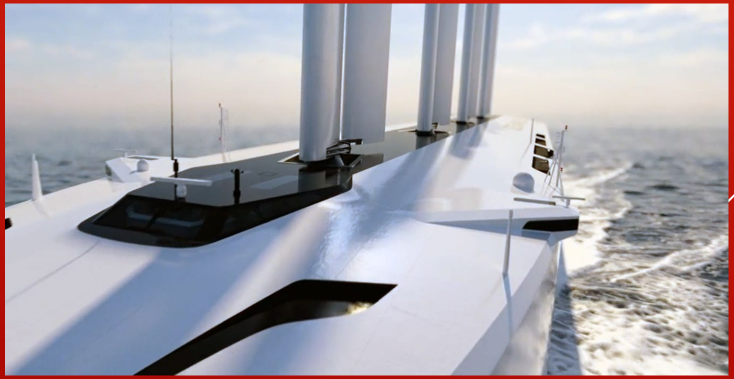

Offshore Wind Energy:
25 Projects & Leased Areas (To date)
Long Island Sound
New York
Trenton
Philadelphia
Delaware Bay
Dover
NY & New England areas (M-V): over 921,426 acres
DE, NJ, & NY areas (A-L): 1,033,716 acres
M
N
O
P
Q
R
S
T
U
V
J
K
L
I
H
F
G
E
D
C
B
A
LEGEND:
A Skipjack Wind
B Garden State Offshore Energy
C Ocean Wind II
D Ocean Wind I
E Atlantic Shores I & II
F Atlantic Shores Offshore Wind Bight, LLC
G Invenergy Wind Offshore, LLC
H Bight Wind Holdings, LLC
I Attentive Energy, LLC
J Empire Wind I & II
K Mid-Atlantic Offshore Wind, LLC
L OW Ocean Winds East, LLC
M Block Island Wind Farm
N South Fork
O Revolution Wind
P Sunrise Wind
Q Bay State Wind
R New England Wind I & II
S Vineyard Wind
T Beacon Wind
U Mayflower Wind
V Liberty Wind
Prepared by Clean Ocean Action, Updated June 2022
Map Source: MARCO



Graph of humpback whale strandings from Maine to Florida


OCEANBIRD
OCEANBIRD

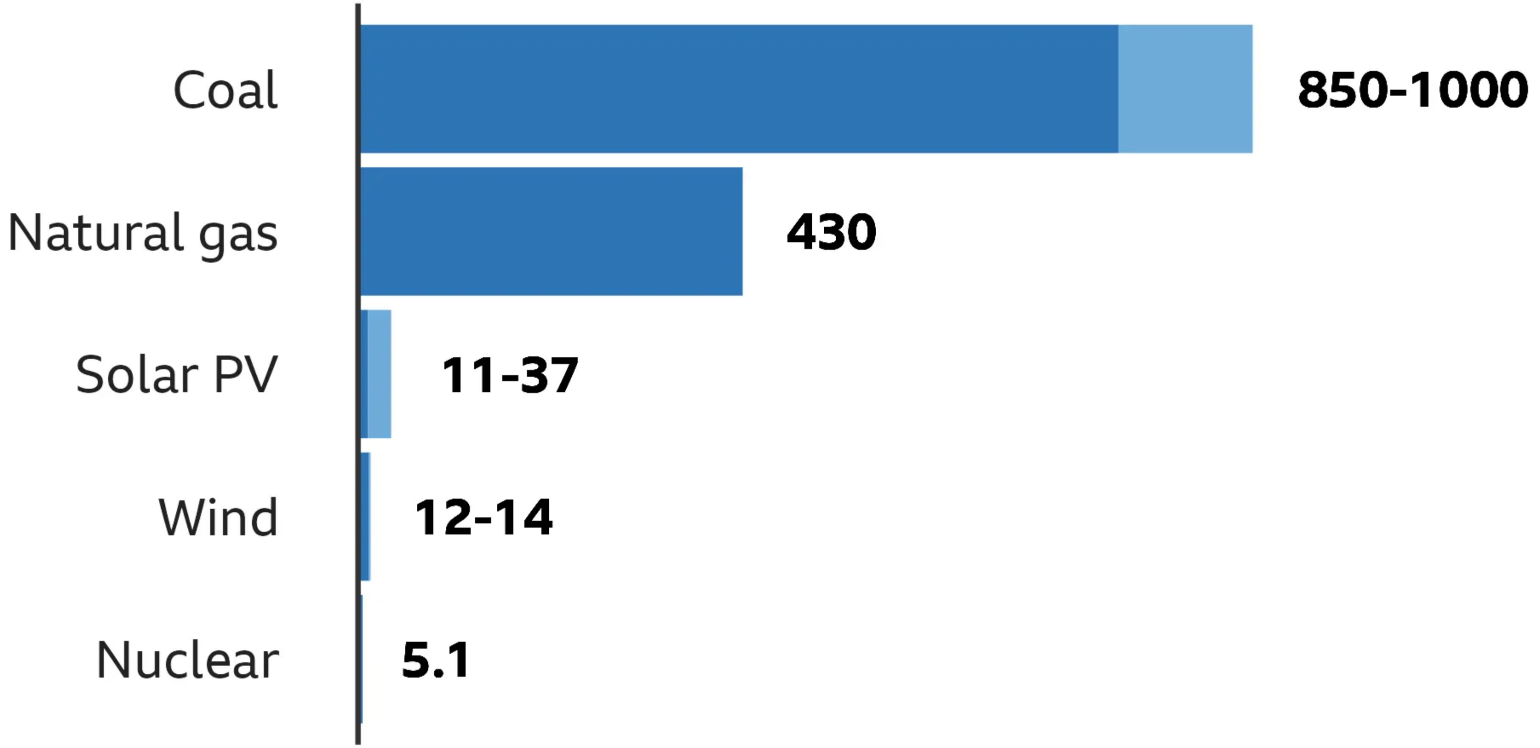

WALLENIUS WILHELMSEN




Aeromine

Carbon footprint of electricity sources

Average emissions, grams of CO_2 equivalent per kilowatt hour, in Europe in 2020



Ranges shown where there are different figures for different power sources, for example offshore and onshore wind. Solar PV stands for solar photovoltaics. Data from the European Union and the UK.

Source: UN Economic Commission for Europe (2022)

The Levelized Cost Of Electricity (LCOE) in electrical energy production can be defined as the present value of the price of the produced electrical energy in cents / kW.hr, considering the economical life of the plant and the costs incurred in the construction, operation and maintenance, and the fuel costs.

$$LCOE = \frac{\left[\left(\sum_{t=-N}^{t=-1} \frac{I_t}{(1+i)^t}\right)\right]_{construction} + \left(\sum_{t=0}^{t=n-1} \frac{(F_t + O\&M_t - D_t + T_t)}{(1+i)^t}\right)_{production}}{\left(\sum_{t=0}^{t=n-1} \frac{G_t}{(1+i)^t}\right)_{production}}$$

The fuel cost F_t is zero in wind power generation, and the wind turbine is factory-assembled and directly delivered to the wind park site, resulting in a short construction period t in the range [-N, -1].

$$LCOE_{wind} = \frac{\sum_{t=1}^{t=n} \frac{(I_t + O\&M_t - PTC_t - D_t + T_t + R_t)}{(1+i)^t}}{IF \sum_{t=1}^{t=n} P_t}$$

Milestone

Utility MidAmerican Energy in Des Moines, Iowa on Sept. 25, 2023, reached a new milestone – delivering 100% renewable energy to serve its Iowa customers' electricity.

In 2022, MidAmerican's wind fleet of 3,700 turbines generated more than 27,000 gigawatt-hours GWhr of electrical energy over the 12-month period, exceeding the total annual usage of the company's Iowa customers.

MidAmerican's about 740,000 customers did not run 100% on wind, daily excess wind was sold into the grid, shortages were covered by coal and natural gas.

For the year, the turbines did produce more energy than the 740,000 customers used.

The retail MidAmerican customer rate, taxes/fees/etc, works out to ~11 cents per kWh which puts them in the top 10 lowest USA rates.

DISCUSSION

No energy source is free of environmental effects, even solar and wind energy.

As the renewable energy sources make use of energy in forms that are diffuse, larger structures, or greater land use, tend to be required and attention may be focused on the visual effects.

In the case of wind energy, there is also discussion of the effects of noise and possible disturbance to wildlife, especially birds and bats.

It must be remembered, however, that one of the main reasons for developing the renewable sources is an environmental one: to reduce emissions of greenhouse gases.

The attractiveness of wind as a source of electricity which produces minimal quantities of greenhouse gases is generating ambitious targets for wind energy in many parts of the world.


21.77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