Introduction to Lecture Course on Wind Energy Systems

Moritz Diehl and Nick Harder

Systems Control and Optimization Laboratory
Department of Microsystems Engineering (IMTEK) and Department of Mathematics
University of Freiburg (Germany)

Freiburg, May 12, 2020

A sunny morning in Freiburg …

A sunny morning in Freiburg …

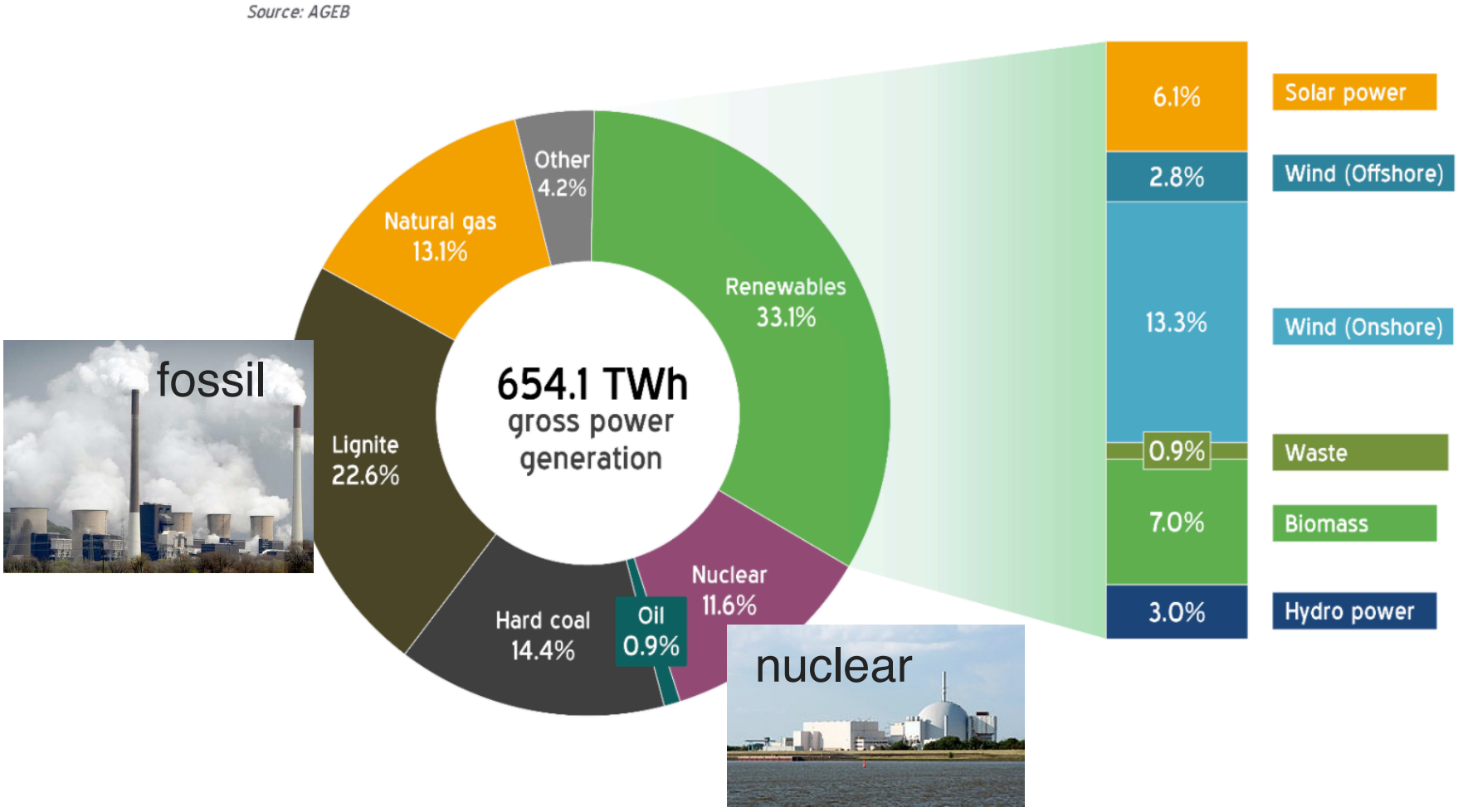
1) Even on a sunny day, there is some wind up in the hills.

2) There is still a lot of sky above the turbine.

2022: The last German nuclear power plant stops operation

Neckarwestheim

Today, 66% of Germany's electricity is of nuclear or fossil origin



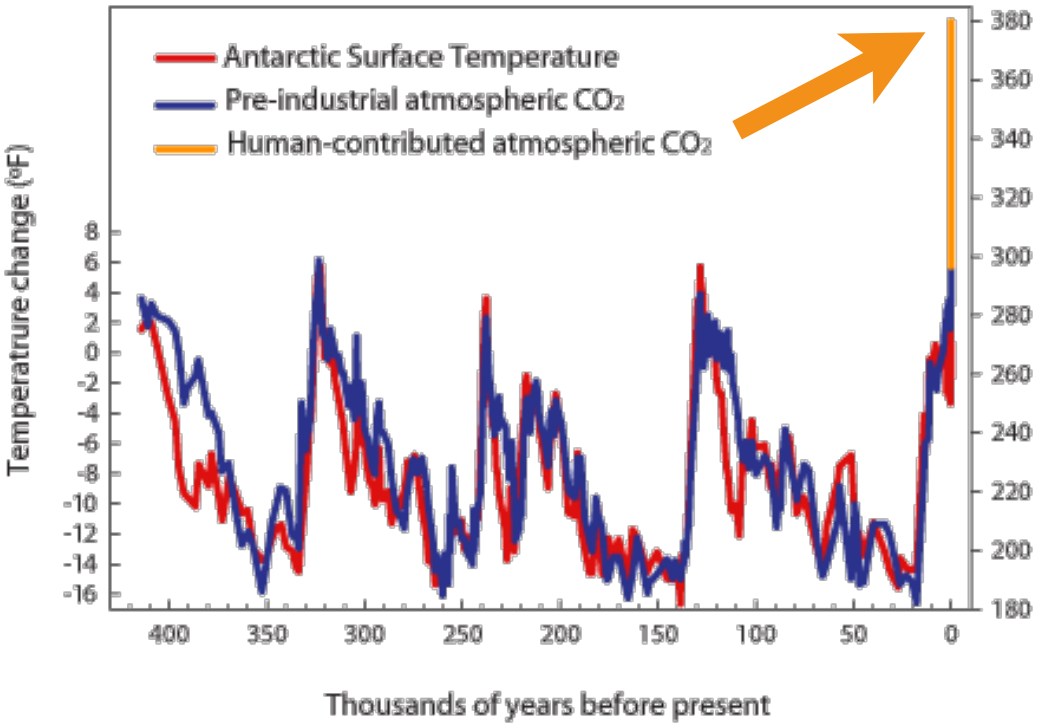
(https://energytransition.org/2018/01/german-energy-consumption-2017/
also see: https://www.energy-charts.de/energy_pie.htm)

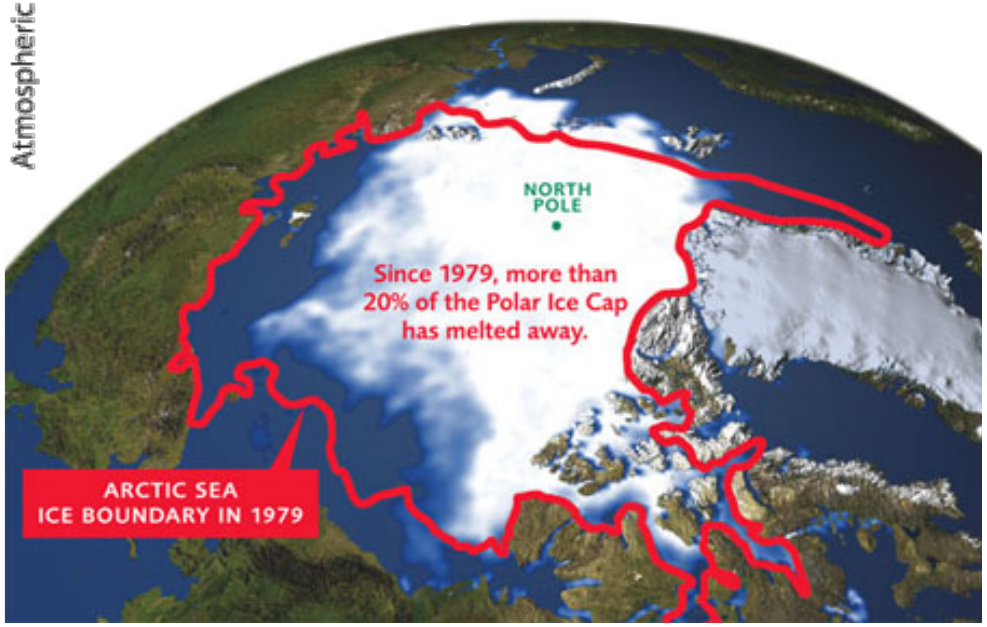
Do we need to get back to coal ?

Coal plant “Datteln 4” starts operation in June 2020 [DLF/picture-alliance].
Worldwide, each year about 40 new coal power plants start operation…

There is already more CO_2 in the atmosphere than anytime since half a million years

CO_2 increases global temperatures and melts arctic ice





Carbon Dioxide and Temperatures over last 500 000 years, and melting ice caps [C2ES / gws]

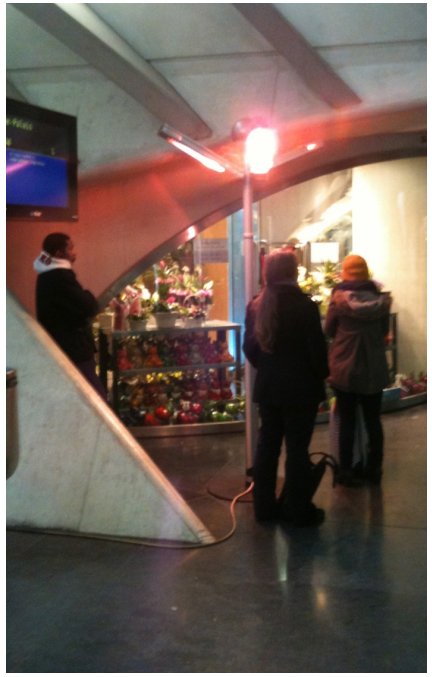
Our personal energy consumption: 5 kW

- a typical European needs 5 kW
(1 kW electricity + transport + heating …)

- this equals 120 kWh, or 12 litres of petrol, per day

- one return flight from Europe to China consumes about 1200 litres of kerosene per person (~100 days)

[MacKay 2009. wikipedia]



5 kW: one large electric heater, switched on from birth to death

Sustainable Energy Sources

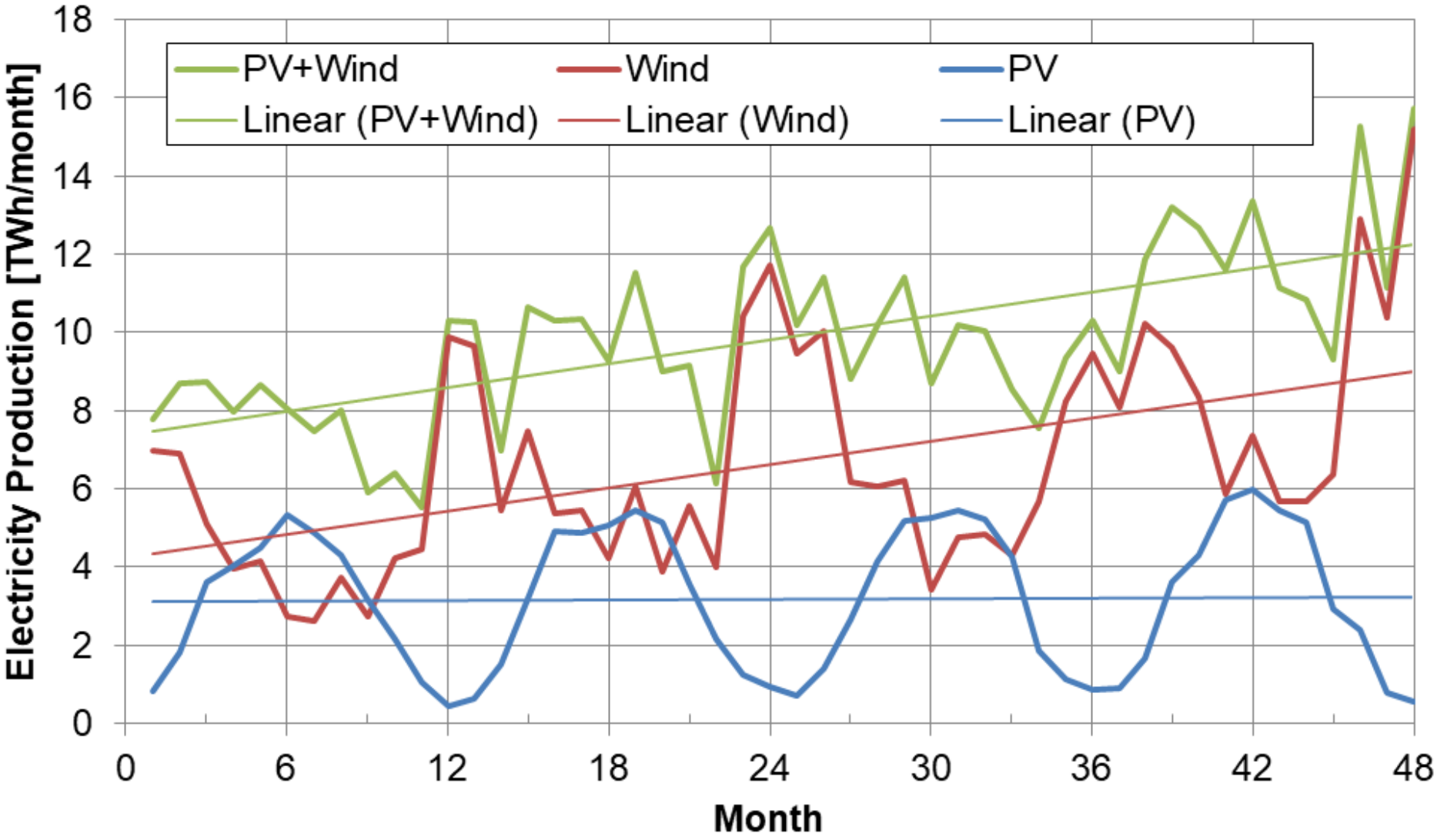
Solar and wind energy are abundant and have the potential to cover all human energy needs

E.g. 125 m^2 solar cells per person, or 10% of the Sahara desert for humanity.
Or 10% of the Atlantic covered with offshore wind parks.

Two main problems of both:

- not available at all times
- low power densities

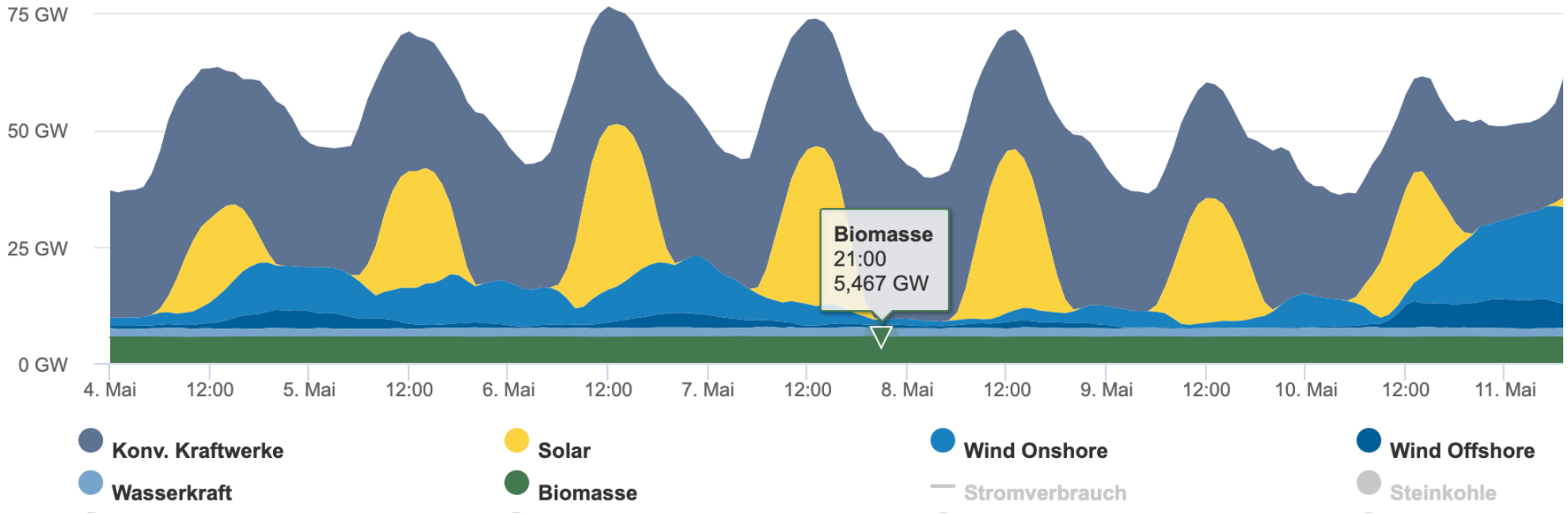
Wind and Solar Power are complementary (nice!)



Monthly production of wind and photovoltaic power in Germany, 2014-2017

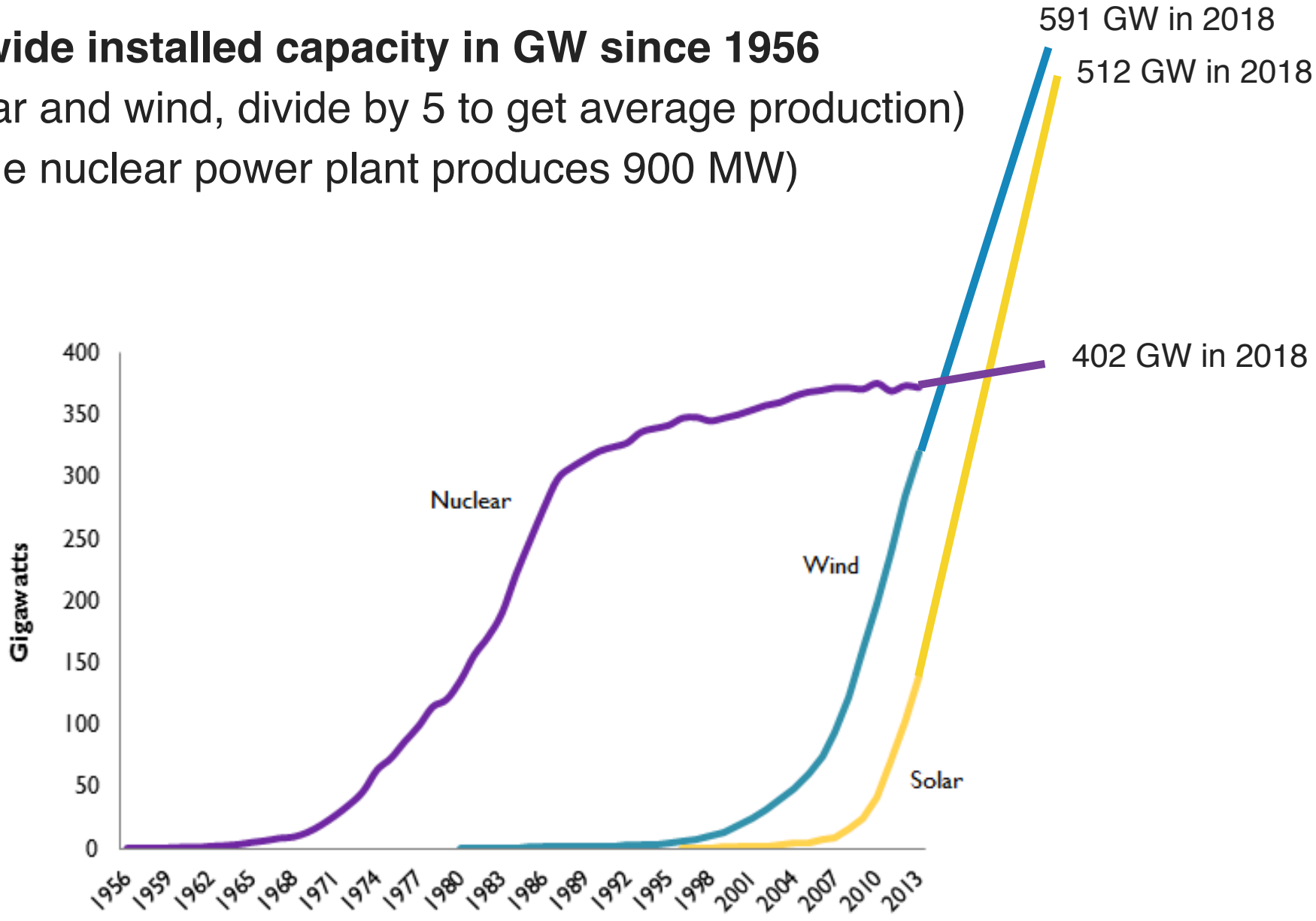
[Wirth, Fraunhofer ISE, 2020]

Electricity production in Germany last week [Agora]



Worldwide, wind and solar power grow strongly and provide already as much electricity as 250 nuclear power plants

Worldwide installed capacity in GW since 1956
(for solar and wind, divide by 5 to get average production)
(average nuclear power plant produces 900 MW)



Sources: IAEA; Ochs and Ray; BP; Flavin

Installed Capacity and Capacity Factor of Energy Systems

Installed Capacity:
maximum power that can be delivered [Megawatt]

Capacity Factor:
average yearly production divided by installed capacity

Example:
A wind turbine of 5 MW installed capacity delivers 8760000 kWh of electricity in one year. What is its capacity factor?

1 year = 8760 hours, so average yearly production is
8760000 kWh / 8760 h = 1000 kW = 1 MW.

Thus, its capacity factor is 1 MW / 5 MW = 0.2 = 20 % (a typical value)

What is needed for 5 MW installed power ?

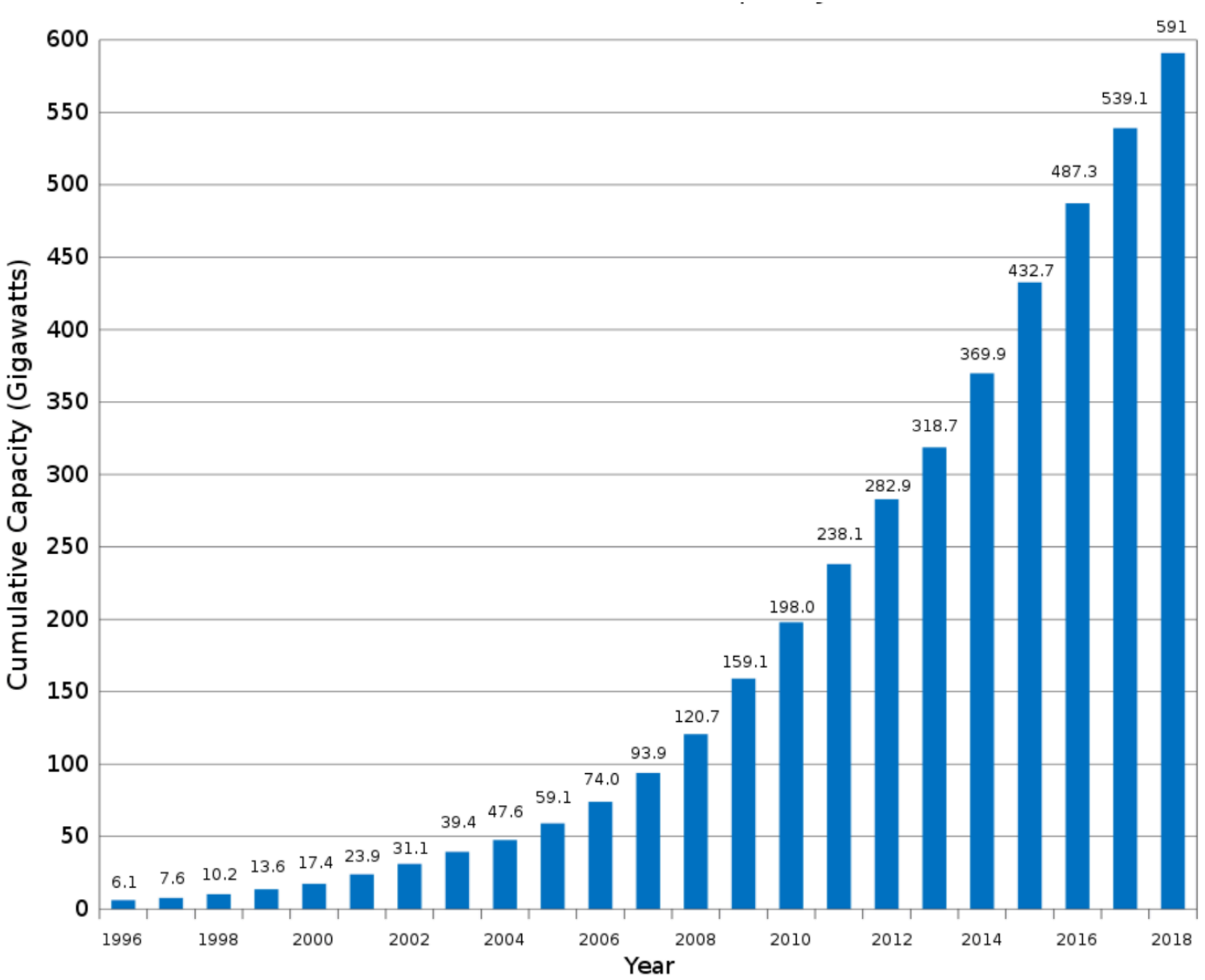
Solar in Southern Europe: area of 125 m x 200 m

What is needed for 5 MW installed power ?

Solar in Southern Europe: area of 125 m x 200 m

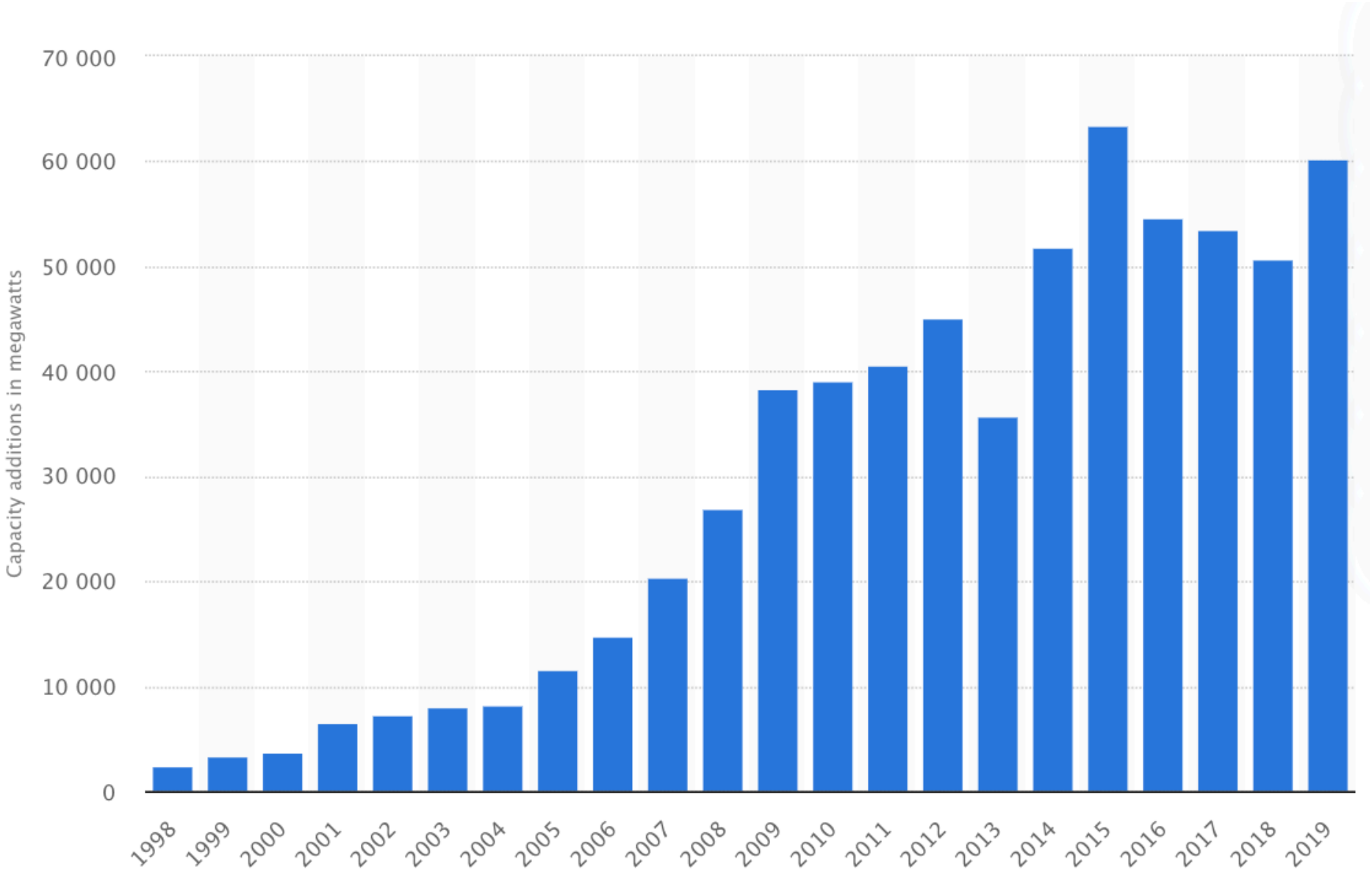
Wind in North Sea:
turbine of 150 m height

Worldwide installed wind power capacity 1996-2018

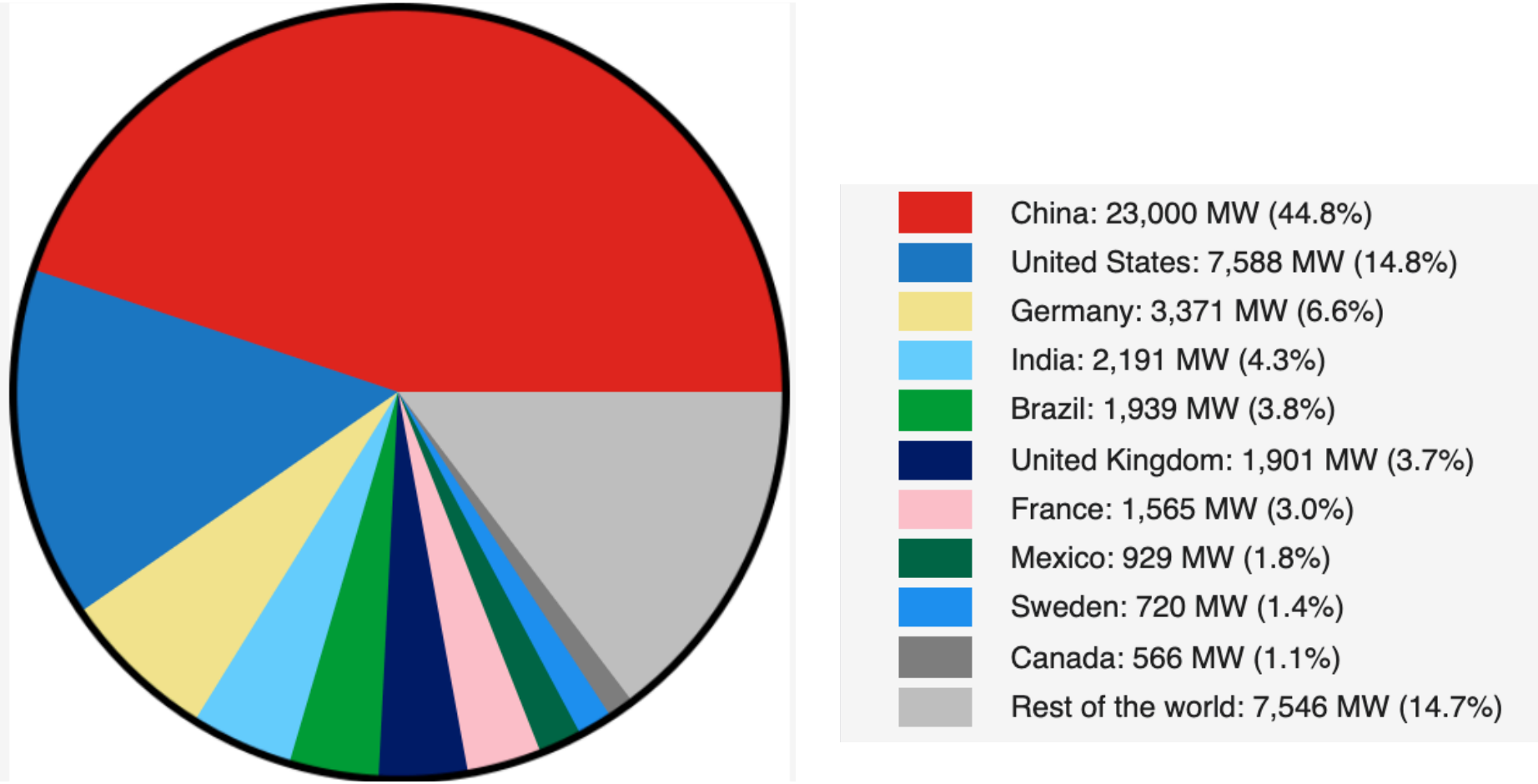


32x more since start of the millennium, 6% growth last year [GWEC]

Worldwide added wind power capacity 1998-2019



Added wind capacity in 2018 by country



[GWEC]

Wind Energy Systems Lecture Overview

Contents:

1. Introduction
2. The Wind Resource
3. Aerodynamics of Wind Turbines
4. Mechanics and Dynamics of Wind Turbines
5. Control of Wind Turbines
6. Alternative Concepts

Organization:

- 2 x 2h slots per week (via zoom)
- Slots: Tuesday and Wednesday from 12:30-14:00
- blackboard lectures, some slides (recordings uploaded the same day)
- interactive exercise sessions every 2nd week (same slot, same link)
- preliminary lecture manuscript available
- all info and contents on public webpage: www.syscop.de/teaching

Introduction of Teachers and Audience

- Moritz Diehl
  - studied physics and mathematics in Heidelberg (D) and Cambridge (UK) in 1993-1999
  - PhD in numerical methods for optimal control in Heidelberg in 2001
  - professor for optimization in engineering at KU Leuven (B) in 2006-2013
  - since 2013 head of Systems Control and Optimisation Laboratory at IMTEK, Freiburg
  - interested in modelling and control of sustainable energy systems, in particular (airborne) wind energy

- Nick Harder
  - studied sustainable systems engineering in Freiburg 2017-2019
  - works towards PhD at INATECH with Anke Weidlich
  - followed Wind Energy Systems course in 2018

- Audience: Students from different master programs
  - Sustainable Systems Engineering (SSE)
  - Renewable Energy Engineering and Management (REM)
  - Embedded Systems Engineering (ESE)
  - Microsystems Engineering (MSE/MST)
  - Computer Science
  - Other ?

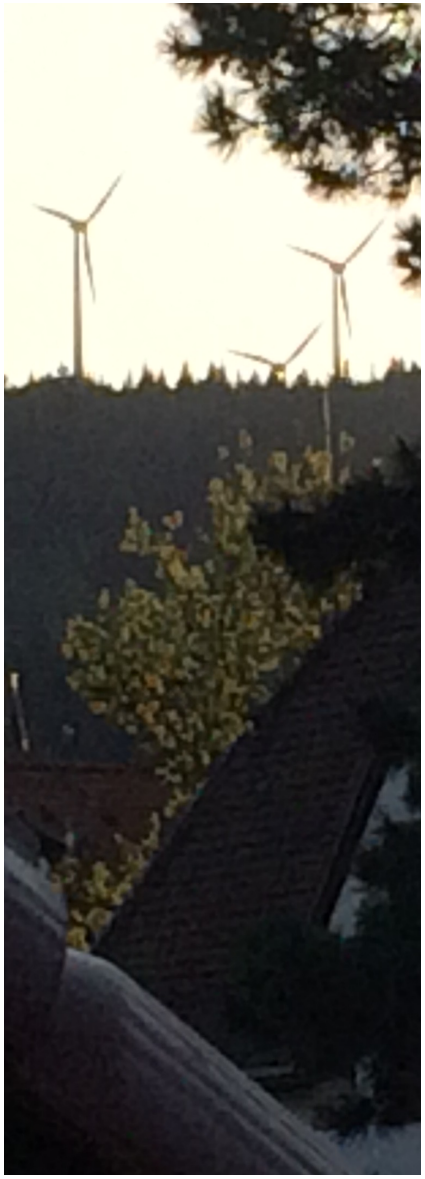
Literature

"Wind Energy Handbook"
by T. Burton, N. Jenkins, D. Sharpe, E. Bossanyi,
2nd edition, Wiley, 2011

“Wind Energy Explained - Theory, Design and Application”
by J. Manwell, J. McGowan, A. Rogers,
2nd editions, Wiley, 2009

“Airborne Wind Energy”
by U. Ahrens, M. Diehl, R. Schmehl (eds.)
Springer, 2013

A Quiz Question



The the five wind turbines on Freiburg's ground are located on Rosskopf and Schauinsland, have each a height of 133 m and a nominal capacity of 1.8 MW.

They deliver together 10.2 GWh per year.

What is their capacity factor?