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zee
Zentrum für Erneuerbare Energien
Centre for Renewable Energy

The Centre for Renewable Energy

Prof. Dr. Moritz Diehl
Managing Director of the Centre for Renewable Energy (ZEE)
& Director of the Department of Microsystems Engineering
University of Freiburg, Germany

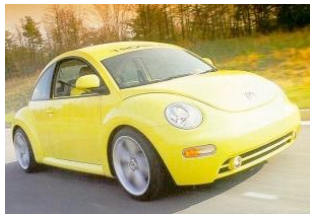
ZEE Miniworkshop on Renewable Energy Research in Laos and Germany
July 27, 2026



Our personal energy consumption: 5 kW (3 kW)







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

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



3 kW: two strong hair dryers, switched on from birth to death

Future electrification can be expected to reduce the energy demand per person to **3 kW** (all electric)

How many solar modules are needed to generate 3 kW?



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My single PV module of 400 W peak power delivers on average, over the year, about 50 W.
It costs 100 EUR and weighs 20 kg.

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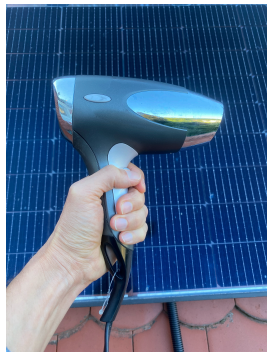









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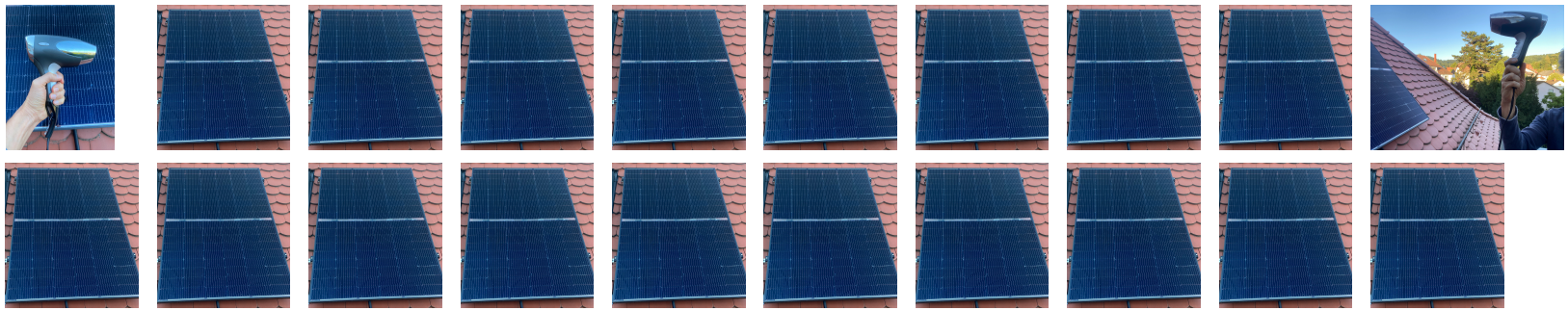

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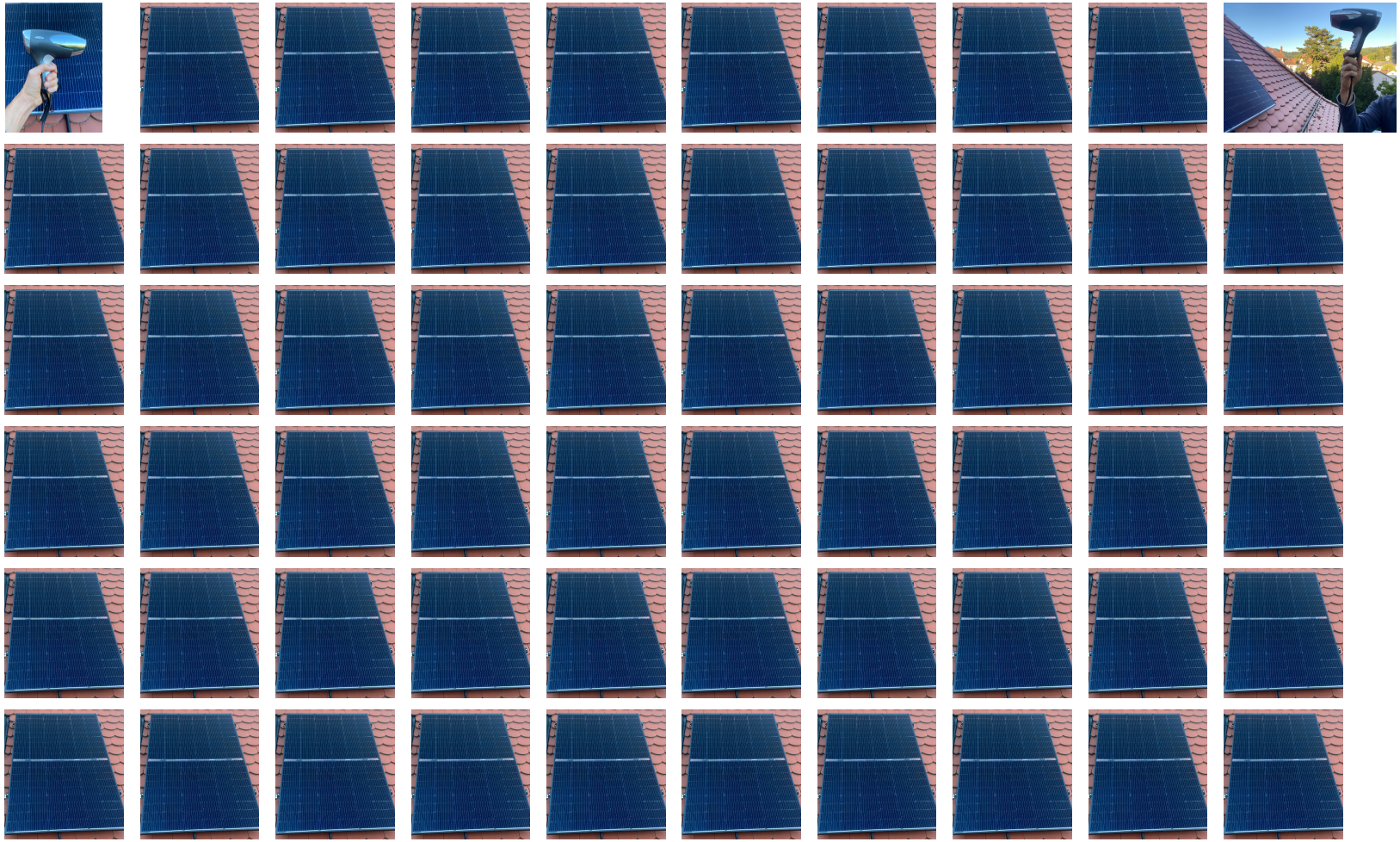


60 solar modules. They weigh 1.2 tons. And they cost 6 kEUR (complete installation 18 kEUR).

Comparison of different primary energy sources:
3 kW electricity per person, continuously provided over 20 years



solar (60 mod.):

- 1.2 tons
- 6-18 kEUR

- ground area
  approx. 300 m^2

(renewables without storage costs)

Comparison of different primary energy sources:
3 kW electricity per person, continuously provided over 20 years





solar (60 mod.):
- 1.2 tons
- 6-18 kEUR

- ground area approx. 300 m²

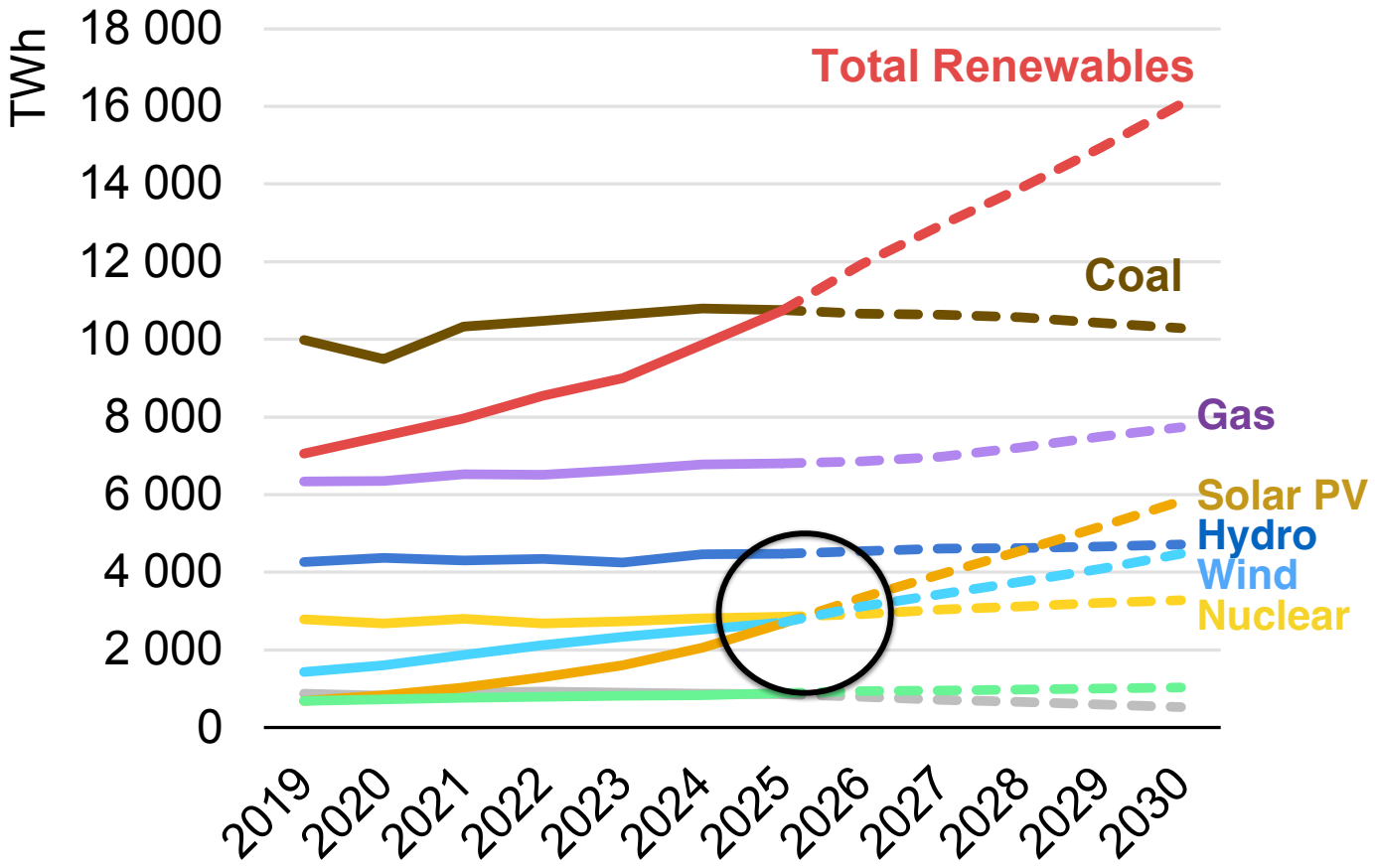
oil:
- 135 tons
- 135 kEUR

Solar electricity is already much cheaper than oil (at market prices).

(renewables without storage costs)

Solar photovoltaics grows spectacularly worldwide

This year, solar will overtake wind and nuclear power (by yearly production).
In 2028 it will also overtake hydro power.



[IEA report “Electricity 2026”]



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The ZEE is an interdisciplinary university centre (founded in 2007 by seven faculties) with a current focus on internal exchange, international cooperation and science communication.

Its aim is to bring together researchers in and around the University of Freiburg who are interested in the topic of renewable energies and to develop interdisciplinary research ideas and joint projects.

The ZEE has four partner institutions:

- Fraunhofer Institute for Solar Energy Systems
- Offenburg University of Applied Sciences
- Forest Research Institute, and
- Öko-Institut e.V.

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Active members:

Prof. Dr. Dierk Bauknecht
Prof. Dr. Andreas Bett
Prof. Dr. Joschka Bödecker
Prof. Dr. Oana Cojocaru-Mirédin
Prof. Dr. Moritz Diehl
Prof. Dr. Sonia Dsoke
Prof. Dr. Stefan Glunz
Prof. Dr. Marten Hillebrand
Prof. Dr. Andrea Kiesel
Prof. Dr. Alexandra-Maria Klein
Prof. Dr. Holger Neuhaus
Prof. Dr. Michael Pregernig
Prof. Dr. Bastian Rapp
Prof. Dr. Dirk Schindler
Prof. Dr. Michael Schmidt
Prof. Dr. Anke Weidlich
Prof. Dr. Markus Weiler
Prof. Dr. Christof Wittwer
Prof. Dr. Peter Woias
Prof. Dr. Cathrin Zengerling

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Current Board of Directors (BoD) and Management Team of ZEE



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(Director)



Prof. Dr. Anke Weidlich
(Director)



Prof. Dr. Moritz Diehl
(Managing Director)



Ida Malou Bechmann
(ZEE Administrator)



Prof. Dr. Stefan Glunz
(Permanent Guest of BoD)



Prof. Dr. Dirk Schindler
(Permanent Guest of BoD)

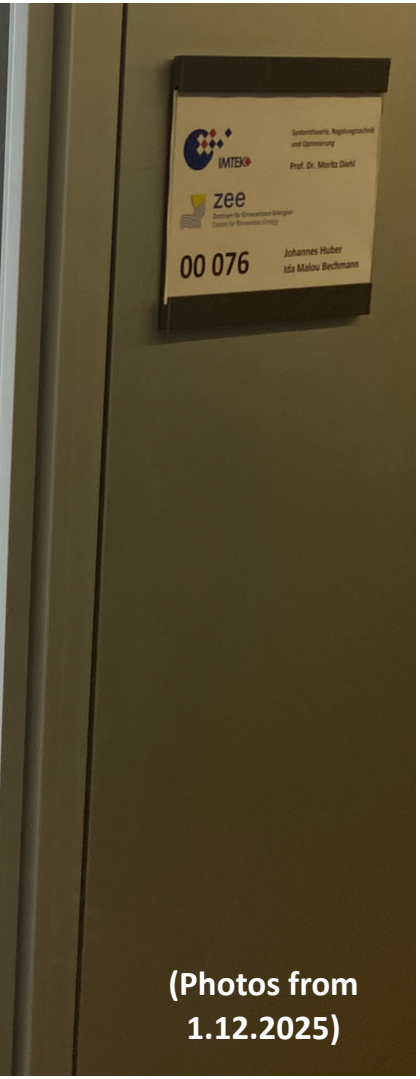


Christine Paasch
(Financial Administrator)

Administration of the ZEE







ZEE Activities







Renewable Energy Day Freiburg

- ➢ university wide event with about 200 participants
- ➢ poster presentations from ZEE members from different faculties of the university
- ➢ open to the public inside and outside the university



ZEE Assembly (once per year)

- ➢ member presentations on current research
- ➢ discussions on plans and collaborations





International ZEE Workshops (irregularly)

- ➢ e.g. Renewable Energy Research Workshop Korea-Germany
- ➢ e.g. ZEE Workshop „Prospects for Canada–Germany Energy Collaboration“

ZEE Discussions (small evening discussions)

- ➢ e.g. “ZEE Discussion on Global Carbon Pricing: Taxes or Certificates ?” (on Jan. 20, 2026)

Yearly Flagship Event since 2023:

Renewable Energy Day Freiburg





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Renewable Energy Day Freiburg 2025



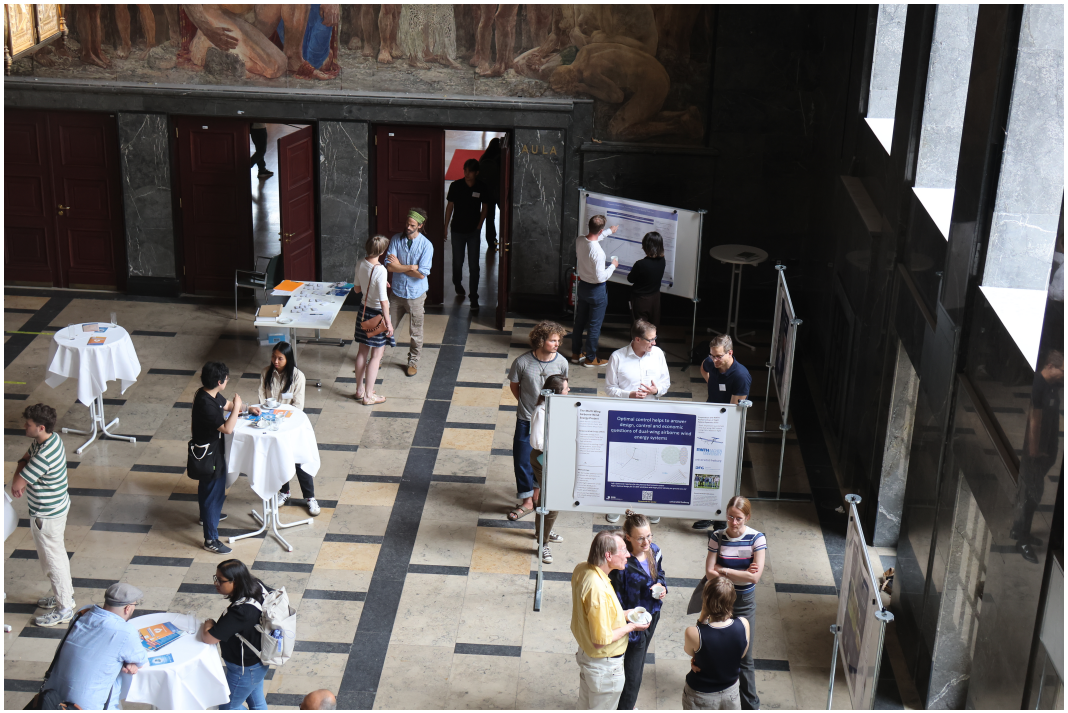
Renewable Energy Day Freiburg 2026

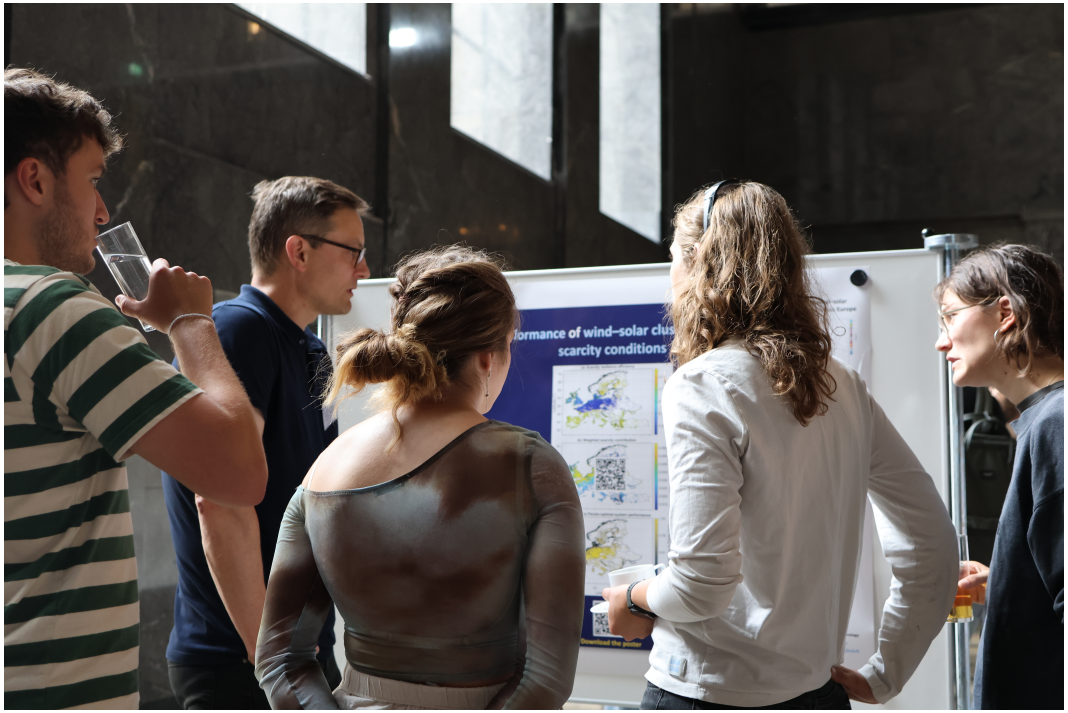






Renewable Energy Day Freiburg 2026





Renewable Energy Research Workshop (Freiburg / Republic of Korea) 19. August 2025

visit by south Korean delegation at ZEE

- Korea University
- Kyungnam College of Information and Technology

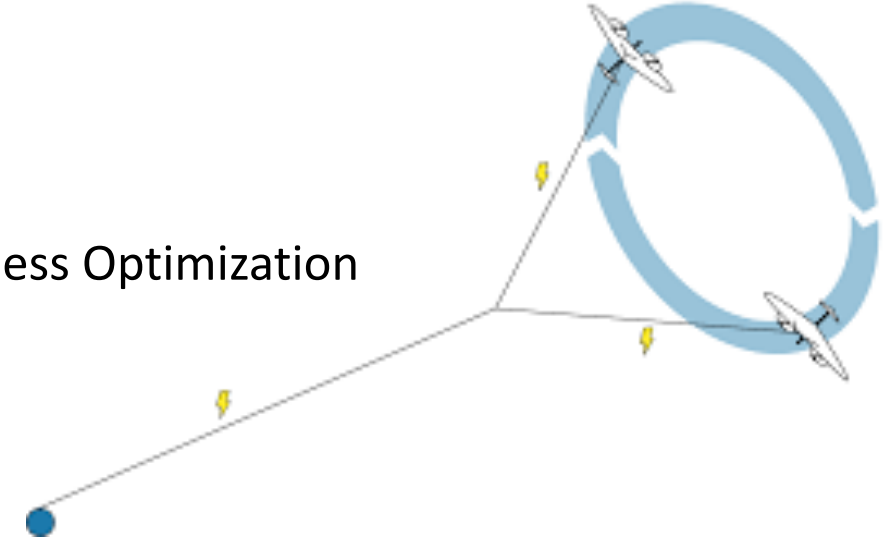






Currently ZEE runs two research projects

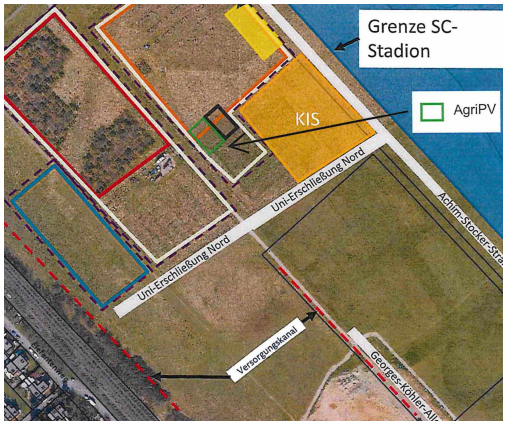
- MAWERO - Multi-wing Airborne Wind Energy Robustness Optimization



- Agri-photovoltaics (Agri-PV) Project

Fraunhofer ISE

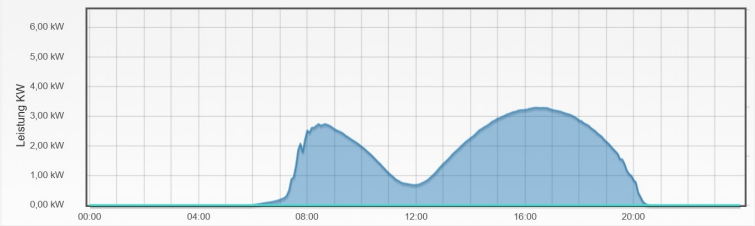




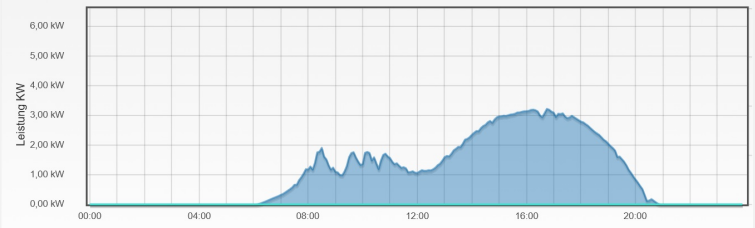
ZEE Agrivoltaics Demonstrator Electricity Production Profiles

Due to south-west facing vertical modules, strawberries get most shade on afternoons, alleviating heat stresses, and electricity production profile avoids the peak at noon and aligns well with daily consumption patterns.

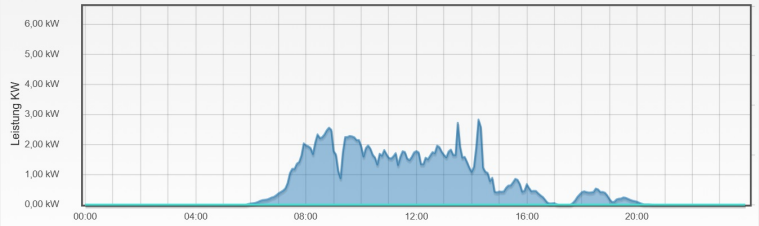
Friday 29.5. (sunny all day)



Saturday 30.5. (sunny afternoon)



Sunday 31.5. (rainy afternoon)





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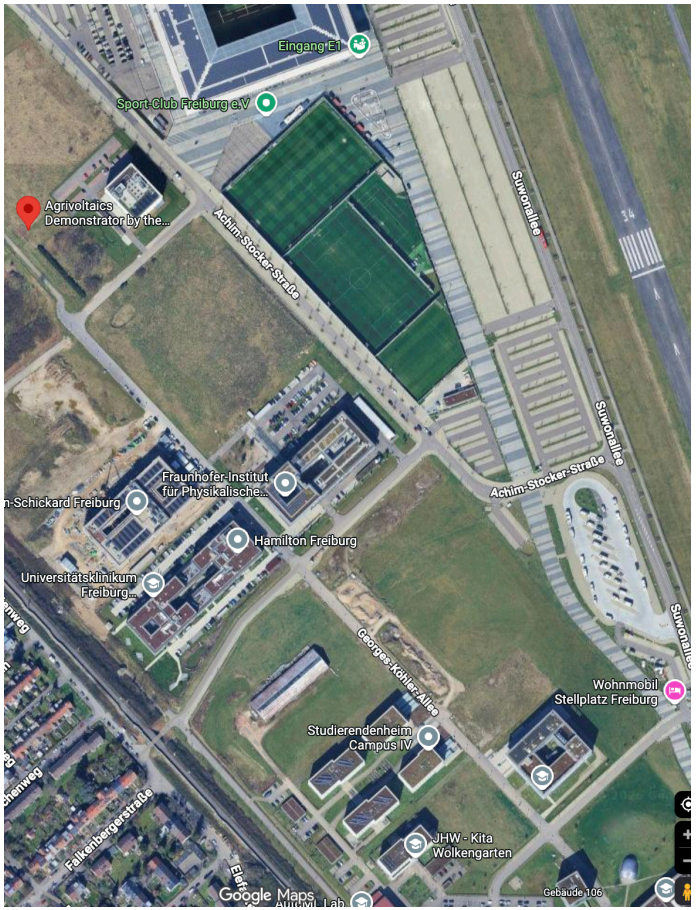
Eingang E1
Sport-Club Freiburg e.V
Agrivoltaics Demonstrator by the...
Achim-Stocker-Straße
Suwonallee
Fraunhofer-Institut für Physikalische...
Hamilton Freiburg
Universitätsklinikum Freiburg...
Georges-Köhler-Allee
Wohnmobil Stellplatz Freiburg
Studierendenheim Campus IV
JHW - Kita Wolkengarten
Falkenbergerstraße
Google Maps
Gebäude 106

Three Remarks

1) The solar age has started.

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2) The fossil age will end if governments agree on a globally harmonised, but nationally collected carbon tax.

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2) The fossil age will end if governments agree on a globally harmonised, but nationally collected carbon tax.

- stored chemical energy is valuable (e.g. for winter and transport)
- discharging fossil fuel reservoirs is cheap (1 cent/kWh for coal, gas, petrol)
- renewable storages cannot become competitive without a carbon tax
- a globally harmonized, but nationally collected carbon tax is the only politically feasible way to reduce global CO_2 emissions

1) The solar age has started.

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1) The solar age has started.

2) The fossil age will end if governments agree on a globally harmonised, but nationally collected carbon tax.

3) All non-solar electricity will only be valuable when the sun does not shine.

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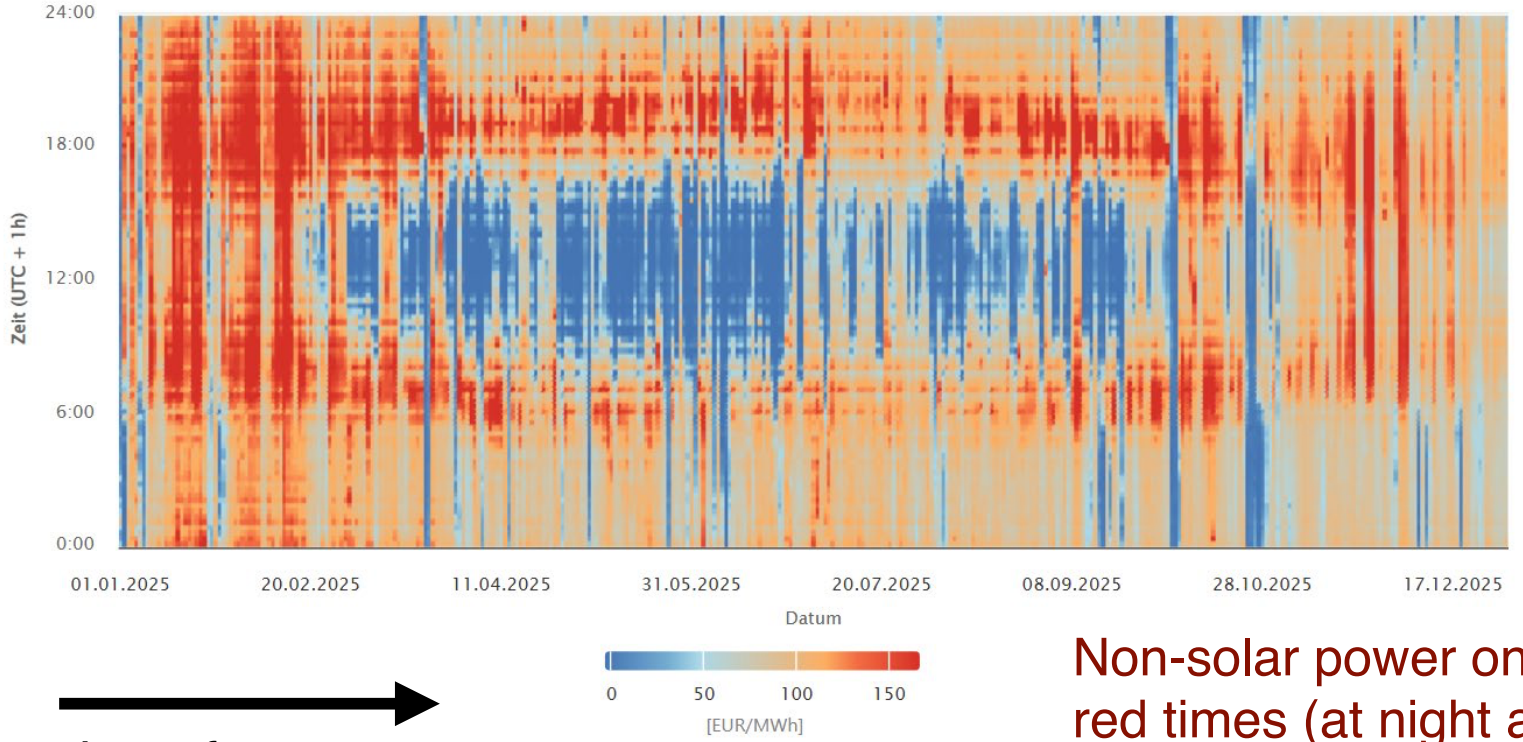
time
of day
(0:00-
24:00)



Electriciy Prices in Germany in 2025
[Energy Charts]

day of year
(1. Jan - 31. Dec)

Non-solar power only needed in red times (at night and in winter).

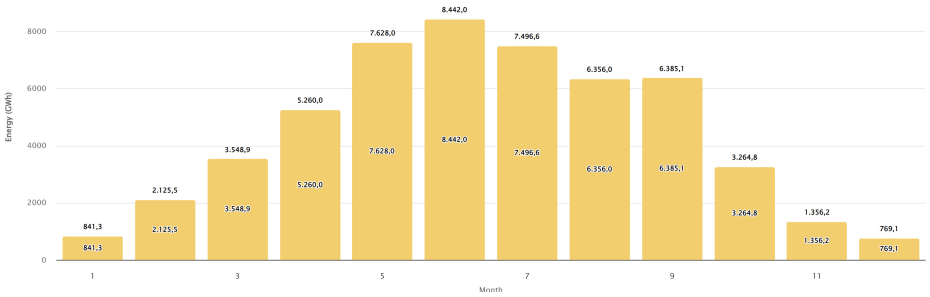
3) All non-solar electricity will only be valuable when the sun does not shine.

A happy coincidence (in Europe)

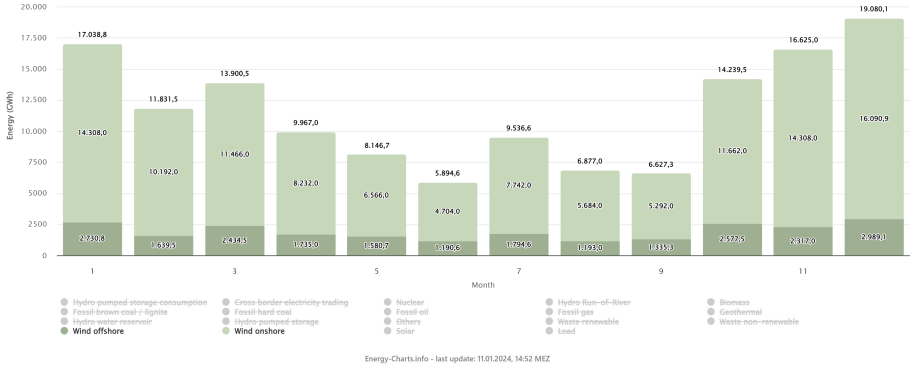
Solar power generation in January 10x smaller than in June

Happy coincidence: wind power in Germany is 3 times stronger in winter than in summer

Monthly solar power generation
Year 2023



Monthly wind power generation onshore and offshore
Year 2023



Source: https://www.energy-charts.info/charts/energy/chart.htm?l=en&c=DE&month=-1&stacking=stacked_grouped&year=2023&partsum=1

*Data on public power generation

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3 kW electricity per person, continuously provided over 20 years





solar (60 mod.):
- 1.2 tons
- 6-18 kEUR

- ground area approx. 300 m^2

oil:
- 135 tons
- 135 kEUR

(renewables without storage costs)

New E-138 wind turbine Freiburg-Holzschlägermatte

(student visit with Tim Schober, Ökostromgruppe, on July 10, 2025)



Hub height 160 m

ca. 1 MW mean power (nominal 4,2 MW)
ca. 8 MEUR investment sum incl. inkl. erection
Weight approx. 4000 t:

- 60 t rotor blades
- 200 t nacelle
- 640 t steel tower
- 3000 t concrete foundation

Turbine supplies 333 Personen each with 3 kW, i.e.

- 24000 EUR investment per person
- 180 kg rotor blades, 12 t total weight per person

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oil:
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- 135 kEUR



conventional wind
(0.3% of wind turbine):
- 180 kg blades
- 1.8 t steel
- 10 tons concrete
- 24 kEUR

- wind farm area approx. 1500 m²

(renewables without storage costs)