A·S·E Applied Solar Expertise

60% solar, 20% wind and 20% all others (hydro, bioenergy, nuclear, fossil et al.) to power the future global energy needs

Dr. Winfried Hoffmann

7th November, 2022,
GCRNRE, Valencia

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Importance of energy efficiency

Global population development & energy justice

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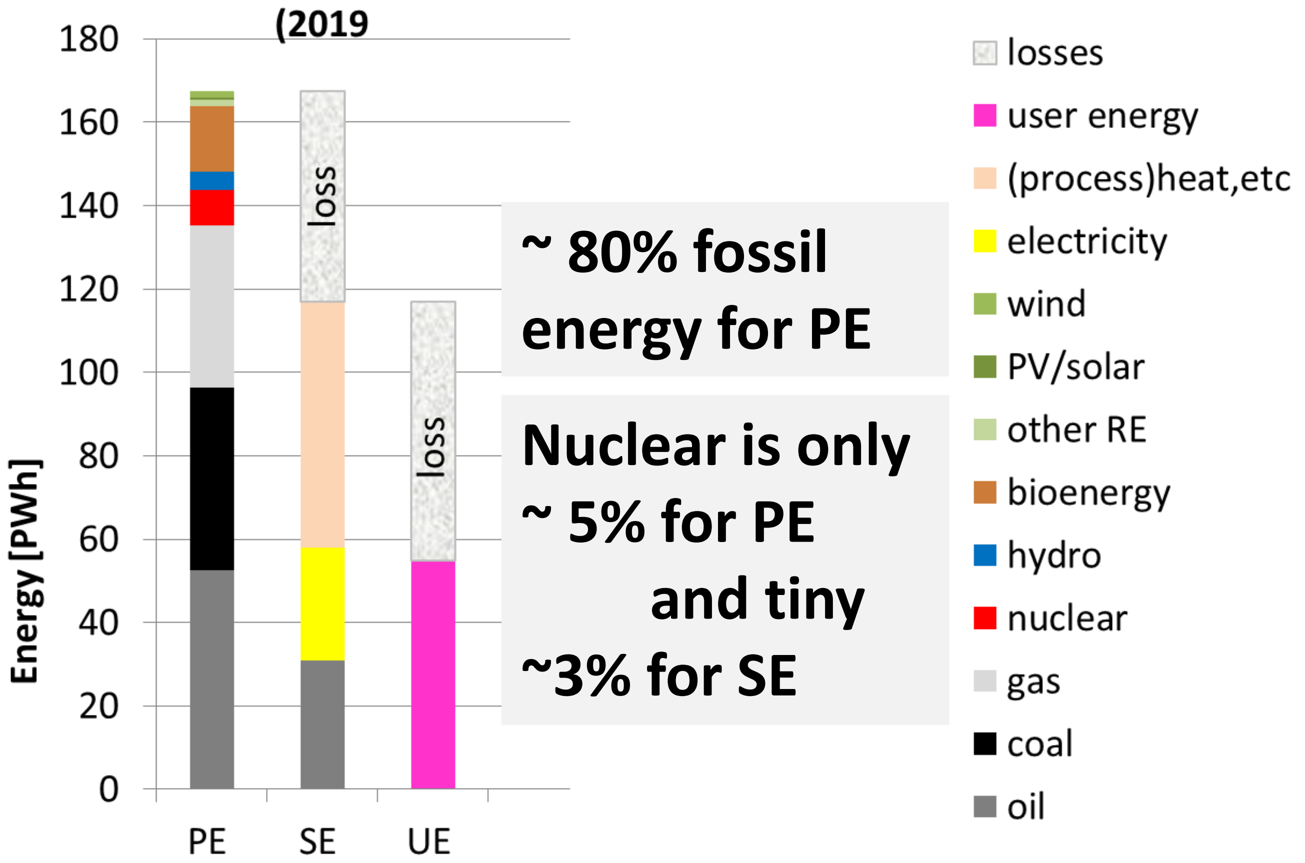
Today‘s energy situation (2019)



~ 80% fossil energy for PE

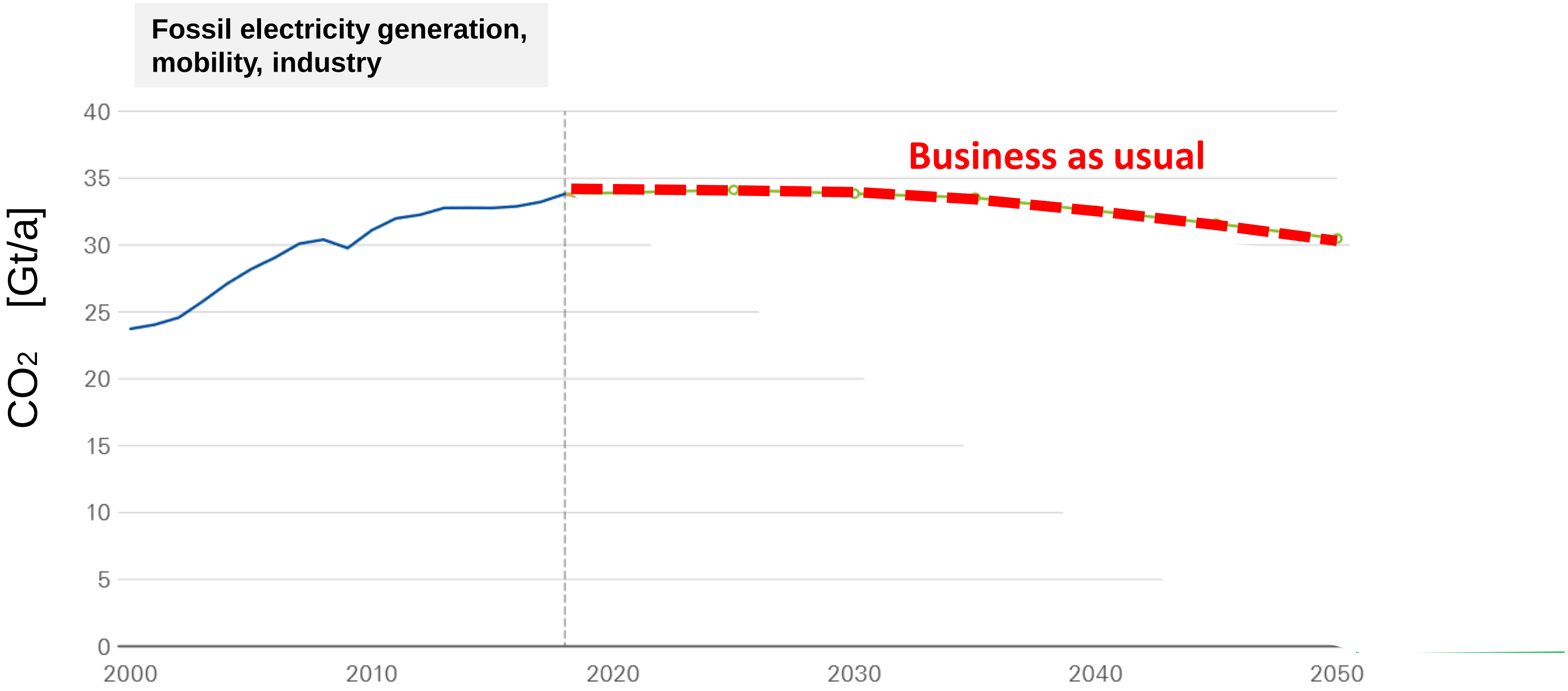
Nuclear is only ~ 5% for PE and tiny ~3% for SE

1 PWh = 10^^15 Wh

PE = Primary Energy
SE = Secondary Energy
UE = (end) User Energy

Source: 2019 data IEA WEO (2020)

Business as usual scenario for the CO_2 - development

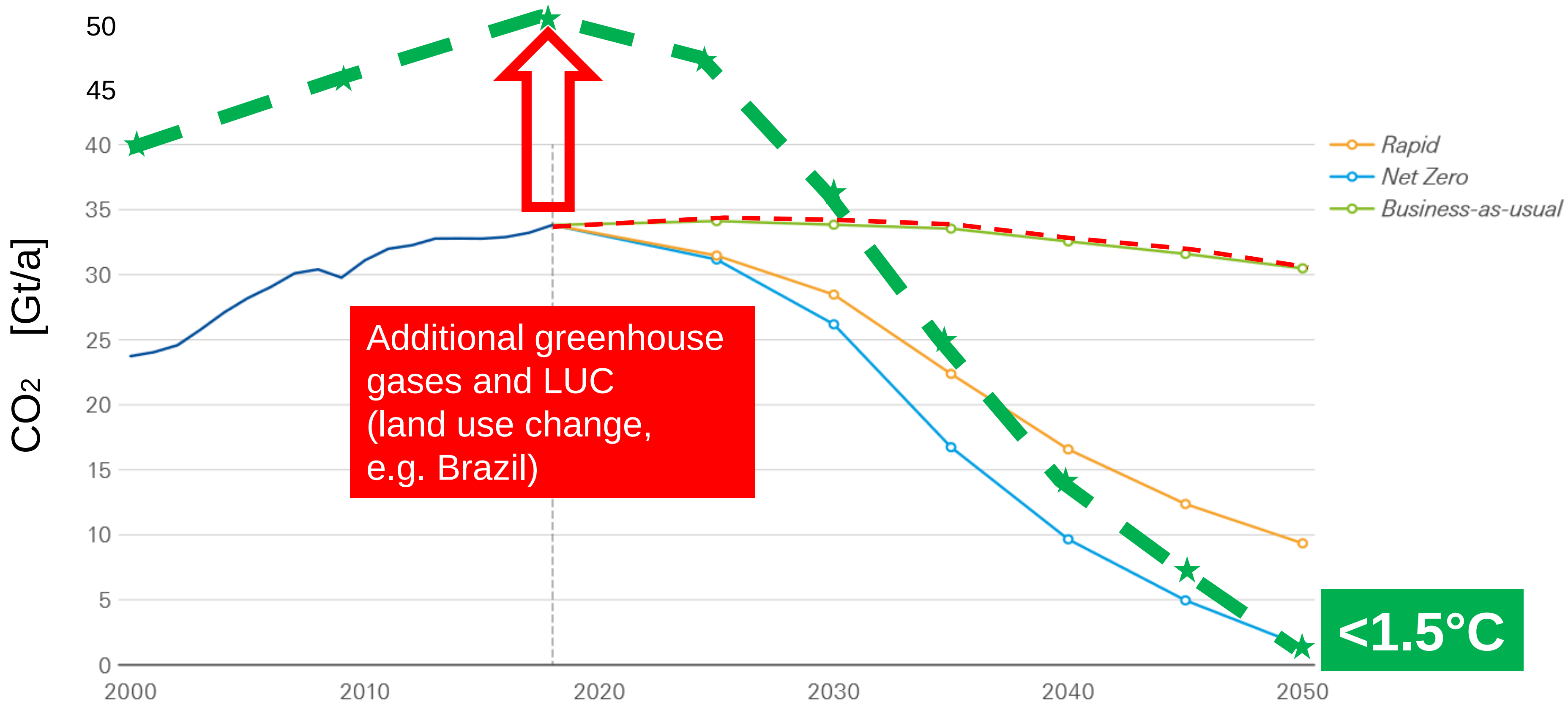


Source: BP energy outlook, 2020;

The consequences of business as usual … > +4°C!

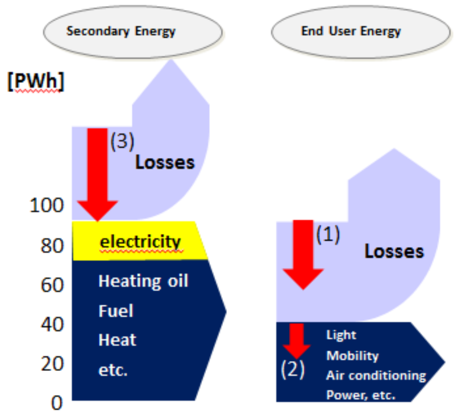
The PETM (Paläozene/Eocene/Temperature Maximum) 55 mio years ago was a ~+6°C increase happening over several 1,000 years … with catastrophic consequences!

Scenario for the necessary Net Zero - CO_2 - development



Source: BP energy outlook, 2020; green dotted line by Winfried Hoffmann

How much energy will be needed globally? (1) Energy efficiency!



ref.: World Energy Council, Greenpeace, IEA, own estimates

(1) and (2):
Improvement of energy efficiency by a factor 3 until 2050
(3):
Losses by converting PE to SE are not counted if renewables are used (PE = SE)

@ the same luminous flux:

100 W electricity
(= secondary energy)

* 0,13 (efficiency) =

13 W user energy
loss 87 W as heat

→ **factor 7**

LED

14 W electricity

* 0,9 (efficiency) =

13 W user energy
loss 1 W as heat

The good old
filament lamp

today

5 l/**100km** * 9 kWh/l =

45 kWh secundary energy petrol/diesel
* 0,27 (efficiency) =
12 kWh user-energy
33 kWh waste heat

Crude oil to petrol with 90% efficiency → **50 kWh PE**

→ **factor 3**

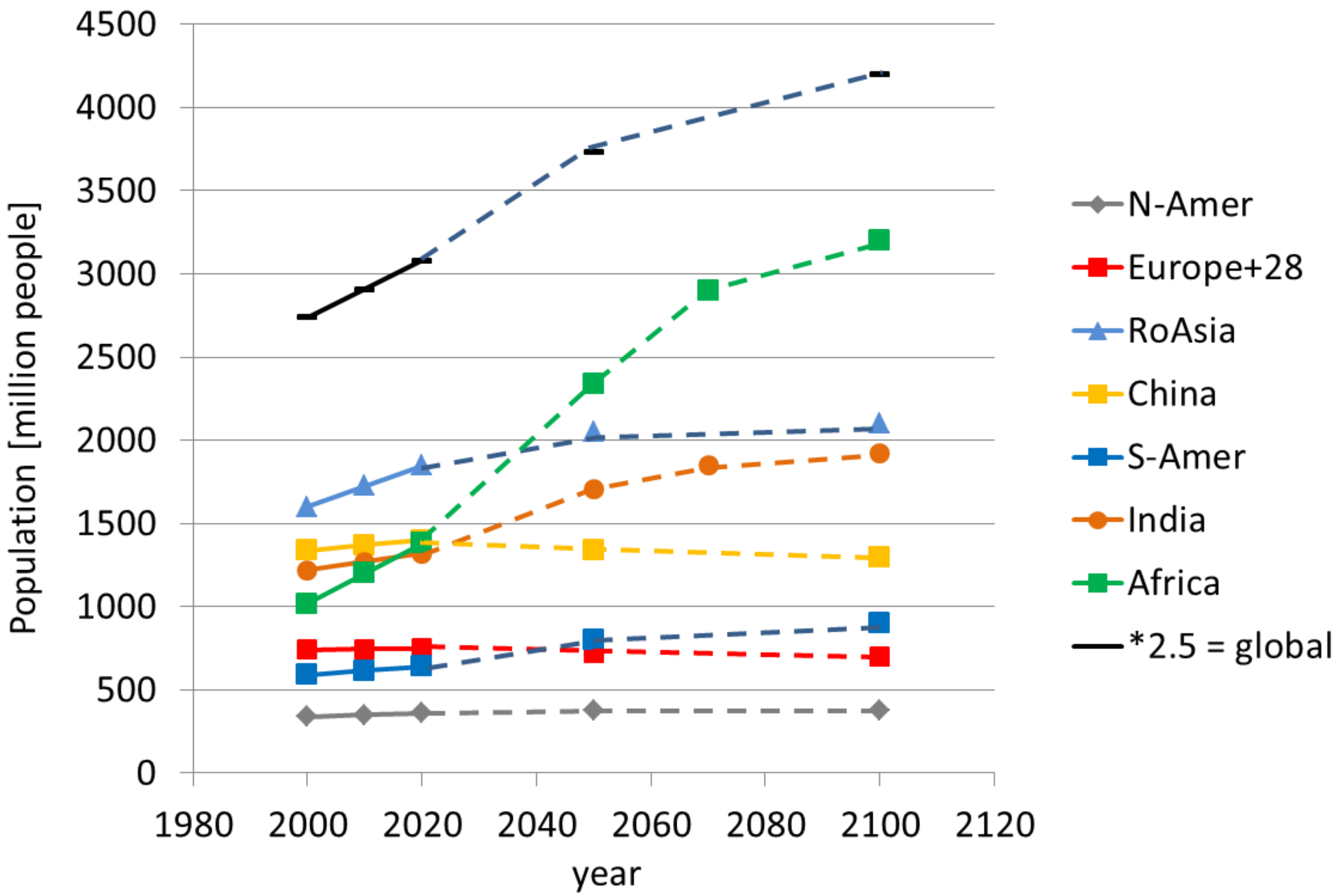
But: if electricity originates from fossil power → factor 1,3 only

100 km * 15 kWh/100km =

15 kWh secundary energy electricity
* 0,8 (effciency) =
12 kWh user energy
3 kWh waste heat

Power station with 40% efficiency → **37,5 kWh PE**

How much energy will be needed globally? (2) how many people?



Source: UN reports, own research

How much energy will be needed globally? (3) Energy justice!

2019: ~120 PWh secondary energy (SE)

¼ of mankind (~2 billion) consume ¾ of this SE (=90 PWh)

→ 45 PWh/1 billion with our comfortable living standard

2050: **Energy efficiency increase by factor 3**

→ 15 PWh/1 billion our living standard

<~10 billion people (UN) will need 150 PWh **–**

ALL the same energy/capita with our living standard!

→ energy justice!

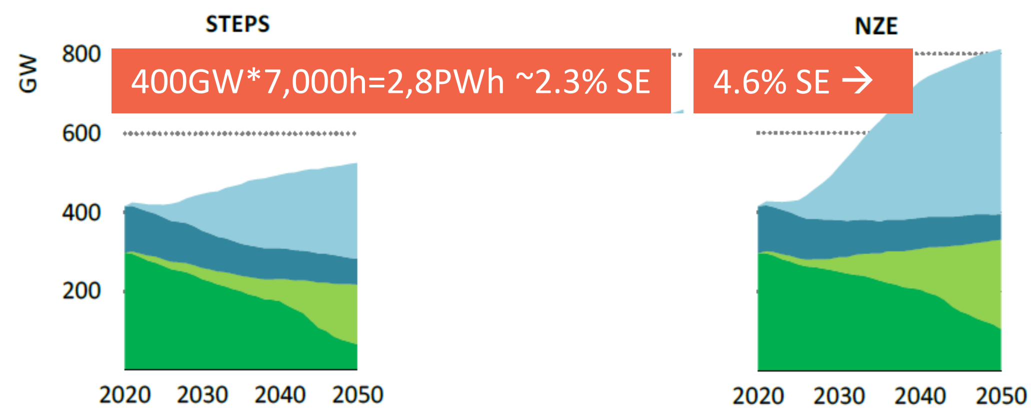
2100: <~12 billion people would need 180 PWh

Resourcing of energy

2019: 160 PWh Primary Energy (~80% fossil, ~5% nuclear) → 120 PWh SE

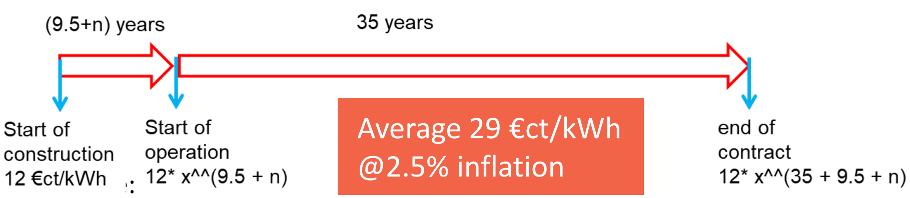
Future of nuclear power stations

IEA-WEO 2021 **Nuclear power capacity by scenario, 2020-2050**



New nuclear „Hinkley point C1 and C2 **Power Purchase Agreement**

- Two Areva EPR 1600 MW reactors (planned investment 26.5 bn **€ (8.3 €/W))**
- EdF would only build these reactors if GB did accept a guaranteed price with the following conditions:
- 92.5 £/MWh (=~ 12 €ct/kWh)
- Duration **35 years** after start of operation
- Adjustment according to **inflation**, starting with the basis year **2012**
- Expected **completion 9.5 years** after start of work



- Even with very optimistic growth assumptions the contribution of nuclear fission is negligible (<5%)
- The ultimate waste disposal is not solved globally
- The price for electricity from new built reactors is very high
- Security is still a hot topic due to „unexpected and unforeseen events“ e.g. Fukushima, Ukraine
- Small modular reactors have typically higher cost compared to large ones

Future of fossil power stations
- additional CO_2 cost to fuel cost and power station -

Version 1: CSUS (Carbon Sequestration , Utilization and Storage)

- If this technology should work at all – final storage for ever – the experience from European utilities are disillusioning : way too expensive **(>10 €ct/kWh)**
- A company in Iceland (www.carbfix.com) has developed an interesting solution(*) : CO_2 dissolved in water and pressed into basalt (or other reactive rocks) forms in less than 2 years stable carbonate minerals. **>70€/t CO_2 → >6.3€ct/kWh**

Version 2: CO_2 tax per ton

In 2004 the European emission trade was introduced. It started with ~10 €/t and – after erratic ups and downs continued to decrease until 2018 towards ~5 €/t. Since then it increased to ~40 €/t until today. GB defined already in 2015 a price of 30 €/t. In order to reach the Paris climate goal, we would need prices starting in **2020 with ~50 €/t** and from**2030 ~100 €/t**! **→ 4,5 and 9 €ct/kWh only for CO_2 tax (@50 and 100€/t)**

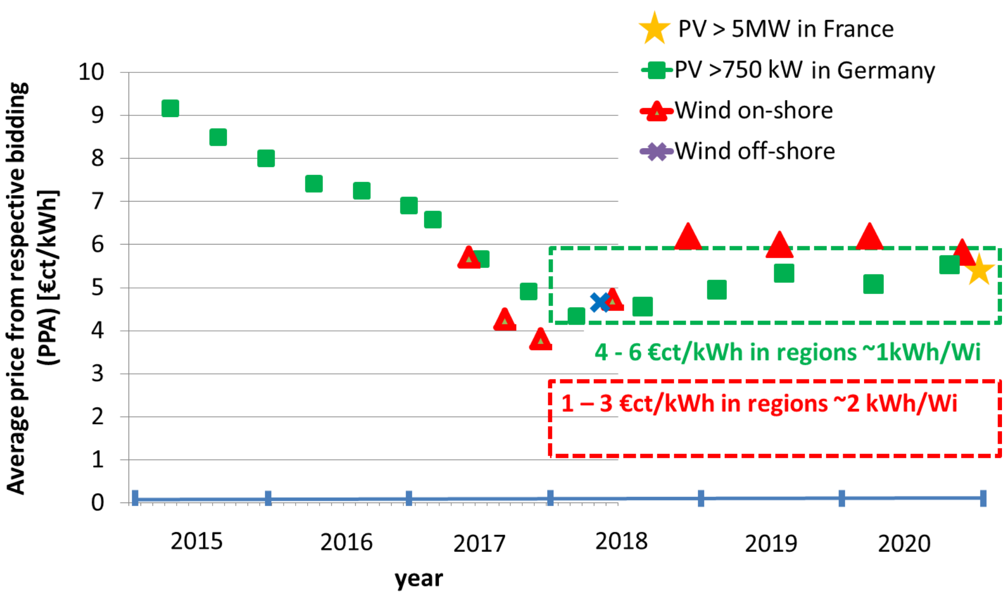
Version 3: unabated CO_2

due to global warming this version should be forbidden globally as soon as possible!

Source: Winfried Hoffmann, 10/2017, eigene Recherchen; (*)Handelsblatt, No 85, p 28 (04.05.2021)

Cost comparison fossil, nuclear fission and renewables (PV and wind)

Development of PPA‘s for wind and PV plants



PPA (Power Purchase Agreement)
PV and wind (on-/off-shore) in Ger
4 – 6 €ct/kWh

PV in southern regions (2kWh/W_i)
1 – 3 €ct/kWh

PPA (Power Purchase Agreement)
New nuclear fission
20 – 35 €ct/kWh depending on inflation rate

Fossil power stations
CO_2 tax (6 – 9) €ct/kWh (or CCUS >10 €ct/kWh) plus
fuel cost and power station ~5+/- €ct/kWh → total (10 – 15+)€ct/kWh

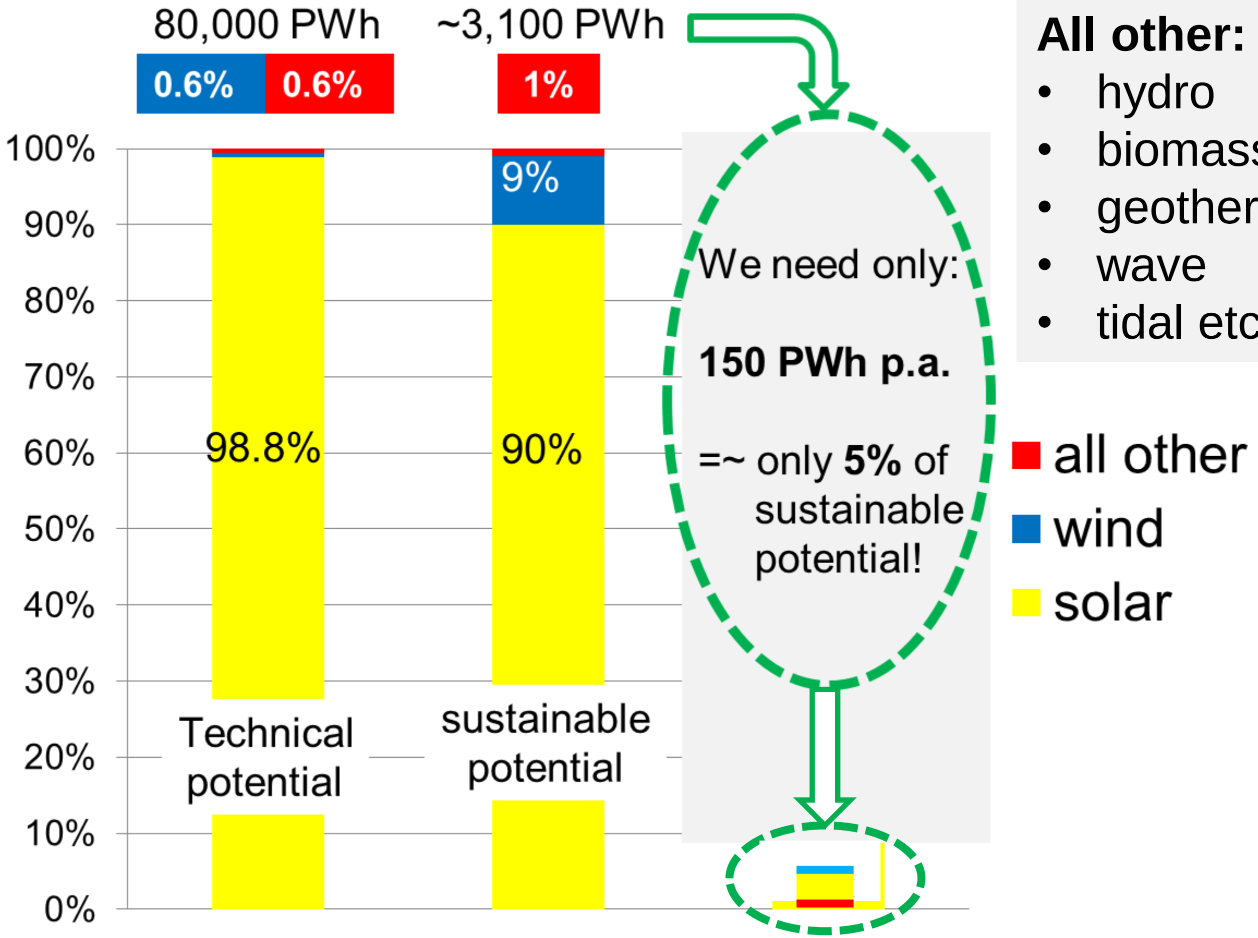
Source:

Resourcing of energy

2019: 160 PWh Primary Energy (~80% fossil, ~5% nuclear) → 120 PWh SE

2050: 90% green electricity (inclusive P2G&L), because all important renewable
→ technologies produce electricity (PV, wind, hydro, geothermal, tidal etc.);
2100: to match demand and supply: batteries for small daily storage, redox flow for big daily and weekly storage, gas network (H_2 and/or CH_4) for dark doldrums

Technical and sustainable potential for renewable technologies (1)

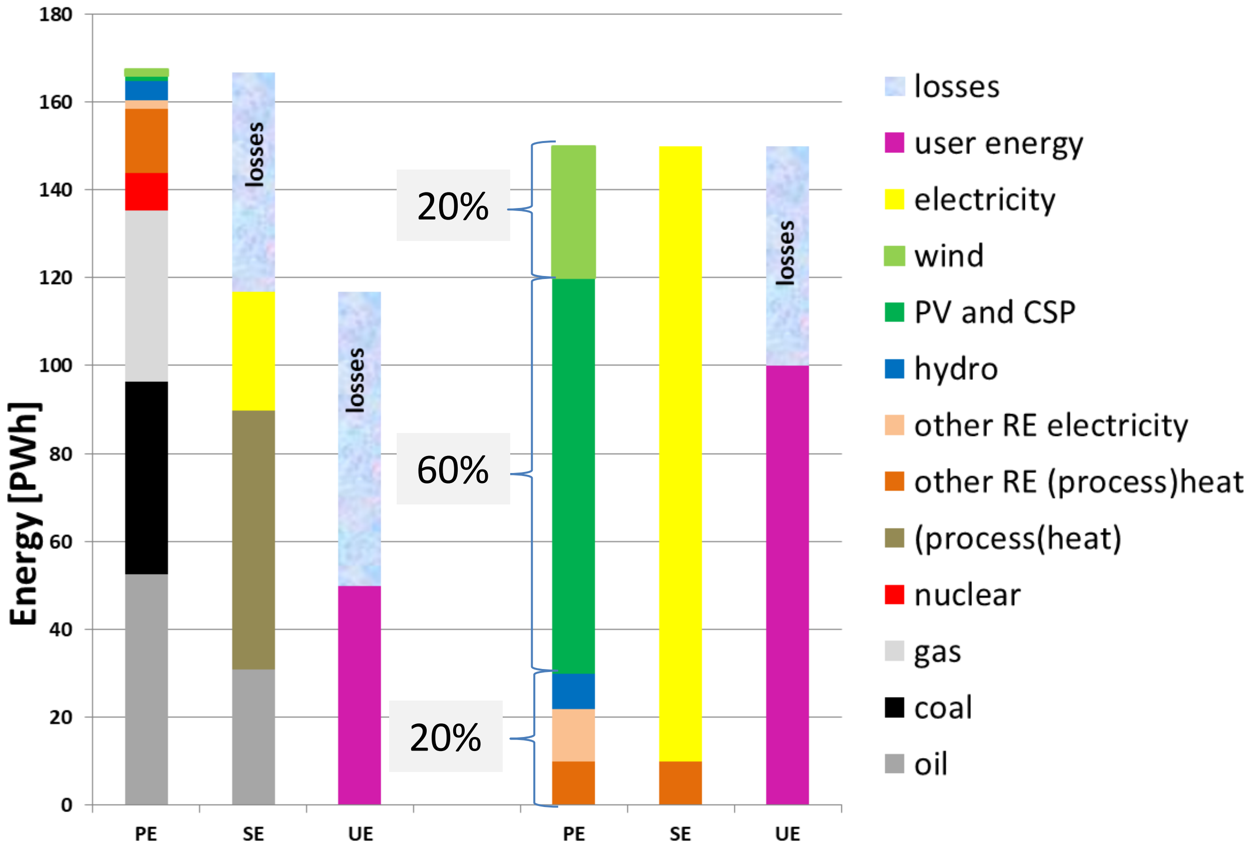


All other:

- hydro
- biomass
- geothermal
- wave
- tidal etc.

Source: www.WBGU.de (2008), Scientific council to the German government on global environmental changes

today (~2019) → future (~2050+)



electricity in 2050 includes P2G(&X)

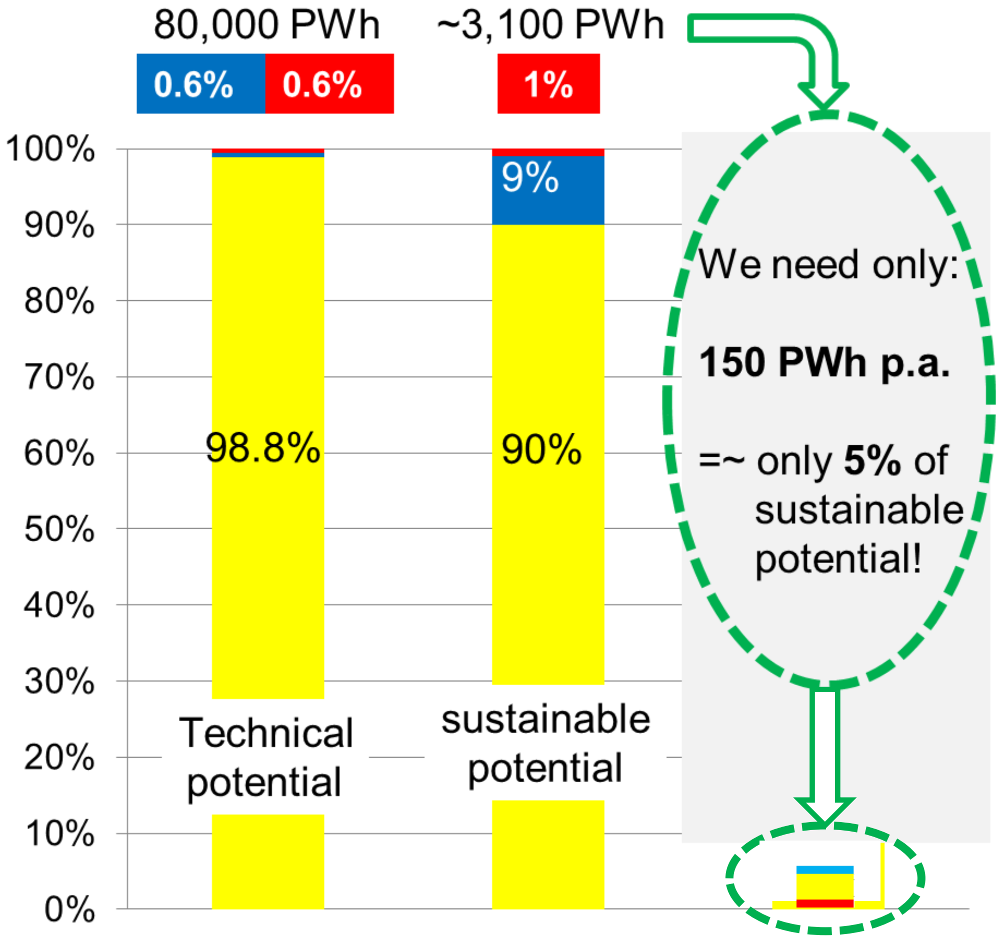
Zero Carbon

Equal energy for all 10 billion people

Efficiency & only RE

Source: 2019 data IEA WEO (2020), 2050 data Winfried Hoffmann (2021)

Technical and sustainable potential for renewable technologies (2)



All other:
- hydro
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- tidal etc.

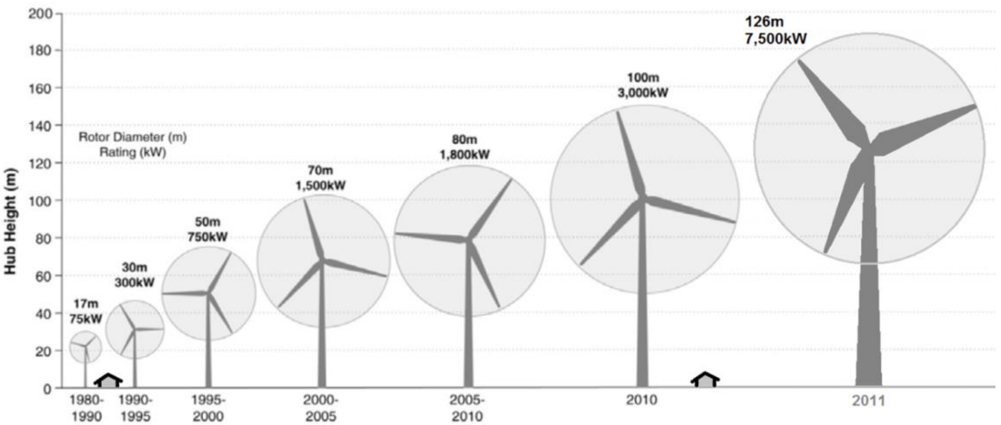
150 PWh needs:

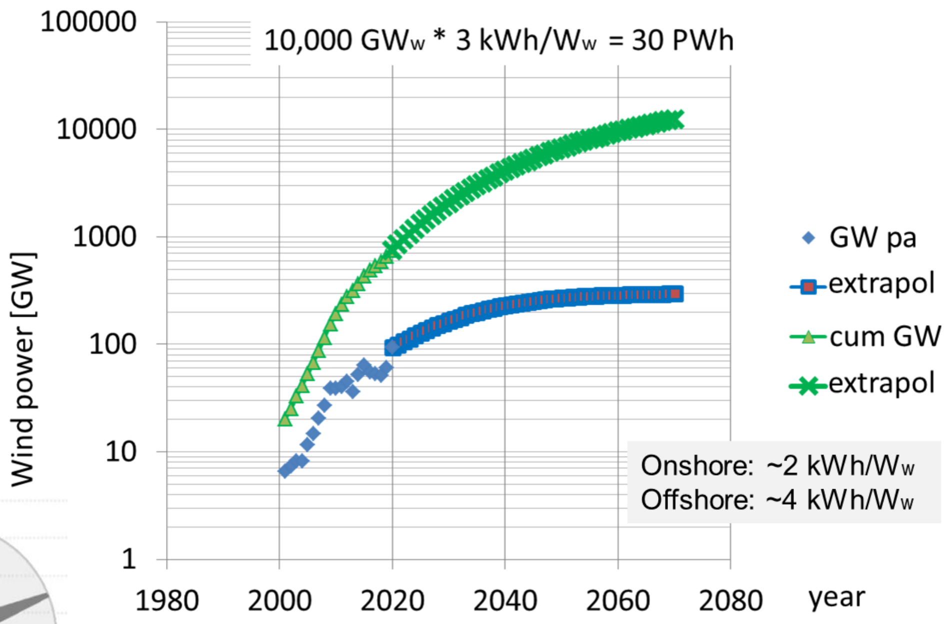
- **20%** (>9%) **wind** because we need it for seasonal balancing in north & south

Source: www.WBGU.de (2008), Scientific council to the German government on global environmental changes

Wind energy – historical development and needed installations

$$P_{wind} \sim d_{blade}^{2} \times v_{wind}^{3}$$

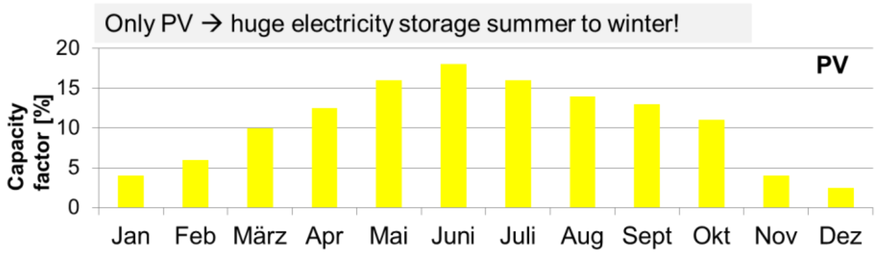


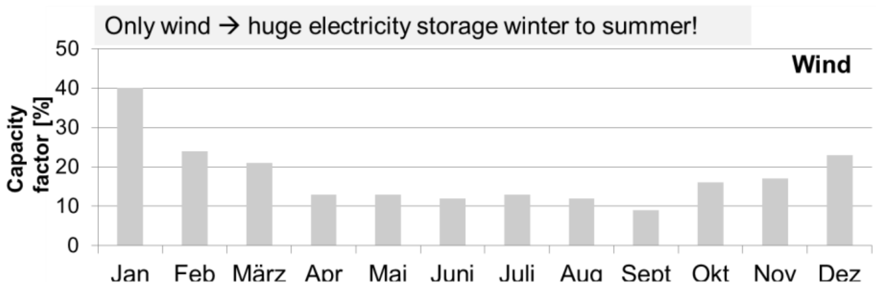


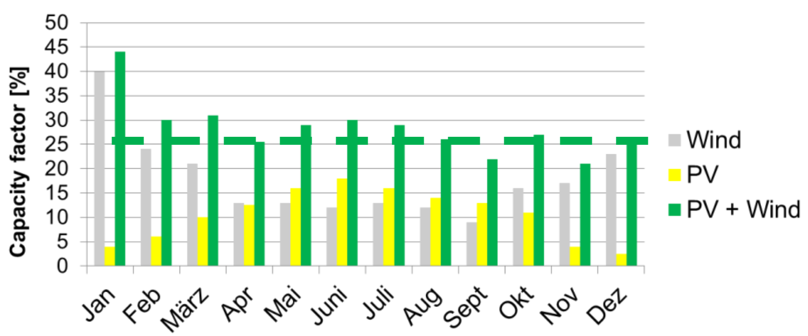
Source: Data until 2020 from GWEC, Global Wind Report 2021; extrapolation logistic annual growth by Winfried Hoffmann (06/2021)

Wind energy – why more than 9% share?

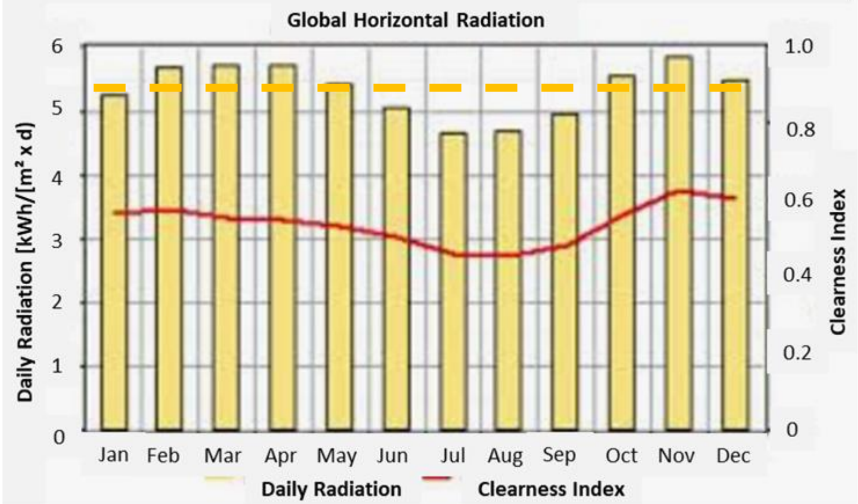
Solar and wind energy per month in Germany

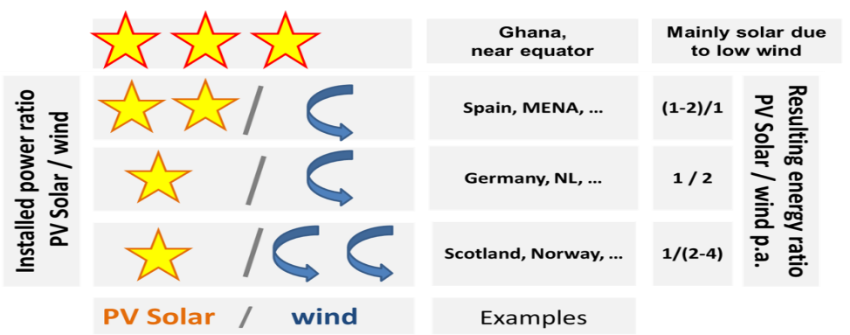




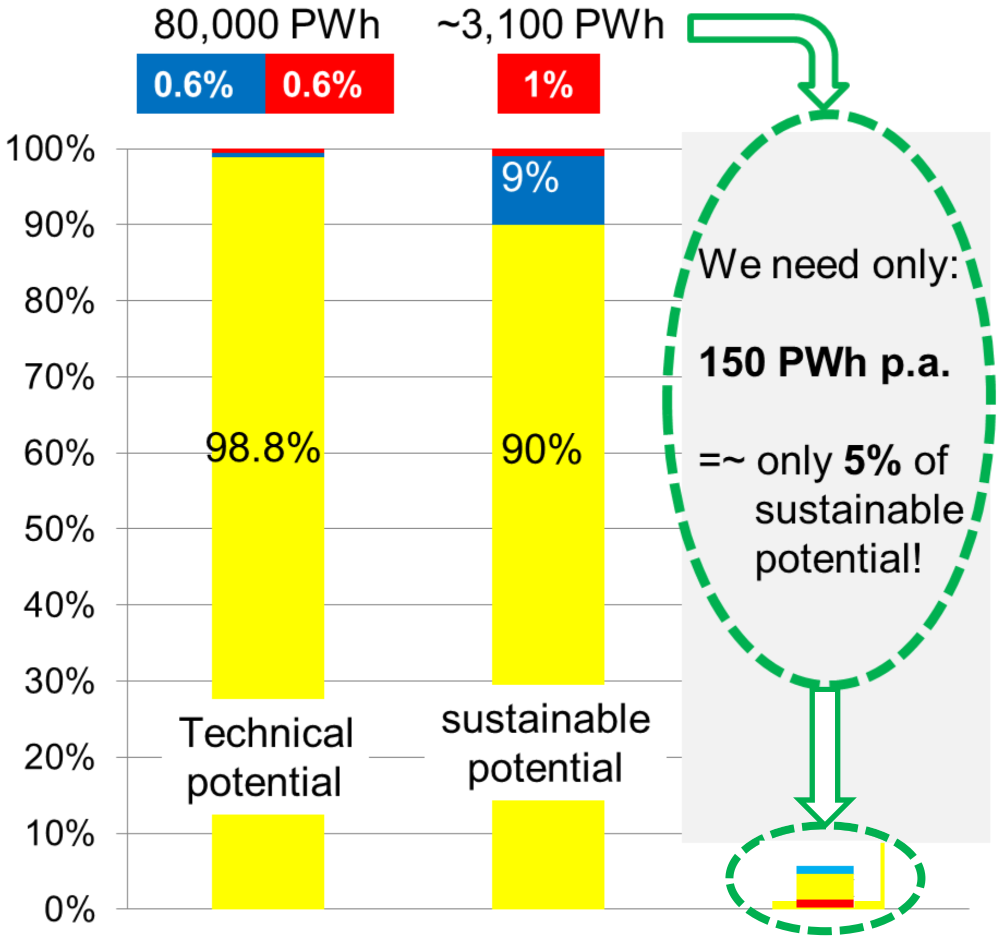


Solar energy per month in Ghana





Technical and sustainable potential for renewable technologies (3)



All other:

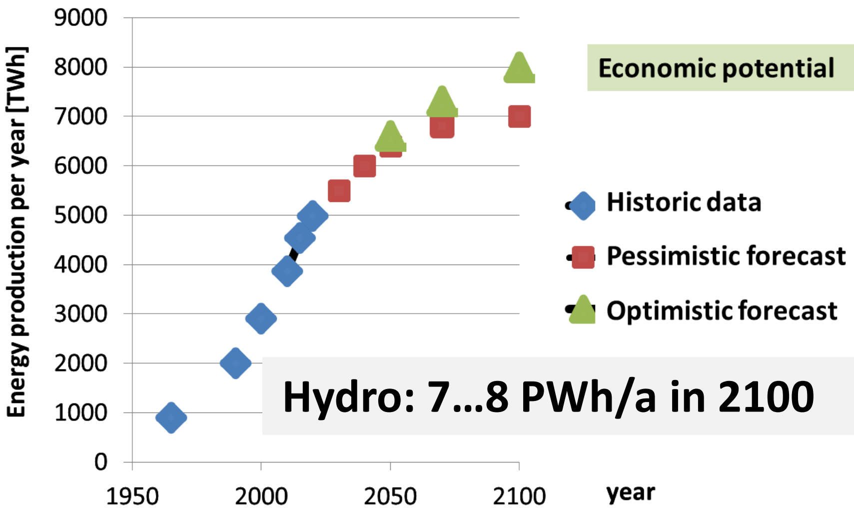
- hydro
- biomass
- geothermal
- wave
- tidal etc.

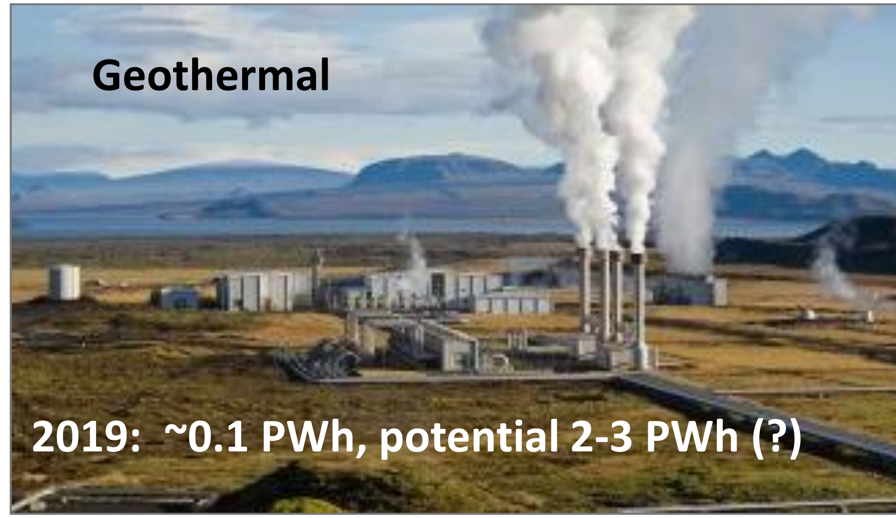
150 PWh needs:

- **20%** (>9%) **wind** because we need it for seasonal balancing in north & south
- **20%** (>>1%) **all other** to utilize locally easy to use offerings

Source: www.WBGU.de (2008), Scientific council to the German government on global environmental changes

Other renewable technologies to contribute to 20% or 30 PWh SE

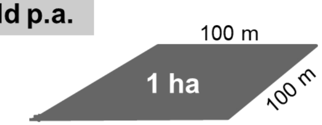




Biogas/-electricity p.a.

Corn to biogas at best conditiones ~50 MWh/ha
Power plant eff 50%
25 MWh/ha electricity

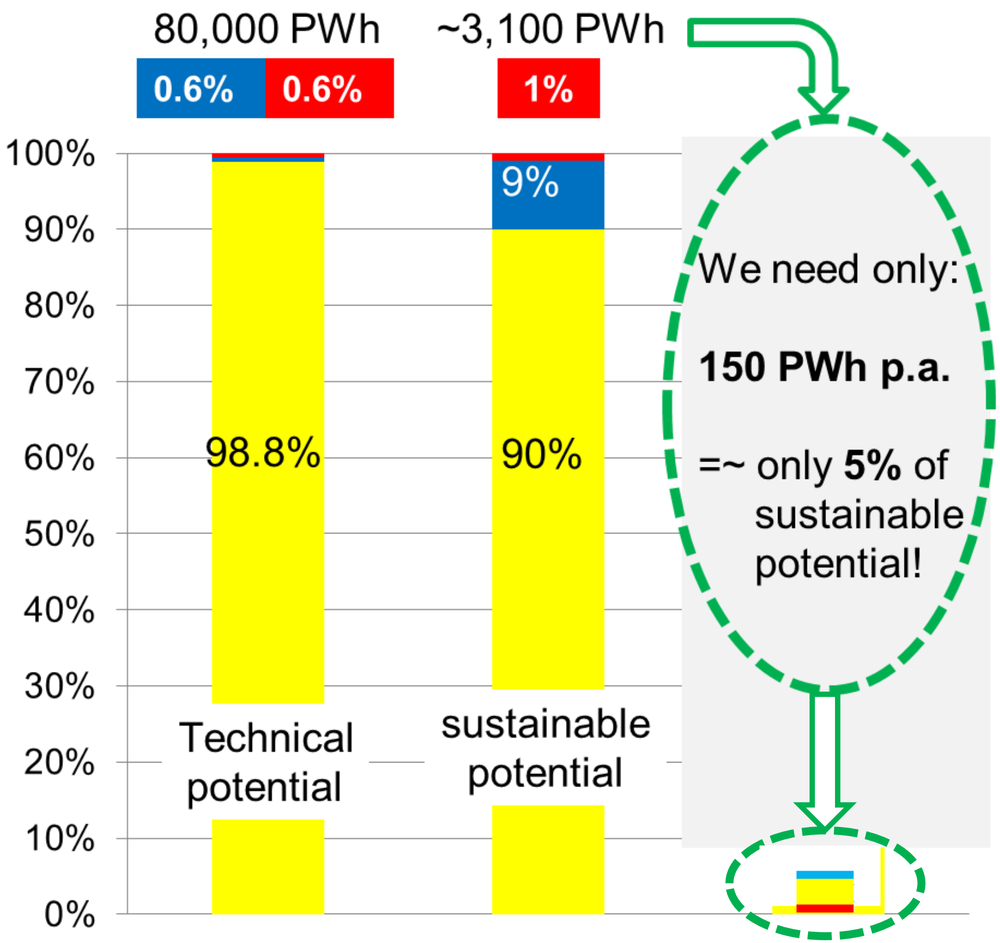
PV green field p.a.



PV green field 20(30)% eff & 50% cover :
1,000 (1,500) MWh/ha in Ger
2,000 (3,000) MWh/ha in South

On same area: PV has 40 -120 times more output!

Technical and sustainable potential for renewable technologies (4)



All other:

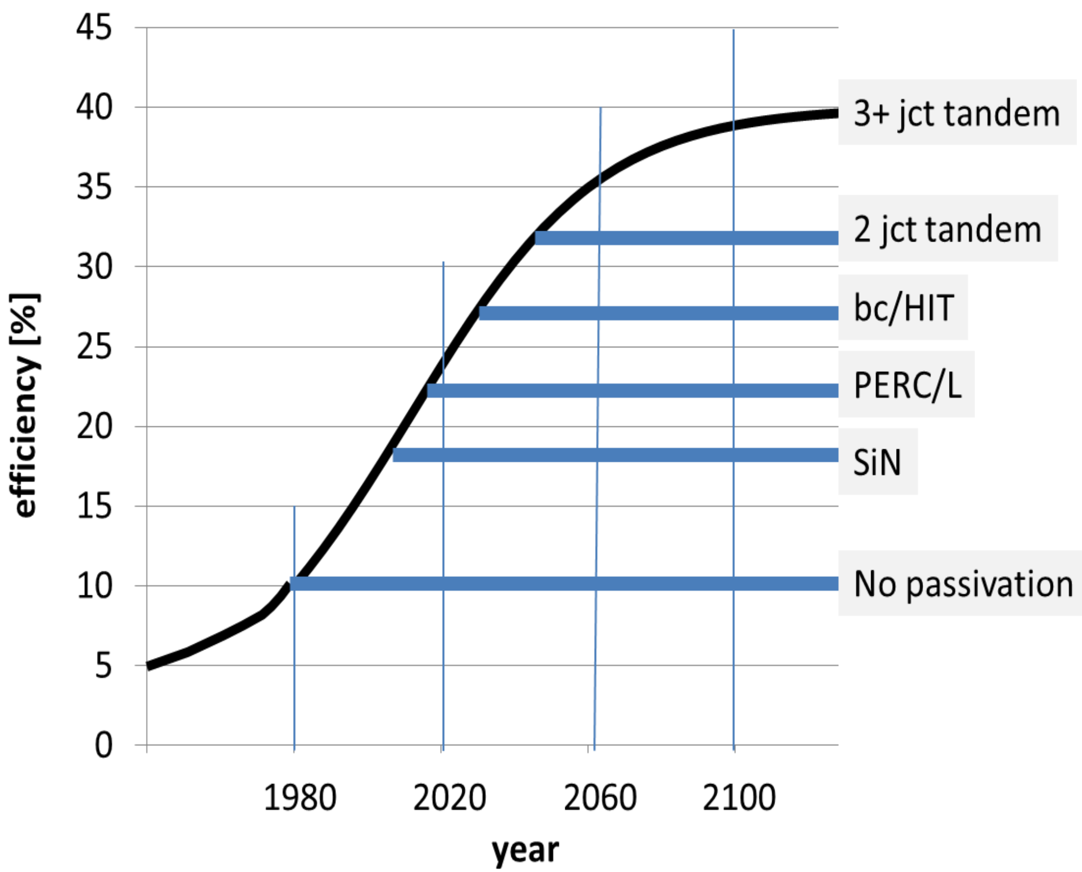
- hydro
- biomass
- geothermal
- wave
- tidal etc.

150 PWh needs:

- **20%** (>9%) **wind** because we need it for seasonal balancing in north & south
- **20%** (>>1%) **all other** to utilize locally easy to use offerings
- → **60%** (<90%) for **solar** as consequence

Source: www.WBGU.de (2008), Scientific council to the German government on global environmental changes

c-Si and tandem cell and module technology dvlp. and applications

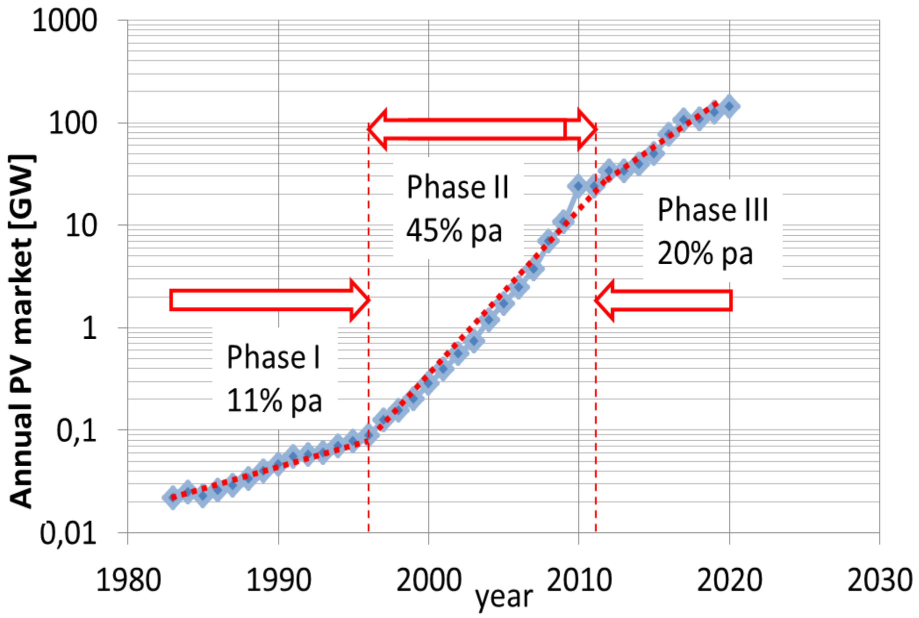


Integration of PV cells

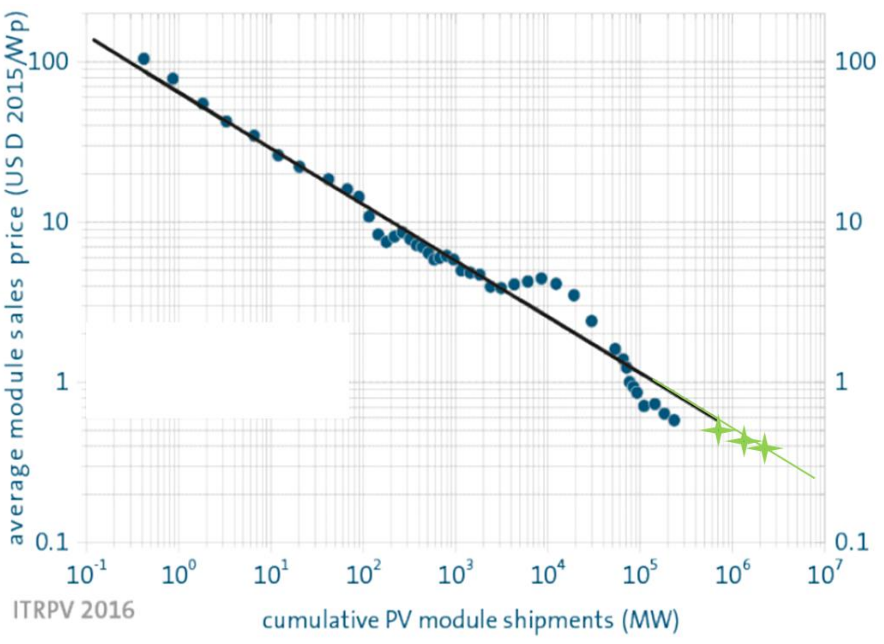
- For power plants
  big high power modules
  500→700→1000 W/module
- **FPV** (floating PV)
- **BIPV** (building integrated PV)
  „construction material“
- **VPV** (vehicle integrated PV)
- **IPV4E** (Integration of PV for Everything)

Historical market growth and price development (PEC) for PV

PV market development

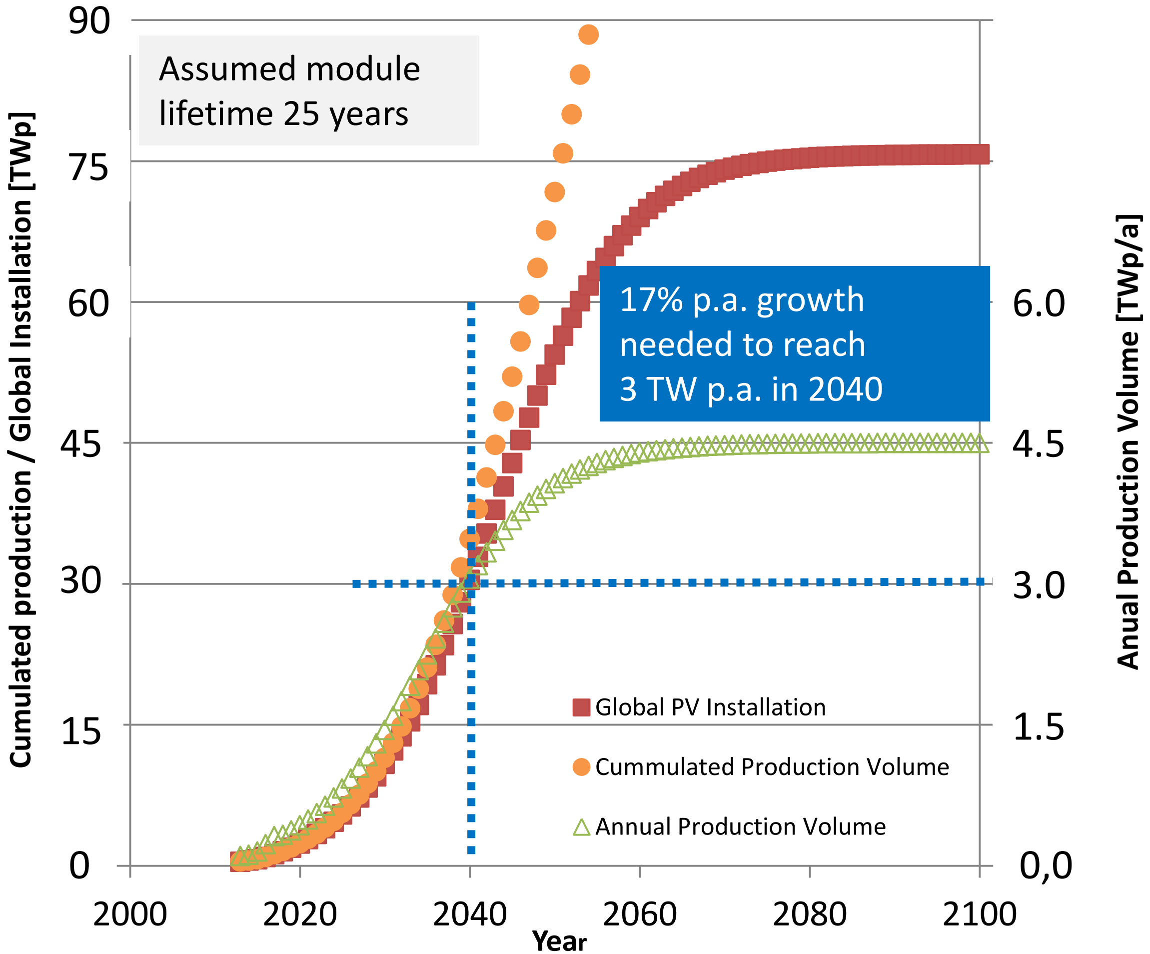


Price Experience Curve (PEC) PV modules



Source: SPE-GMO‘s, IRENA

Growth assumption to reach 90 PWh electricity with PV in 2050+



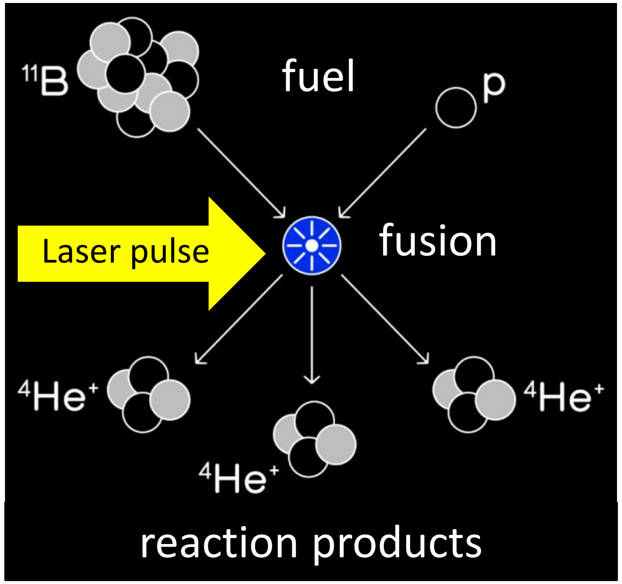
Source: Axel Metz, Winfried Hoffmann (2018)

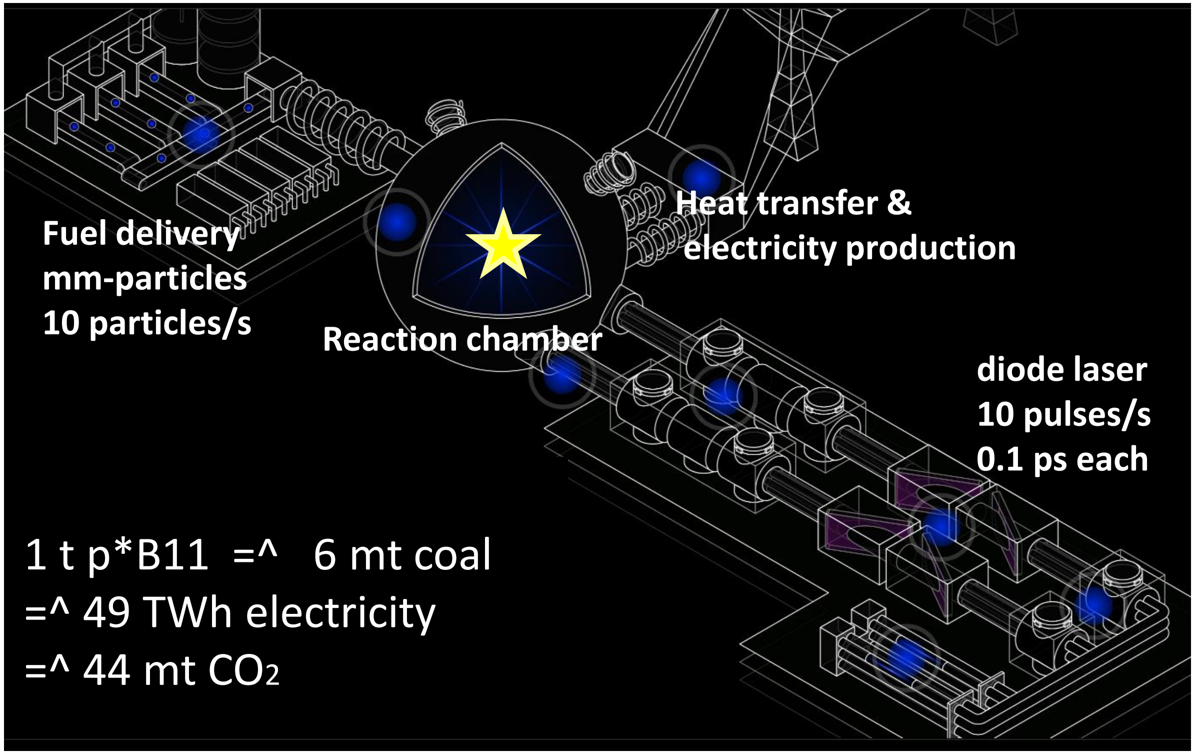
75 TW_p cumulative installations

correspond to ~90 PWh annual electricity

assuming ~1.2 kWh/W_p as global average

New nuclear (inertia) fusion (Marvel Fusion GmbH) ...? 2030+ ?...





- Non-radioactive fuel and reaction products (unlike DT-fusion)
- GW reactors feasable
- Particularly suited for energy intensive industry and future mega-cities

Source: Marvel Fusion GmbH

Summary

We know **how much energy** is needed to supply mankind in 2050 (2100): **150 (180) PWh**

This includes **energy justice** (same energy sonsumption) for **all people globally**

The assumption for **energy efficiency increase by factor 3** is ambitious but doable

Fossil energy not allowed for mobility due to non avoidable CO_2 release and **too expensive** if CO_2 is captured and stored (CCS) for **electricity production**

Nuclear fission not allowed because too expensive and ultimate waste disposal unclear

Nuclear inertia fusion could help if demontrated (technically and economically)

Fortunately we have all renewable technologies (including storage) at hand - technically and economically – to supply above needed energy of 150 (180) PWh

Taking into account sustainable offerings for solar, wind and all others and utilization of local offerings we conclude 60% solar / 20% wind / 20% all other renewables

Applied Solar Expertise

Thank´s for listening
and an urgent request:
please help actively, to master the huge challenges!
Otherwise latest our grandchildren will
no longer have a comfortable life!

7th November, 2022,
GCRNRE, Valencia

CV Winfried Hoffmann

- Since 1979 active in photovoltaic and CEO of production companies (RWE Solar GmbH: PV wafer, cells and modules, Applied Materials GmbH: Production equipment for deposition), president of associations (EPIA, today SolarPower Europe, BSW Solar), member/chairman of supervisory board (SMA Solar Technology AG/ Solar-Fabrik AG) and many institutes (FhG-ISE, ISFH, HZB, DLR, ZSW)

- **Today‘s activities in September 2022:**

❖ Member advisory board from Solnet group (EPC)

❖ Member scientific board at ISFH (Hameln)

❖ lectures/Seminars at universities in Konstanz and Freiburg