EPFL

# Energy supply, economics and transition

## Mitigating $CO_2$ emissions and scenarios

# 100‘000 TWh annual electricity production: 4 Major options

**Reminder**

1GW Nuclear → 8 TWh/year (8000 hours)

1GW solar → 1-2 TWh/year (1000-2000 hours)

1GW wind → 2-4 TWh/year (2000-4000 hours)

Which can be combined ...

- a e.g. 40‘000 GW of Solar and 15‘000 GW of Wind (+ Hydro + Biomass +… )
- b 13’000 x 1 GW nuclear power plants
- c Carbon sequestration
- d Don’t care (or too late…)

- M Revolutions: natural hydrogen / fusion

https://energy.economictimes.indiatimes.com/news/renewable/india-on-path-to-triple-renewable-energy-capacity-by-2030-but-faces-financing-hurdle-report/105584911

# $CO_2$ Capture and Sequestration

**Carbon capture and storage (CCS)** → separation and capture of $CO_2$ from the emissions of industrial processes prior to release into the atmosphere and storage of the $CO_2$ in deep underground geologic formations

- Enables industry to continue to operate while emitting less GHGs.
- It can be applied across the energy system.
- Requirements for storage → safe, environmentally sustainable (no release) and cost-effective.
- Target policy measures and support for innovation are critical for CCS.

https://www.iea.org/reports/ccus-in-clean-energy-transitions/a-new-era-for-ccus

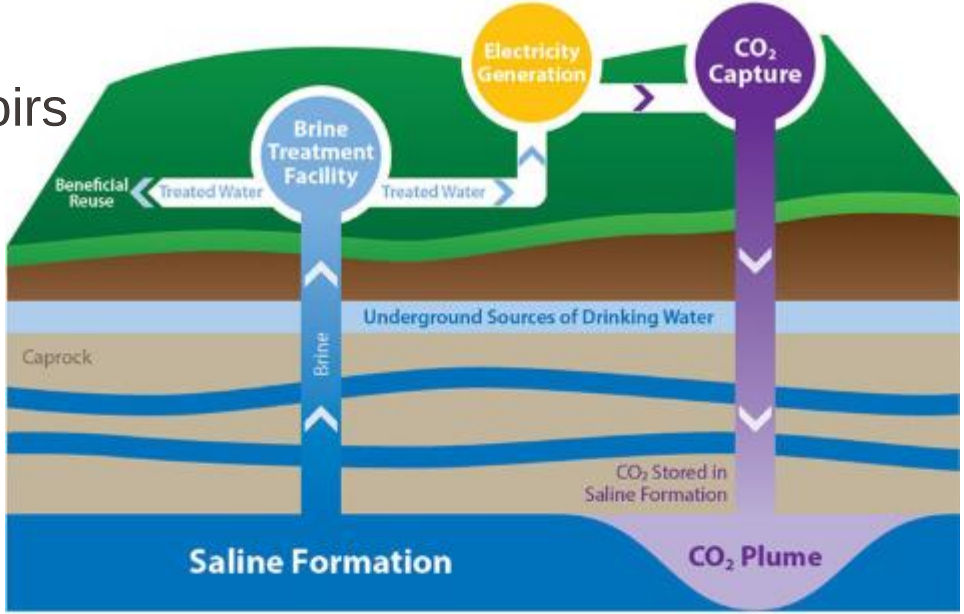
# $CO_2$ Capture and Sequestration – Methods



**Geologic storage**: placement of $CO_2$ into subsurface formation.

**Types**:

- Saline formations
- Oil and natural gas reservoirs
- Unmineable coal seams
- Organic-rich shales
- Basalt formations



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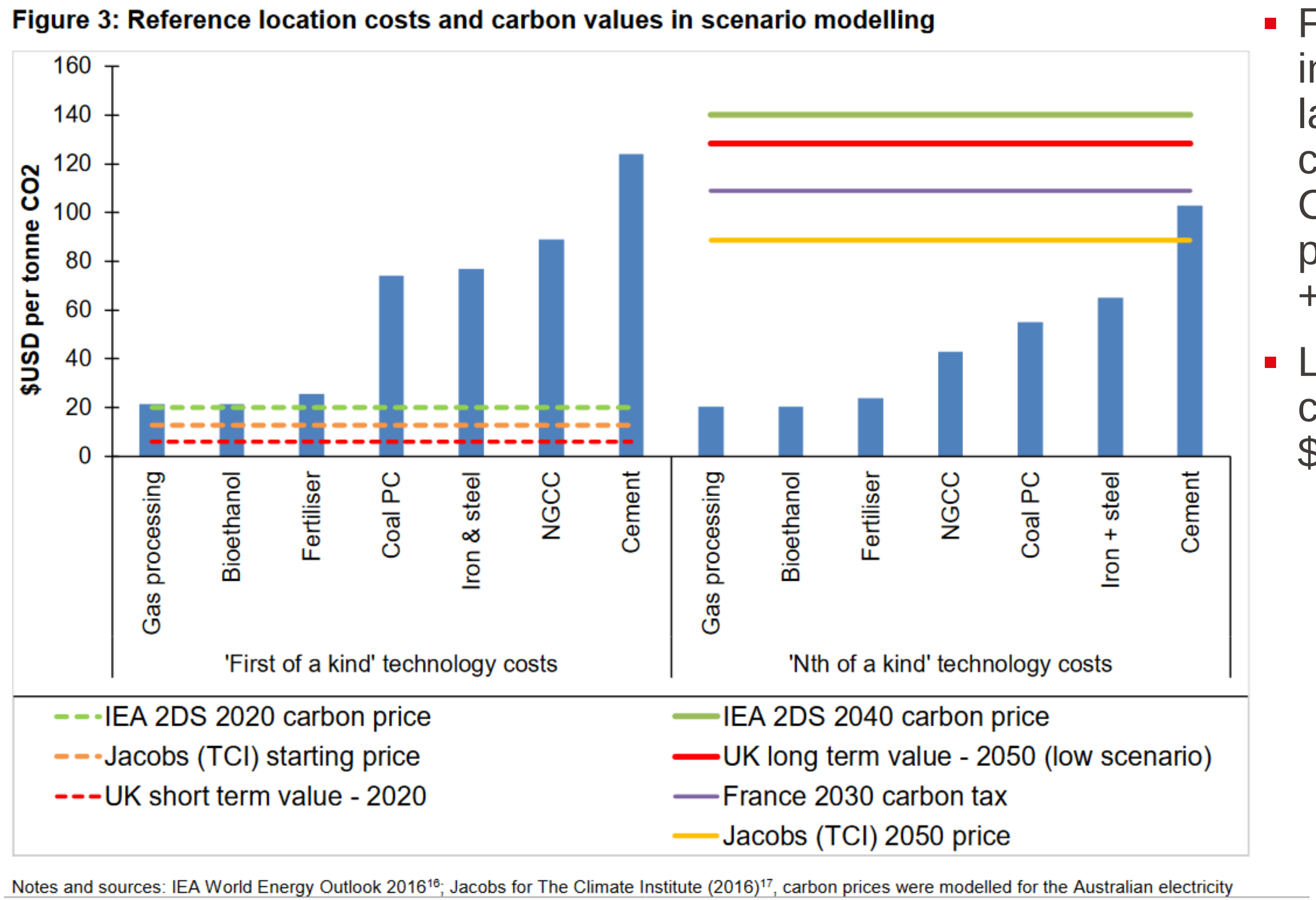
# Cost of Direct Carbon Sequestration




- First large scale installation will have large investement costs: ~ 100 $/tons $CO_2$ for coal and gas power plant (Coal PC + NGCC)
- Later projects could come down to 40 – 50 $/tons $CO_2$ avoided



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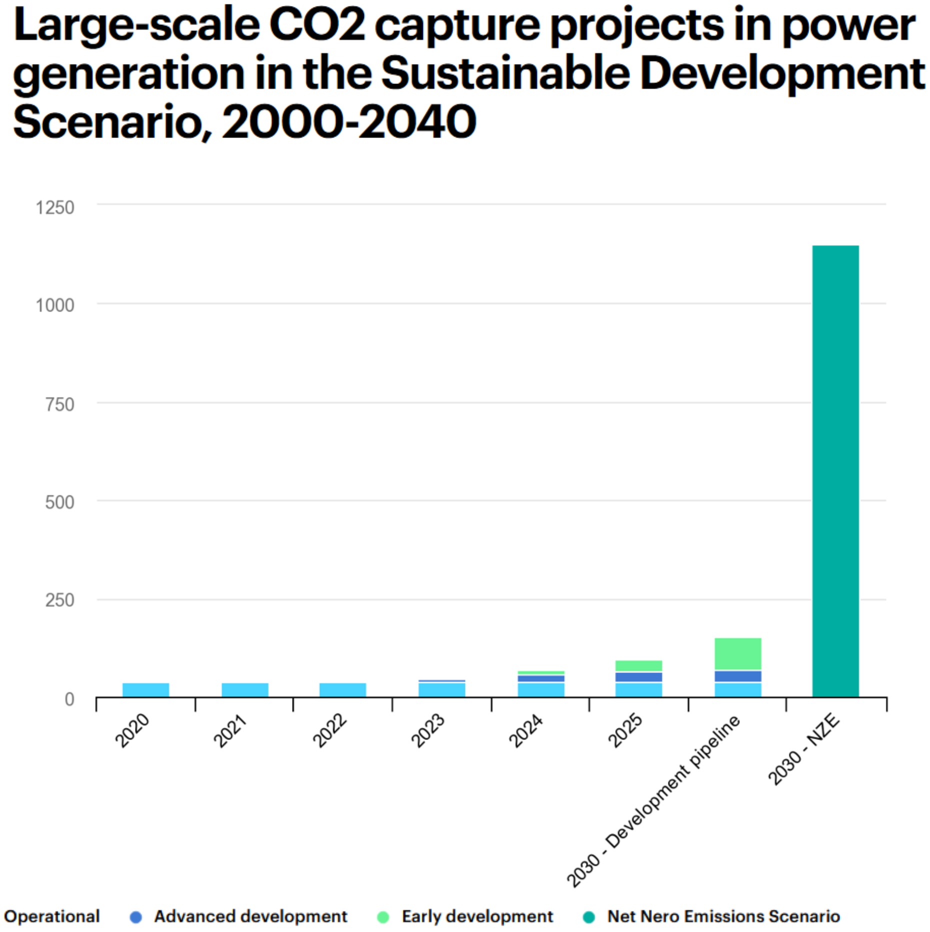
# $CO_2$ Capture and Sequestration




Difficult to kick-start (without high CO2 taxes)

Several projects starting for cement factories (chemical reactions emits CO2)

If CO2 capture costs of 100€/tons → 5 cts/kWh more for gas electricity and 10 cts/kWh for coal power plants.
→ in direct (loosing) competitions with renewable + storage, or nuclear

**A lot of talks and not much happening !**

https://www.iea.org/reports/ccus-in-industry-and-transformation



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[We're On A Path To Reach Net-Zero Emissions - Pathways Alliance]

Make oil production less dirty (around 20% of emission from extraction/processing per future emission when burning)

# $CO_2$ Capture and Sequestration

**Direct air capture (DAC) or direct $CO_2$ capture from the air** (e.g. Climate works, Global Thermostat….)

→ needs at least 250 kWh electricity per tons of $CO_2$

→ Cost of ~ 100$/ton claimed possible (or even 50 in 2050**), right now likely more 500-600$/tons


**Direct $CO_2$ capture from the air → will be costly for several decades**

→ **Possible business for sales of $CO_2$,**
→ At 100$/ton → cost of carbon in 1 $m^3$ of $CH_4$ (power to gas) → 0.27$/$m^3$ (n.b. current price of gas)

**Open question: should we however work on DAC?**
→ Less costly to substitute fossil with renewables.
→ Less costly in volume to make CSS from Coal/gas powerplants ?
→ Or prepare the world for massive DAC when system decarbonised ? (likely yes)

**Techno-economic assessment of CO2 direct air capture plants, Fasihi et al. 2019

# $CO_2$ Capture and Sequestration – Land Use, Land-Use Change and Forestry (LULUCF)



Christophe Ballif / Philippe Thalmann / Claudia Binder

## Biological carbon sequestration

- Plants absorb $CO_2$ from the atmosphere and store some as aboveground and belowground biomass.
- Soil and dead organic matter/litter can also store some $CO_2$, e.g. in Peatlands.
- In US (since 1990) LULUCF activities have resulted in more removal $CO_2$ than emissions.
- In countries when deforestation happens, the effect is opposite.



https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions#carbon-dioxide

# $CO_2$ Capture and Sequestration – Land Use, Land-Use Change and Forestry (LULUCF)

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Enhance carbon pools to reduce emissions and increase potential to sequester carbon from atmosphere.

**Possible actions**

- Change in Uses of Land:
  - Increase carbon storage by using land differently.
  - Maintain carbon storage by avoiding land degradation.
- Change in Land Management Practices:
  - Improve management practices on existing land-use types (plant after human-induced disturbances to accelerate vegetation growth, reforestation).

# $CO_2$ Capture and Sequestration





## Tree planting 'has mind-blowing potential' to tackle climate crisis

The Guardian

- Worldwide planting programme
  - Additional 0.9 billion ha (to the existing 4.4 billion ha) of forest could store 205 Gt of Carbon (= 3.65x205= 750 Gt of $CO_2$ = 17 years of emission at current rate)
- Crop fields and urban areas are not considered.
- Reforestation could take 50-100 years to remove 750 Gt of $CO_2$
- **Advantages**:
  - Available for starting now.
  - Cheap solution (?).
  - Individuals could make impact by growing trees themselves.

"The global tree restoration potential", Jean-Francois Bastin et al., Science 65 (Jul 2019), 76-79

https://www.theguardian.com/environment/2019/jul/04/planting-billions-trees-best-tackle-climate-crisis-scientists-canopy-emissions

# $CO_2$ Capture and Sequestration



## Planting trees can support the world in mitigating climate change

- But potential likely overestimated (see discussion in https://science.sciencemag.org/content/366/6463/317 )
- Planting trees is one aspect (nice communication) growing them is more difficult and many challenging projects with dying trees. Risks of fire also increase with global warming
- It will only slow down planet warming, as it takes years to act
- **It can be a quite low cost approach (20 to 40$/tonnes). Can easily be scale up**

## Other approaches include (e.g.)

- Creation of Bio-char or Charcoal (by slow pyrolisis) and integration to ground
- e.g. with bamboos (fast growth)
- Potential in x Gt per year (up to 12% according to some scientists)

Woolf, Dominic et al "Sustainable biochar to mitigate global climate change". Nature Communications. 1 (5): (2010) 1–9.

# Energy efficiency and Embedded Energy





- Better insulated and designed house (can save up to 2/3 of energy)
- Better control of hidden consumptions (pumps, ventilation, potential for > 30% saving in CH, close to 12 TWh per year)
- Energy saving bulb, appliances (90% to 30% saving),

- Use electricity instead of fuels to power engines (gain a factor 3* )
- Use electricity and heat pumps to extract heat (gain a factor 3* to 5)

- Build with materials that embeds $CO_2$,(instead of emitting) eg. Wood, and replant !

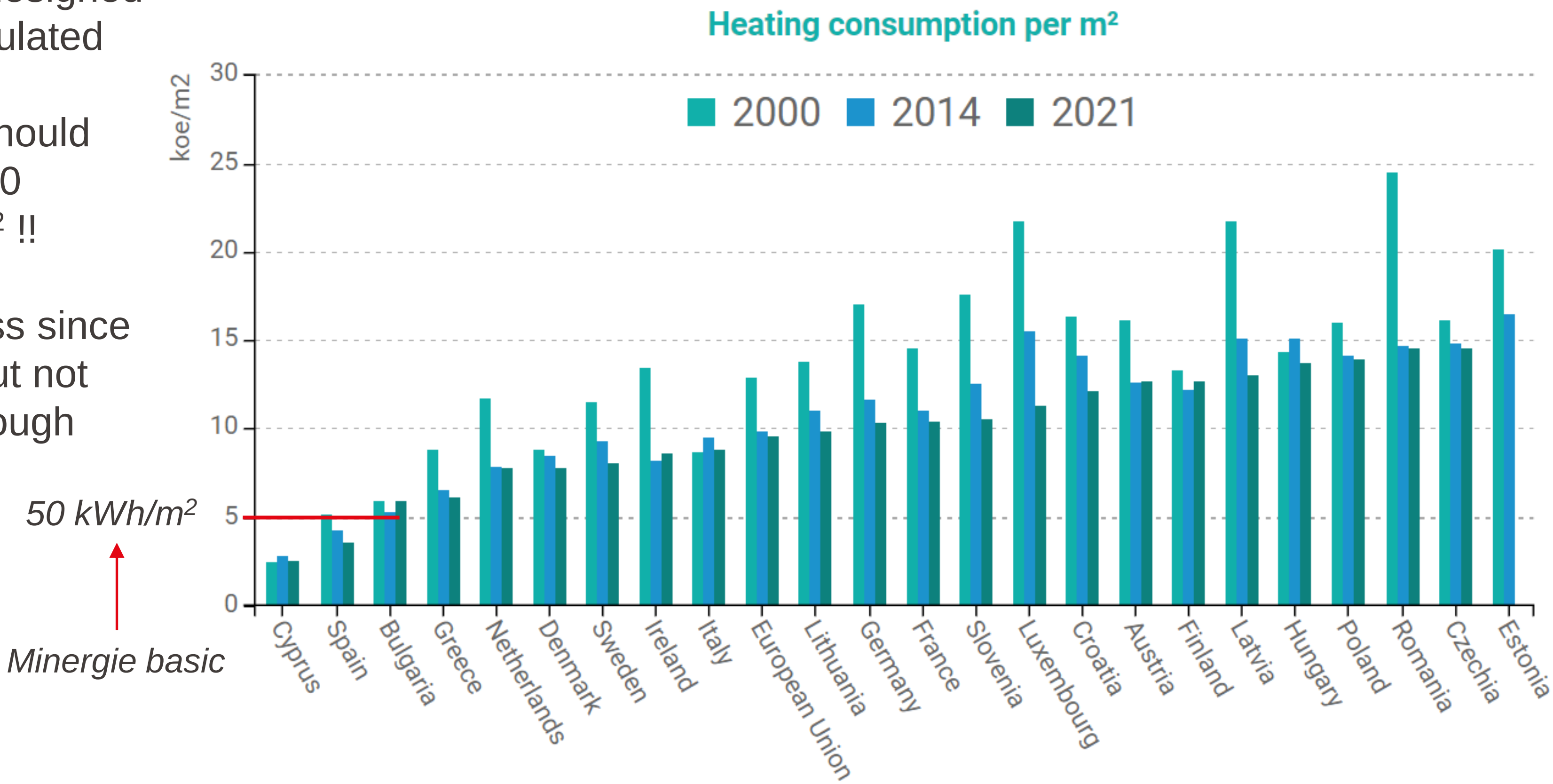
*But almost similar according to the BP method in terms of primary energy

Wood construction, up to 30 floors…
See work by M. Green, Architect

# Building: trend to heating needs in Europe

A well designed and insulated home could/should reach 50 kWh/m² !!

Progress since 2000 but not fast enough




https://www.odyssee-mure.eu/publications/efficiency-by-sector/households/heating-consumption-per-m2.html (updated Dec. 2023)

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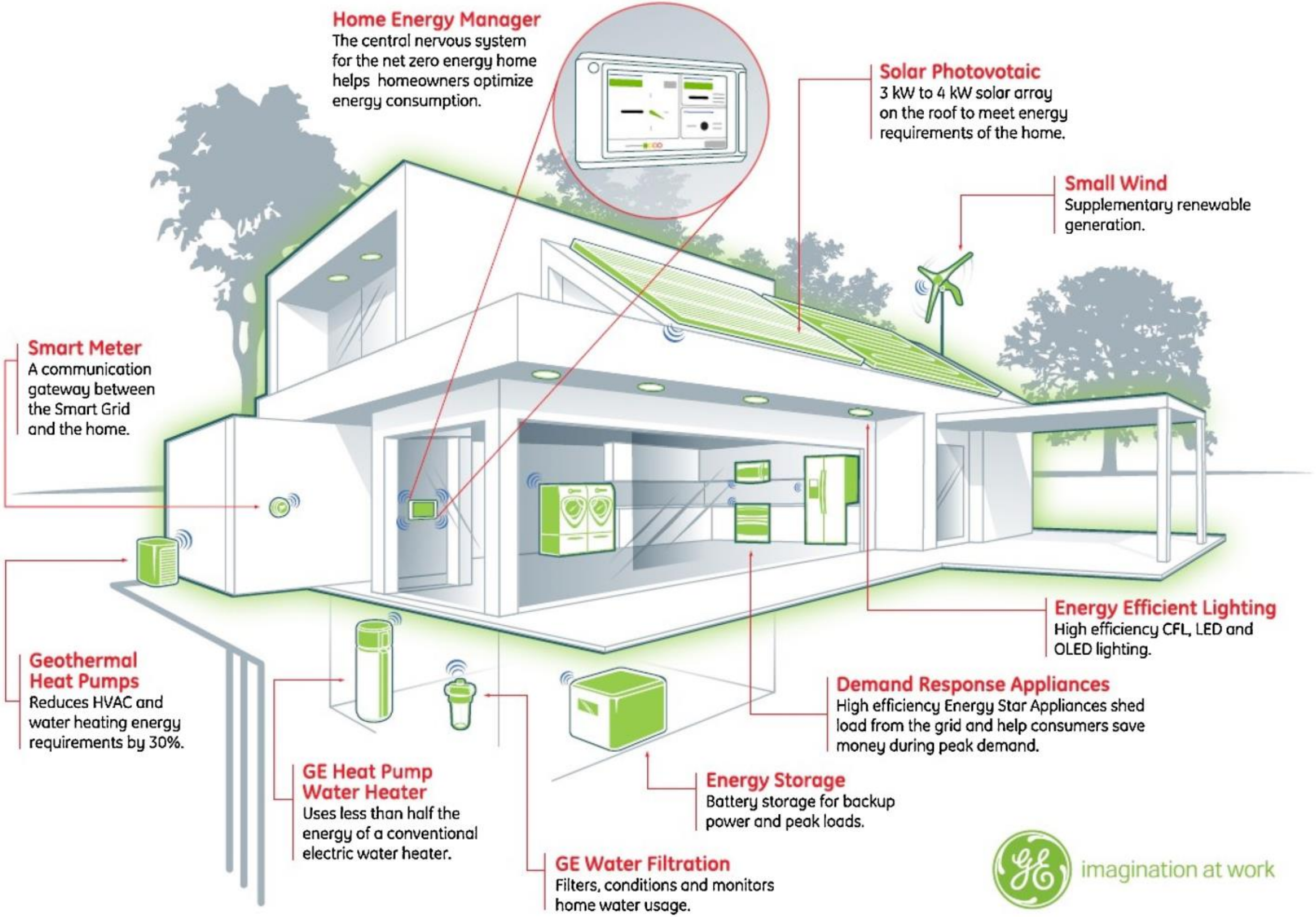
# Net zero energy buildings





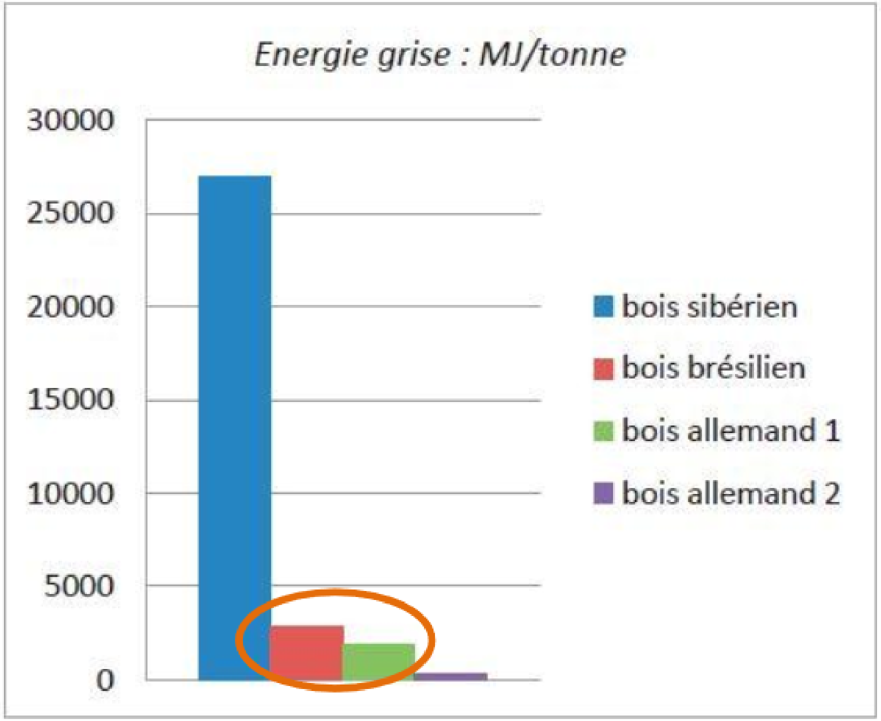


# Wood as a future (and past) building material



- Build with materials that embed $CO_2$ (instead of emitting), e.g. wood.
- For a building in Oslo → Brazilian wood comparable to German wood.
- Pay attention to both the travel distance and the transport model (sometimes disput methodology)


*Mjøsa Tower in Brumunddal near Oslo, Norway*
*85.4 metres world's tallest wooden building.*




- Siberian wood : 10 000 km by road (truck)
- Bresilian wood : 10 000 km by sea (90 %) and road (10 %)
- German wood : 500 km by road (truck)
- German wood : 500km by train

https://www.ashrae.gr/perch/resources/hellenicchapter-teeenergyinbuildings2012trachte.pdf

# Agriculture and Meat

**Sources of GHG emissions:**

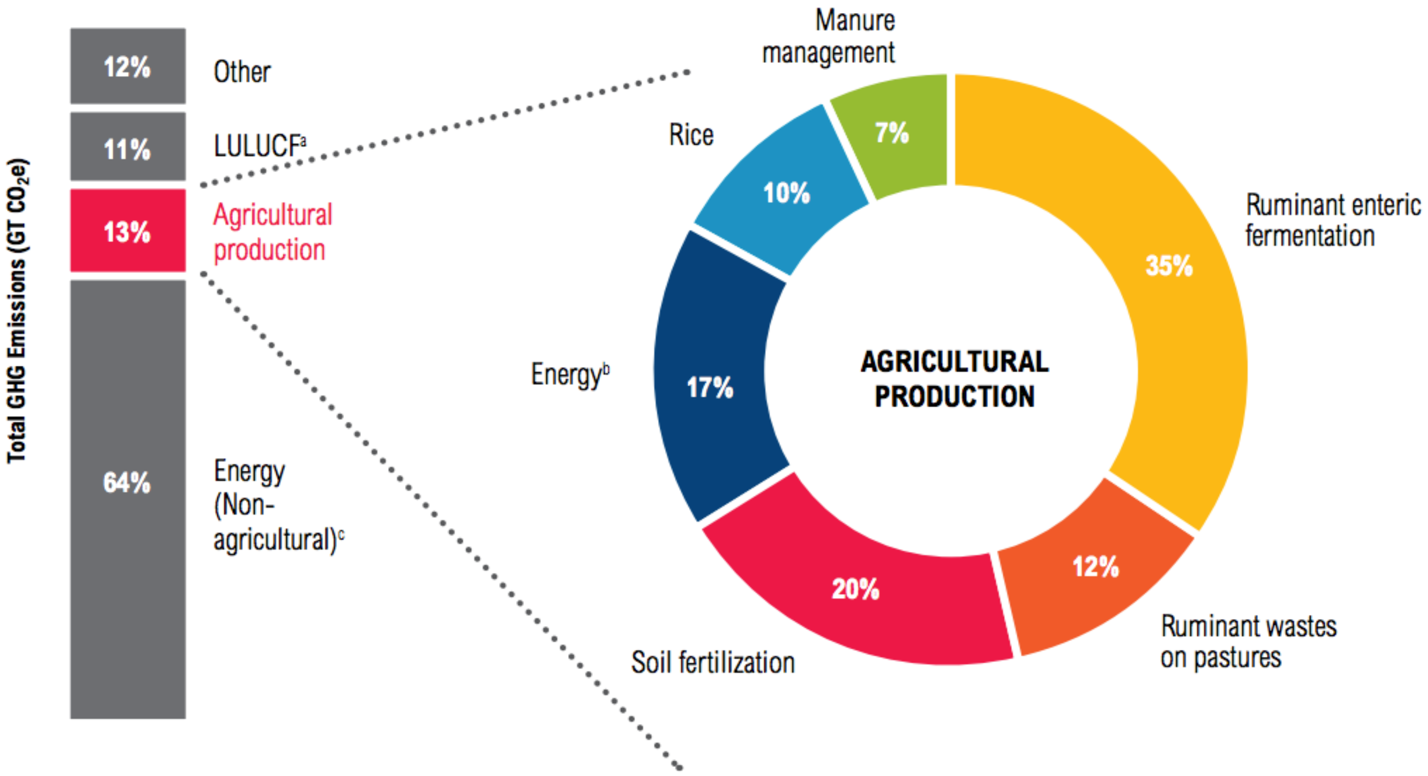
- emissions of $N_2O$.
  - Application of Management practices on soils increase availability of nitrogen in the soil (50% emissions) → synthetic and organic fertilizers.
  - Growth of nitrogen-fixing crops.
  - Drainage of organic soil.
  - Irrigation practices.
- Livestock (cattle) (~30% emissions) → production of $CH_4$ from digestive processes.
- Management manure from livestock → $CH_4$ and $N_2O$ emissions.
- $CH_4$ from rice cultivation (and N2O)… 10% of global methane emission
- Smaller sources:
  - $CO_2$ from liming and urea application.
  - $CH_4$ and $N_2O$ from burning crop residues

https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions#agriculture

# Agriculture and Meat








2009



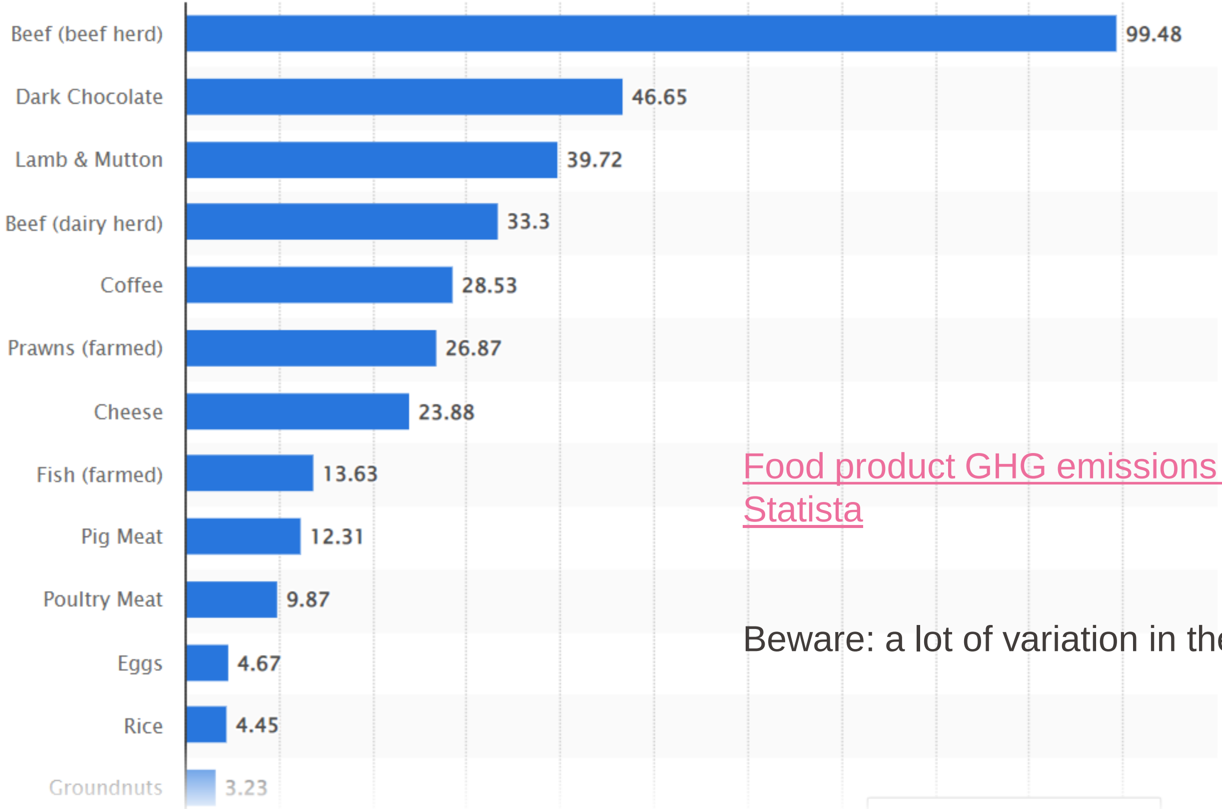
- LULUCF: Land Use, Land-Use Change and Forestry

https://skepticalscience.com/animal-agriculture-meat-global-warming.htm

# Average greenhouse gas emissions per kilogram of major food products worldwide







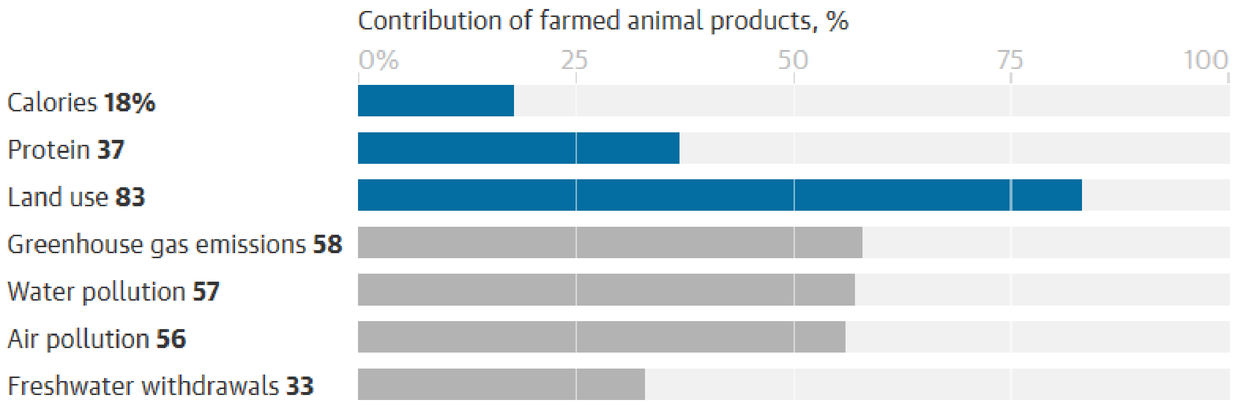

[Food product GHG emissions per kilogram worldwide | Statista]

Beware: a lot of variation in the data !

# Agriculture and Meat

- **Vegan diet →** best  way to reduce impact on GHG, global acidification, eutrophication, land use and water use.
- Withoug meat and diary consumption, global farmland use could be reduced by > 75%.

**More than 80% of farmland is used for livestock but it produces just 18% of food calories and 37% of protein**




https://www.theguardian.com/environment/2018/may/31/avoiding-meat-and-dairy-is-single-biggest-way-to-reduce-your-impact-on-earth



Christophe Ballif / Philippe Thalmann / Claudia Binder

# Agriculture and Meat

Christophe Ballif / Philippe Thalmann / Claudia Binder

**Courses of action for reduction of emissions:**

- Land and crop management → adjust methods for managing land and growing crops.
- Livestock management →adjust feeding practices and other issues to reduce $CH_4$ emissoins (and reduce livestock)
- Manure management:

  → control the decomposition of manure to reduce $N_2O$ and $CH_4$ emissions.

  → Capture $CH_4$ from manure decomposition to produce renewable energy.



https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions#agriculture

# Quiz



Christophe Ballif / Philippe Thalmann / Claudia Binder

1. What is the economic sector that contributes more to the GHG emissions?
   a) Industry
   b) Electricity and heat production.
   c) Agriculture, forestry and other land use.

2. Will planting trees mitigate strongly the $CO_2$ emissions in the atmosphere?
   a) Yes.
   b) No.
   c) It could but it would take long and a huge effort …

3. In agriculture, the $CO_2$ emission go from largest to lowest:
   a) Beef, farmed fish and tofu.
   b) Poultry, beef and nuts.
   c) Beef, tofu and poultry.

# Quiz

1. What is the economic sector that contributes more to the GHG emissions?
   a) Industry
   **b) Electricity and heat production.**
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   **a) Beef, farmed fish and tofu.**
   b) Poultry, beef and nuts.
   c) Beef, tofu and poultry.

Christophe Ballif / Philippe Thalmann / Claudia Binder

# Renewable Energies





**Consumption can be decreased, human can be more reasonable but Energy will still be needed !**

**→ Development of renewables**

**Challenges:**

1. Policy and regulatory uncertainty.
2. High investment risks in developing countries.
3. System integration of wind and solar.

**Source of additional potential:**

1. Solar PV.
2. Onshore/Offshore wind.
3. Hydropower, biomass, geothermal



https://www.iea.org/reports/renewables-2019

# Somes scenario for the future

- To differentiate between models «what should be done», and scenarios «what will likely happen»
- Scenarios/models based on announed policies by country
- Levels of details of analysis or simulation/optimisation very different
- Of course strongly diverging numbers depending on the sources
- Often cost perspectives and learning curves not integrated (e.g. for renewable and electricity storage)

E.g. a simple tool to start

SWISS ENERGYScope

https://www.energyscope.ch/fr/

En-ROADS (climateinteractive.org)

Note: in the last session we'll have a guest who will present one scenario/model based for Switzerland



Christophe Ballif / Philippe Thalmann / Claudia Binder

# World final energy demand by : one scenario, still keeping a lot of fossile by DNV

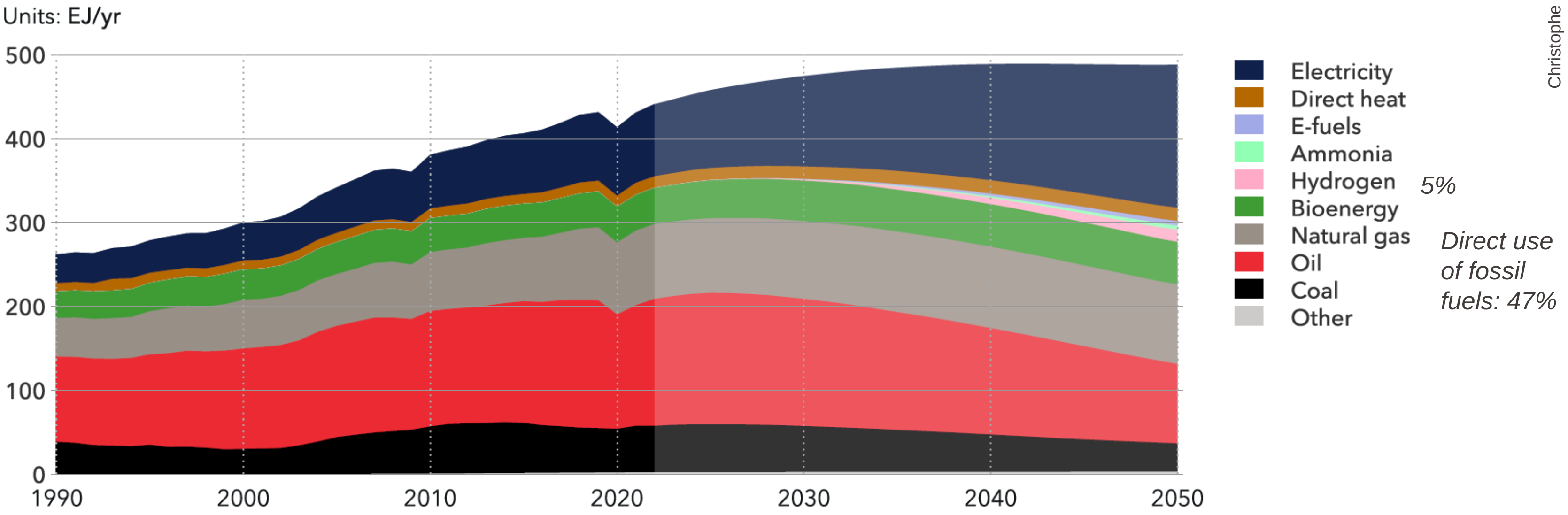


Christophe Ballif / Philippe Thalmann / Claudia Binder

*! Use The Physical Energy Content Method (IEA reports).*
*kWh from wind, solar and hydro, and thermal kWh for nuclear and bioenergy*

FIGURE 1.29

**World final energy demand by carrier**




Historical data source: IEA WEB (2023)



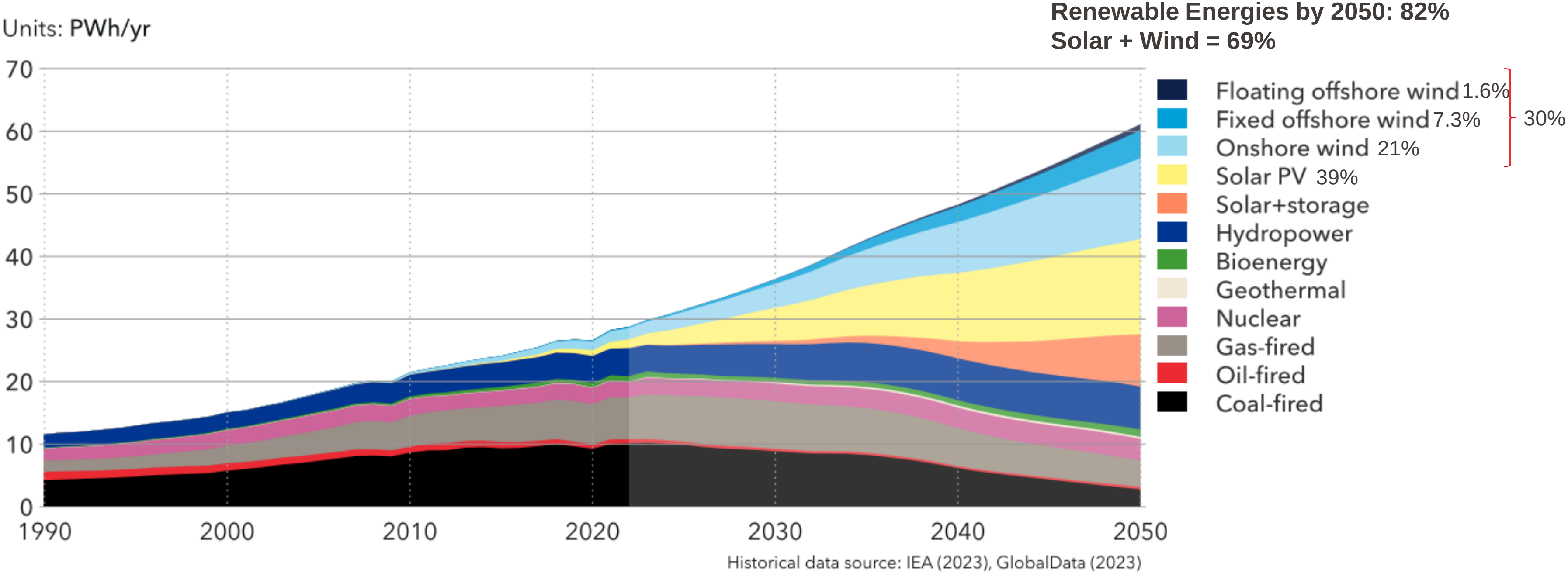
*Source: Energy Transition Outlook, DNV.com - When trust matters - DNV*

# The same scenario for the power sector 57’000 TWh



FIGURE 2.4

**World grid-connected electricity generation by power station type**




*Source: Energy Transition Outlook, DNV.com - When trust matters - DNV*

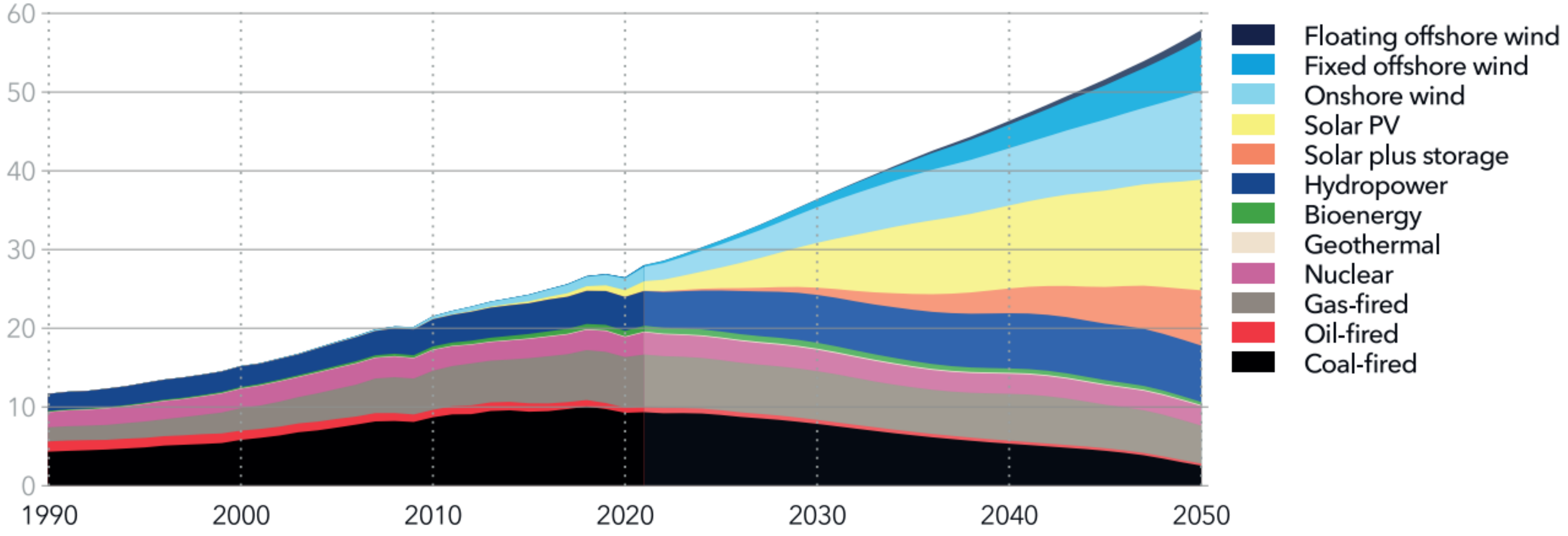
ENERGY SUPPLY, ECONOMICS AND TRANSITION

# The same scenario for the power sector 57’000 TWh

FIGURE 2.3

**World grid-connected electricity generation by power station type**

Units: PWh/yr




Historical data source: IEA WEB (2020), GlobalData (2021)

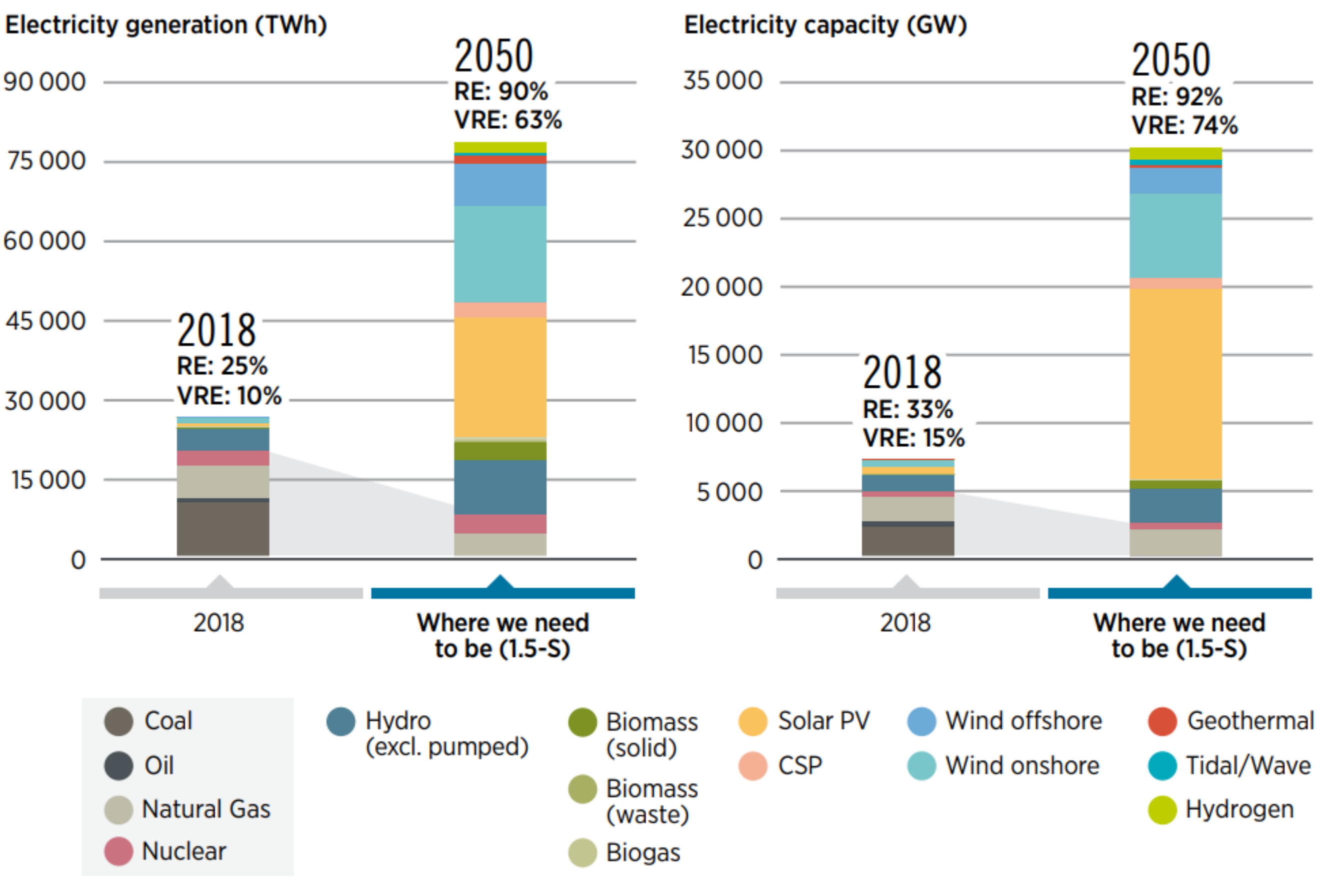
Source: Energy Transition Outlook, DNV.com - When trust matters - DNV

# Renewable Energies – Potential (2050), 1.5°C scenario



Claudia Binder

## IRENA 2021



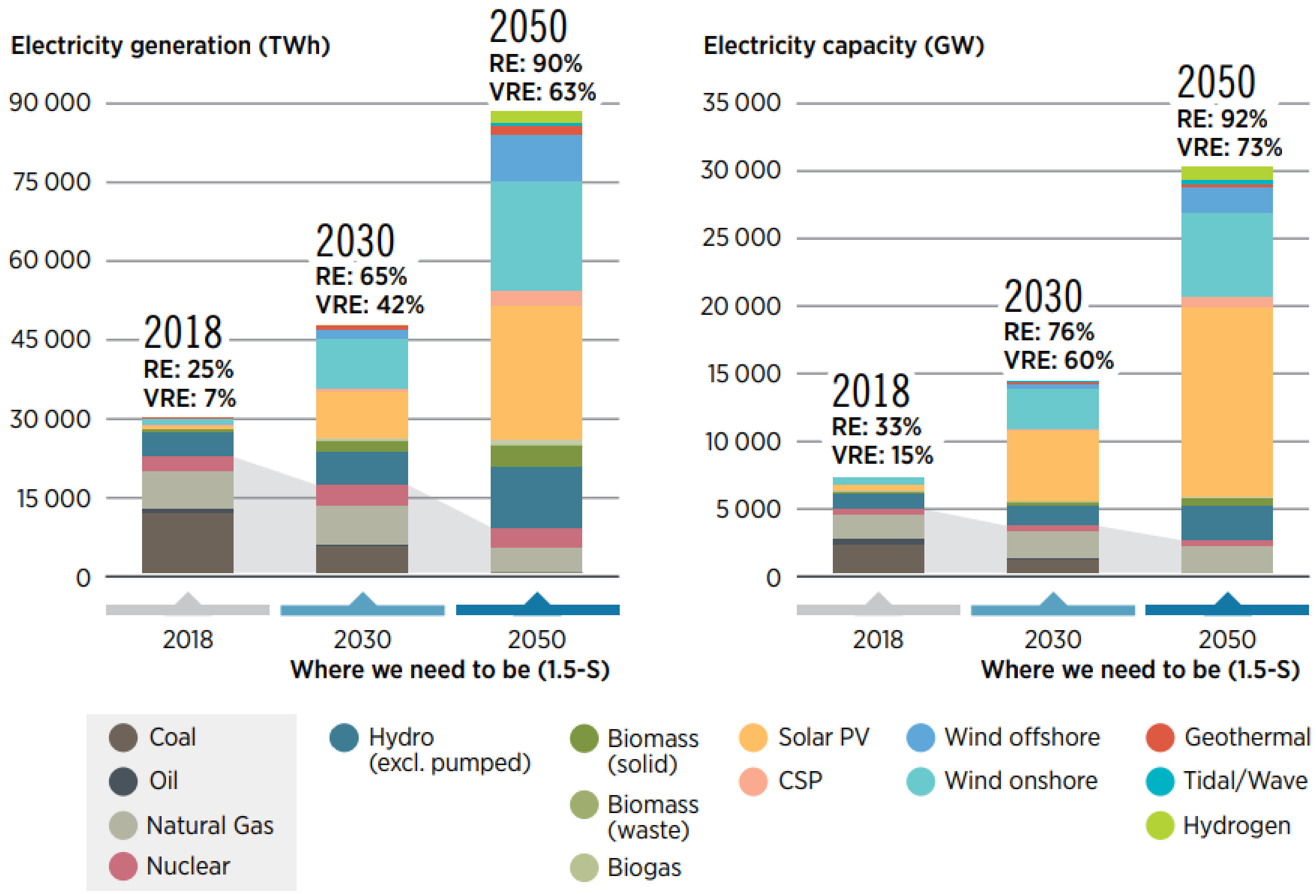

| Tech 2050 | Electricity generation [TWh] | Share [%] |
|---|---|---|
| Wind | 25'000 | 31 |
| Solar PV | 25'000 | 31 |
| Hydro | 10'000 | 13 |
| Bioenergy | 5'000 | 6 |
| Geothermal | 2'000 | 3 |
| Others | 5'000 | 6 |
| **Total** | **72'000** | **90** |

Positive/should be scenario
But still some TWh missing
**(30'000** ?)

https://www.irena.org/publications/2021/Jun/World-Energy-Transitions-Outlook

EPFL

**FIGURE 2.3 Global total power generation and the installed capacity of power generation sources in 1.5°C Scenario in 2018, 2030 and 2050**




# IRENA 2022

## 13’000 TWh added…

## still some gas



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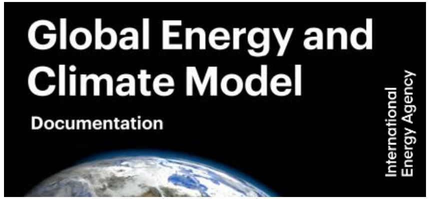
# The IEA scenarios

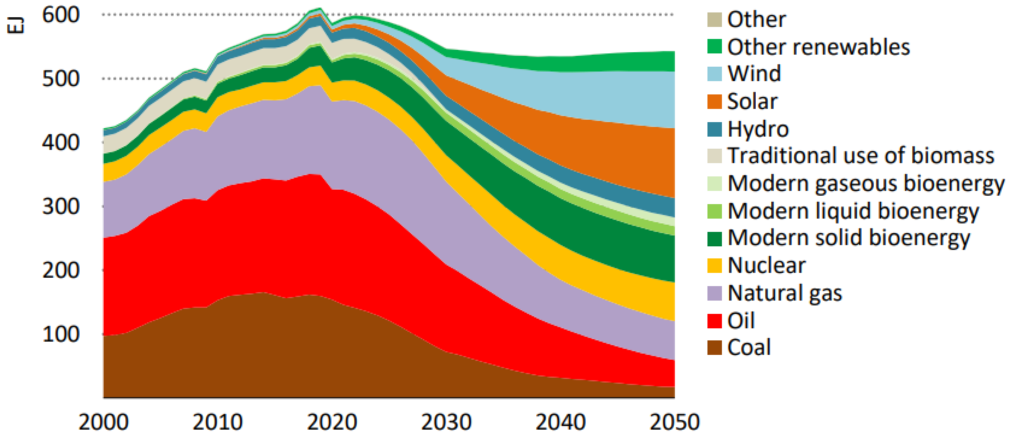





[Global Energy and Climate Model Documentation (windows.net)]


[Net Zero by 2050 - A Roadmap for the Global Energy Sector (windows.net)]

**Figure 2.5 ▷ Total energy supply in the NZE** (net zero emission)






*Renewables and nuclear power displace most fossil fuel use in the NZE, and the share of fossil fuels falls from 80% in 2020 to just over 20% in 2050*

The **2021 NZE** scenario of IEA also relis on new renewable. But it also bets **on carbon sequestration to compensate for fossiles emissions**, and a significant amount of bioenergy.

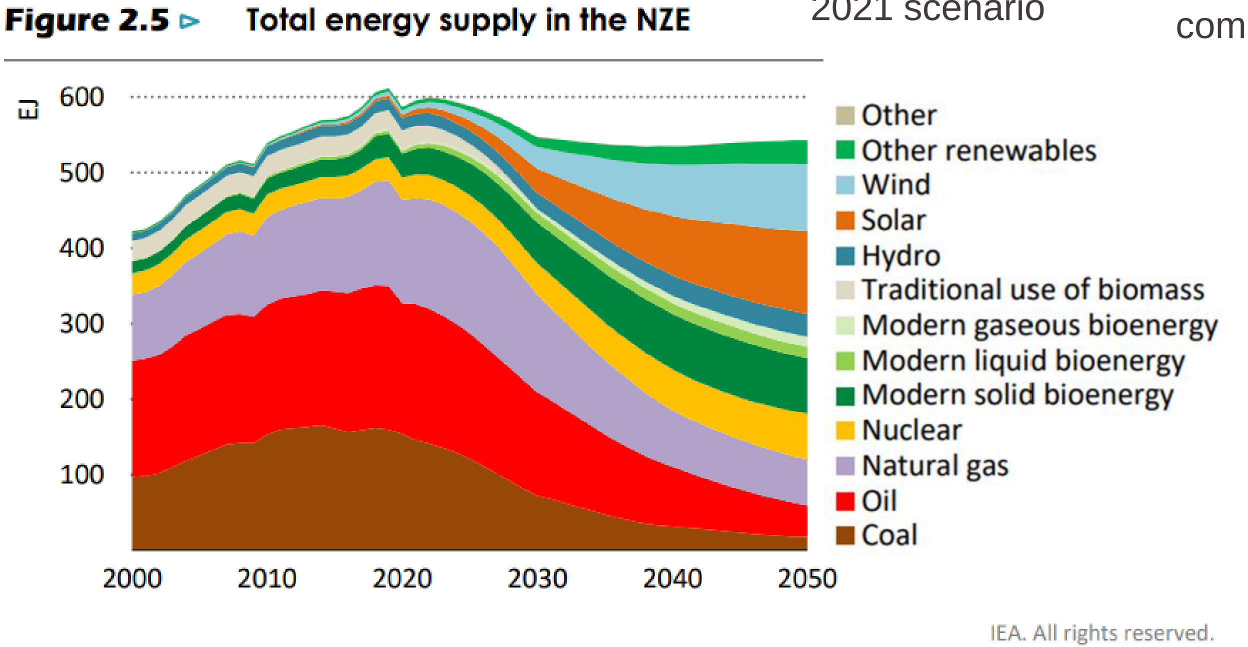
Note on IEA data: kWh of wind, hydro solar counted directly (not muliplied by 2.5 as in BP reports). The thermal kWh for all thermal source counted as such (including for nuclear x3 ). The NZE 2021 would mean around 30’000 TWh solar, 27’000 TWh wind by 2050, Nuclear ~ 4300 TWh (from 2700 today)

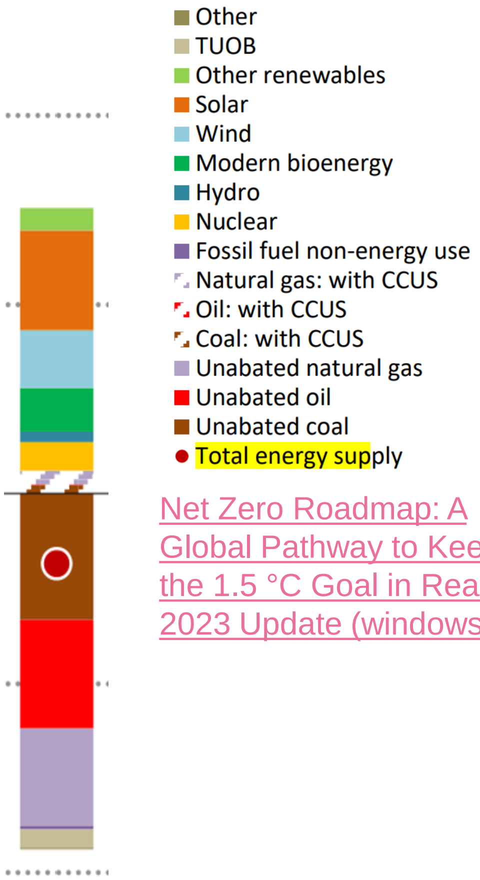
# The IEA scenarios

2021 scenario

(net zero emission)

**2023 scenario**: changes compared to to today




[Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach - 2023 Update (windows.net)]

The 2023 Net zero scenario of IEA sees much less carbon squesestration and much more solar, and more nuclear.
almost 30% increase in PV compared to 2021 scenario → around 39’000 TWh PV, 25’000 TWh wind,………..

# A cautious note:
# all IEA, IPCC prosposed scenario are slow and even IRENA scenario are not ambitious enough for decarbonisation. But they improve over the years….





# A major points in those scenarios

- systemic overevaluation of the costs of new renewables (e.g. IPCC with PV powerplants at 1€/W in 2050 leading to low amount of solar)
- overestimation of the costs required for changes.



*“They explained that the economic potential of solar and renewables keep being largely underestimated while energy transformation and mitigation costs, by contrast, are being overestimated”*

www.pv-magazine.com/2021/03/31/solar-still-largely-underestimated/ and e.g. the cited reference in Joule: Solar photovoltaics is ready to power a sustainable future

# Towards full system modelling

# Flexible electricity generation, grid exchange and storage for the transition to a 100% renewable energy system in Europe






A B S T R A C T

Two transition pathways towards a 100% renewable energy (RE) power sector by 2050 are simulated for Europe using the LUT Energy System Transition model. The first is a Regions scenario, whereby regions are modelled independently, and the second is an Area scenario, which has transmission interconnections between regions. Modelling is performed in hourly resolution for 5-year time intervals, from 2015 to 2050, and considers current capacities and ages of power plants, as well as projected increases in future electricity demands. Results of the optimisation suggest that the levelised cost of electricity could fall from the current 69 €/MWh to 56 €/MWh in the Regions scenario and 51 €/MWh in the Area scenario through the adoption of low cost, flexible RE generation and energy storage. Further savings can result from increasing transmission interconnections by a factor of approximately four. This suggests that there is merit in further development of a European Energy Union, one that provides clear governance at a European level, but allows for development that is appropriate for regional contexts. This is the essence of a SuperSmart approach. A 100% RE energy system for Europe is economically competitive, technologically feasible, and consistent with targets of the Paris Agreement.






Michael Child, C. Breyer, et al. Renewable Energy 139 (2019) 80-101

# Modelling at all country level the Power Sector for full transition



Christophe Ballif / Philippe Thalmann / Claudia Binder

**Considerations**:

- Hourly rate electricity generation and demand in (partially) decarbonized scenario.
- New interconnection lines (Including HVDC).
- Consider Region and Area solutions (more interconnected)
- Biomethane and synthetic methane replace fuels when required
- Increase role of batteries for energy balancing by 2025.
- Learning curve for cost of PV, wind and batteries

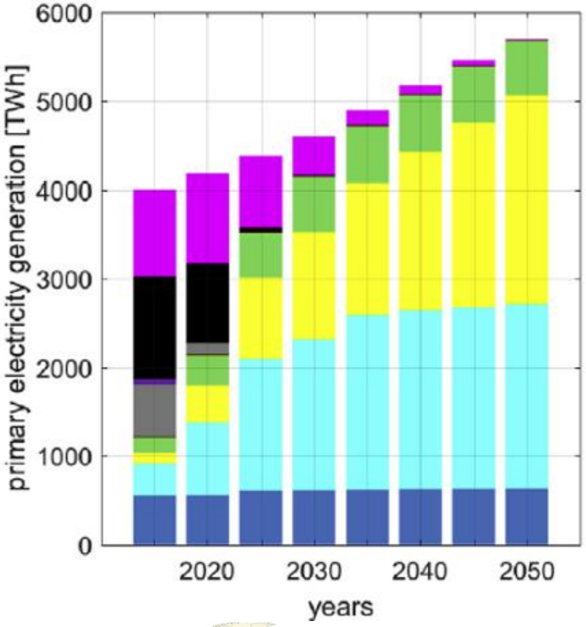
See paper : Low-cost renewable electricity as the key driver of the global energy transition towards sustainability – ScienceDirect and

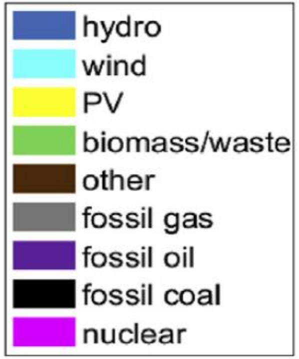
# A short look at Europe: a first partial decarbonisation



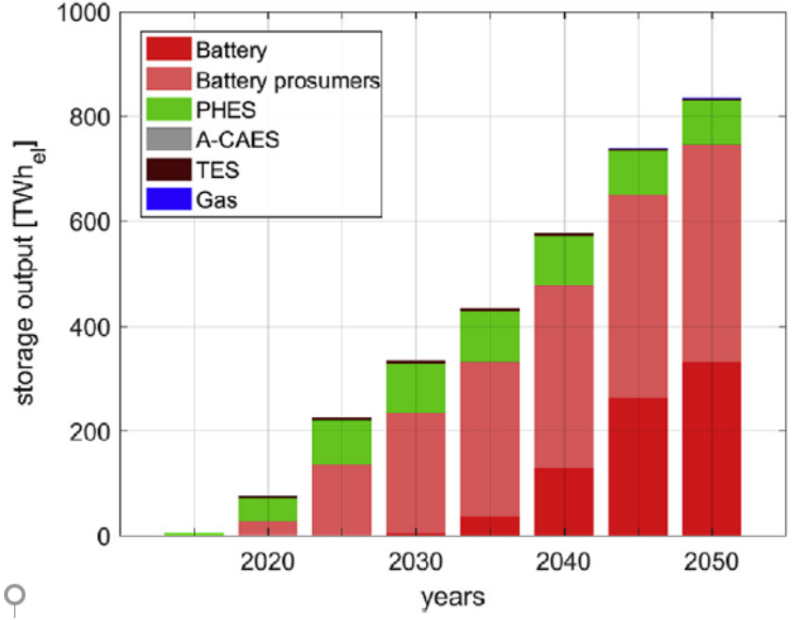
Prof. Christophe Ballif

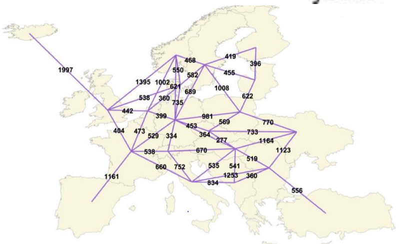
In a area connected scenario for clean power sector (with only moderate electrificiation) **




Michael Child, C. Breyer, et al. Renewable Energy 139 (2019) 80-101

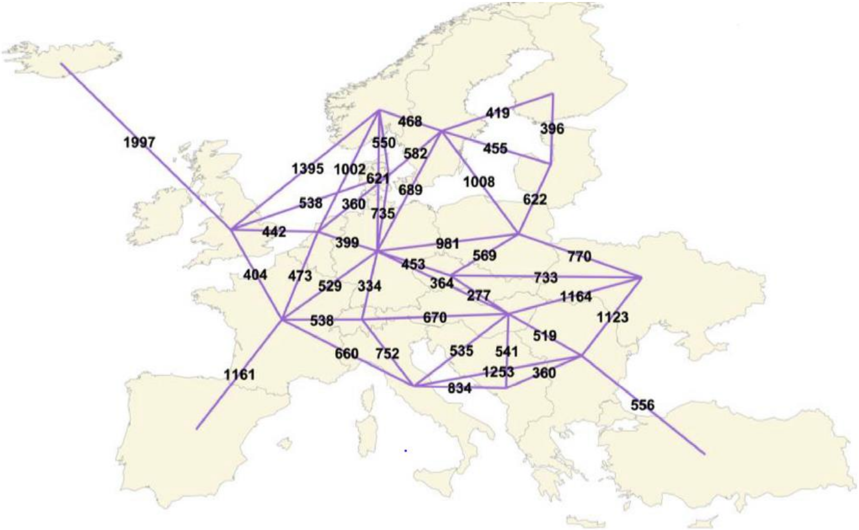


In Europe: good complemtarity between wind and sun on a monthly base. System stable on an hourly base thanks to storage

Battery storage and pumped hydro necessary to balance the grid on hourly bases → **Overall cheaper cost per kWh (6-7 cts/kWh)**

# Grid Adaptation



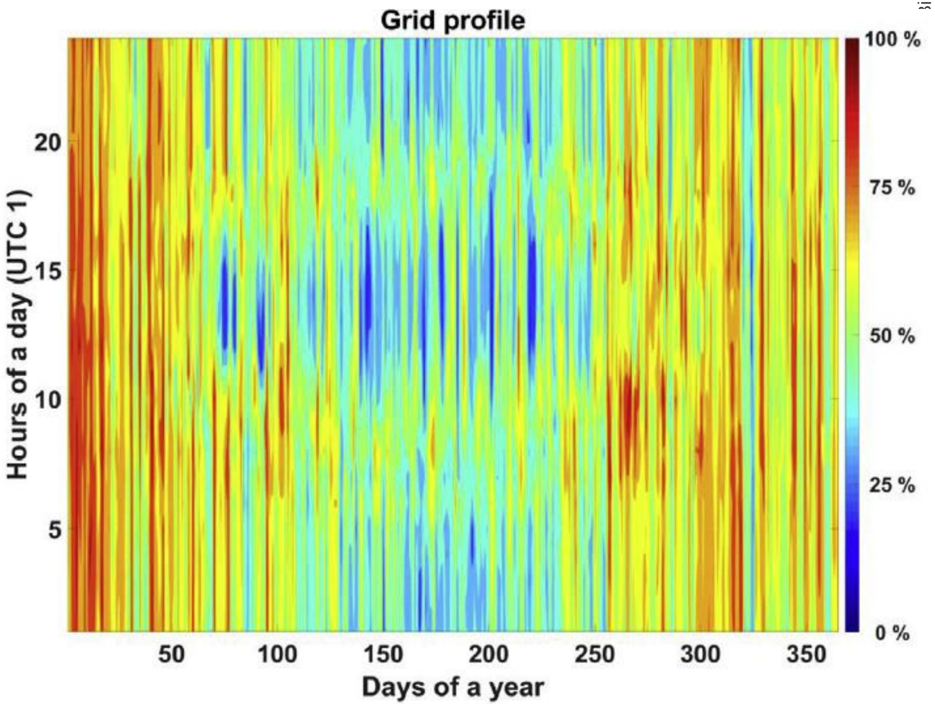




**Fig. 14.** Grid utilisation profile for the Area scenario in 2050.

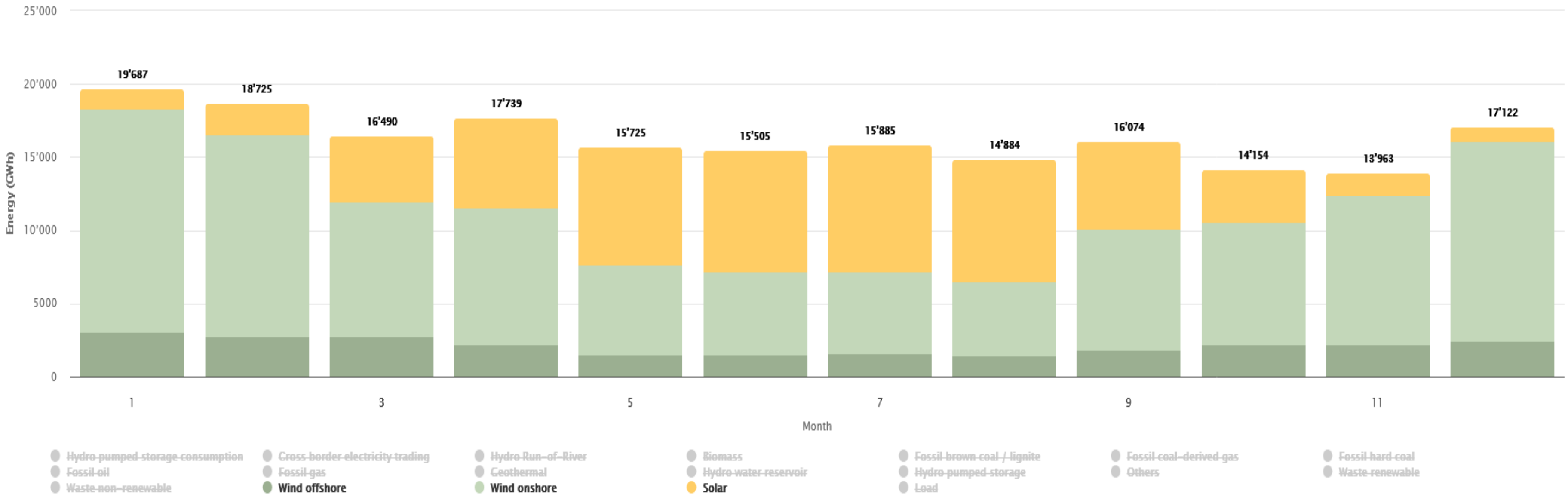
Michael Child, C. Breyer, et al.
Renewable Energy 139 (2019) 80-101

# Exemple of complementarity wind-solar

Wind vs. PV : a good complementarity winter-summer in Europe, CH, and germany

Prof. Christophe Ballif

Electricity generation from wind and solar PV in Germany in 2024.
*Chart by Fraunhofer ISE, 2024.*

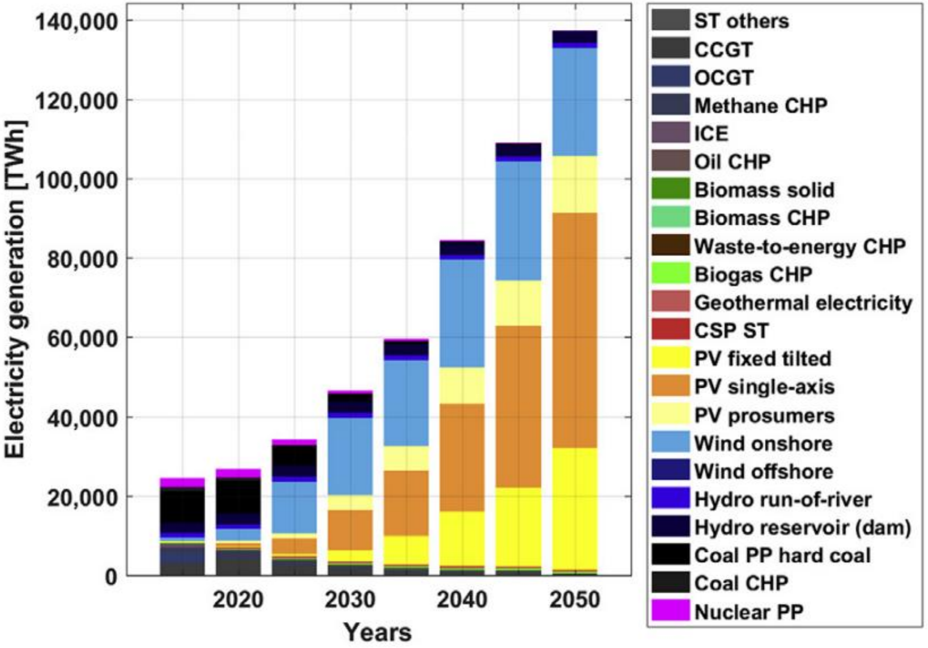


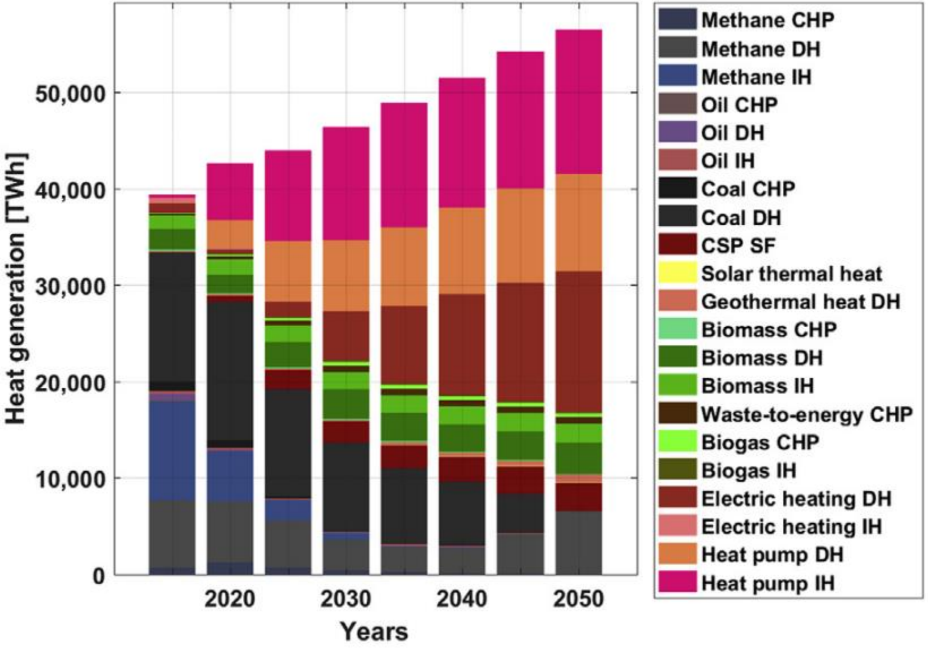



*https://www.energy-charts.info/charts/energy/chart.htm?l=en&c=DE&month=-1&stacking=stacked_grouped&year=2024&legendItems=0000000000000001110&source=public*

# A complete world scenario with 134’000 TWh electricity






Because of its low LCOE,
PV tends to grow in share in such scenario with
**63’000 GW (needs more than 2 TW per year)**
which reserves spaces for Power-to-gas

Low-cost renewable electricity as the key driver of the global energy transition towards sustainability - ScienceDirect

https://doi.org/10.1016/j.energy.2021.120467

Bodganov, Breyer et al.

EPFL

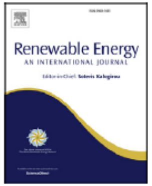
Renewable Energy 184 (2022) 430–442

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

ELSEVIER




# Zero air pollution and zero carbon from all energy at low cost and without blackouts in variable weather throughout the U.S. with 100% wind-water-solar and storage

Check for updates

Mark Z. Jacobson*, Anna-Katharina von Krauland, Stephen J. Coughlin, Frances C. Palmer, Miles M. Smith

*Department of Civil and Environmental Engineering, Stanford University, Stanford, CA, 94305-4020, USA*

Possible even in US !

(but note:author is seen controversial controversial)

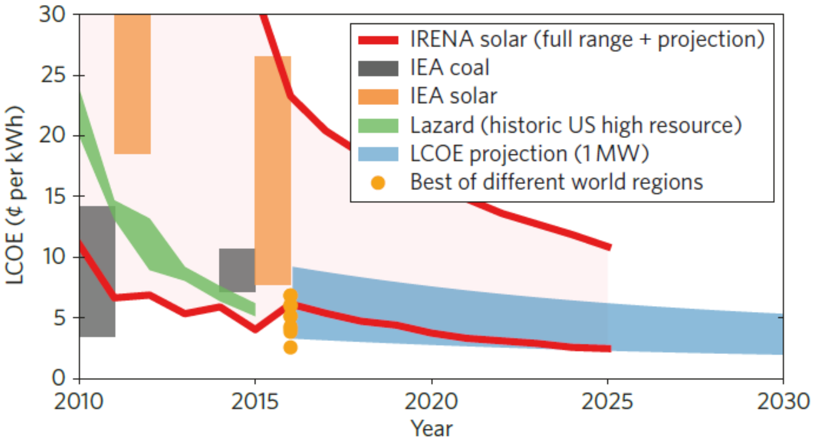
# General Literature to the Feasability of 100% Renewable Systems (more than sector)



Several studies show the feasability. They answer to those who say it is not possible.
Response to ‘Burden of proof: A comprehensive review of the feasibility of 100% renewable-electricity systems’ T.W. Browna,et al. Renewable and Sustainable Energy Reviews 92 (2018) 834–847

**Note**: many scenarios underestimate the potential and potential low cost of Wind, PV**, and batteries.

For example: breyer et al. of Lappeenranta University of Technology, make aggressive but possible assumptions (e.g. 0.3€/W for PV power plants).
People enclined against renewable takes worst case (e.g 1.5€/W for PV power by Jancovici)




Overestimated costs of solar by IEA reports.

# How much does the energy transition costs ?



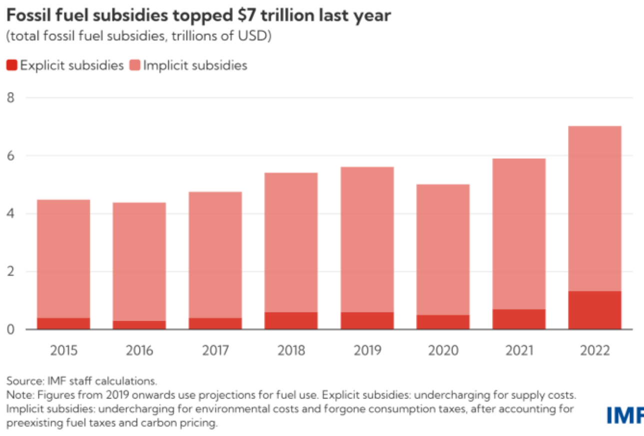


- IRENA (international renewable energy agency) gives high estimates: investments/costs up to ***3.8 Trillions*/year** (typically 3-4% of world GDP). Now cheaper cause of China
- **Current provements in storage, additional flexibility and consideration of lower renewable costs will make the bill lower** (e.g. less grid adaptation). Renewables (and batteries) are always underestimated in the their capacity to decrease…. Can estimate more 1.5% to 2%
- Important parts in buildings and grids, a small part in storage (even though trade-off not always obvious)

## Direct costs are not negligeable for a full transition

- They are bearable or even “cheap” if you consider:

- No more fossile fuel import (CH 6-8 billions/years in CH and continues after 30 years) and fossile fuel subsideies
- Reduced dependency on fluctuating price for consumers
- Improved health, more jobs
- Reduced global warming



# Toward Energy Transition

Some first steps

Of course a lot in the power sector !

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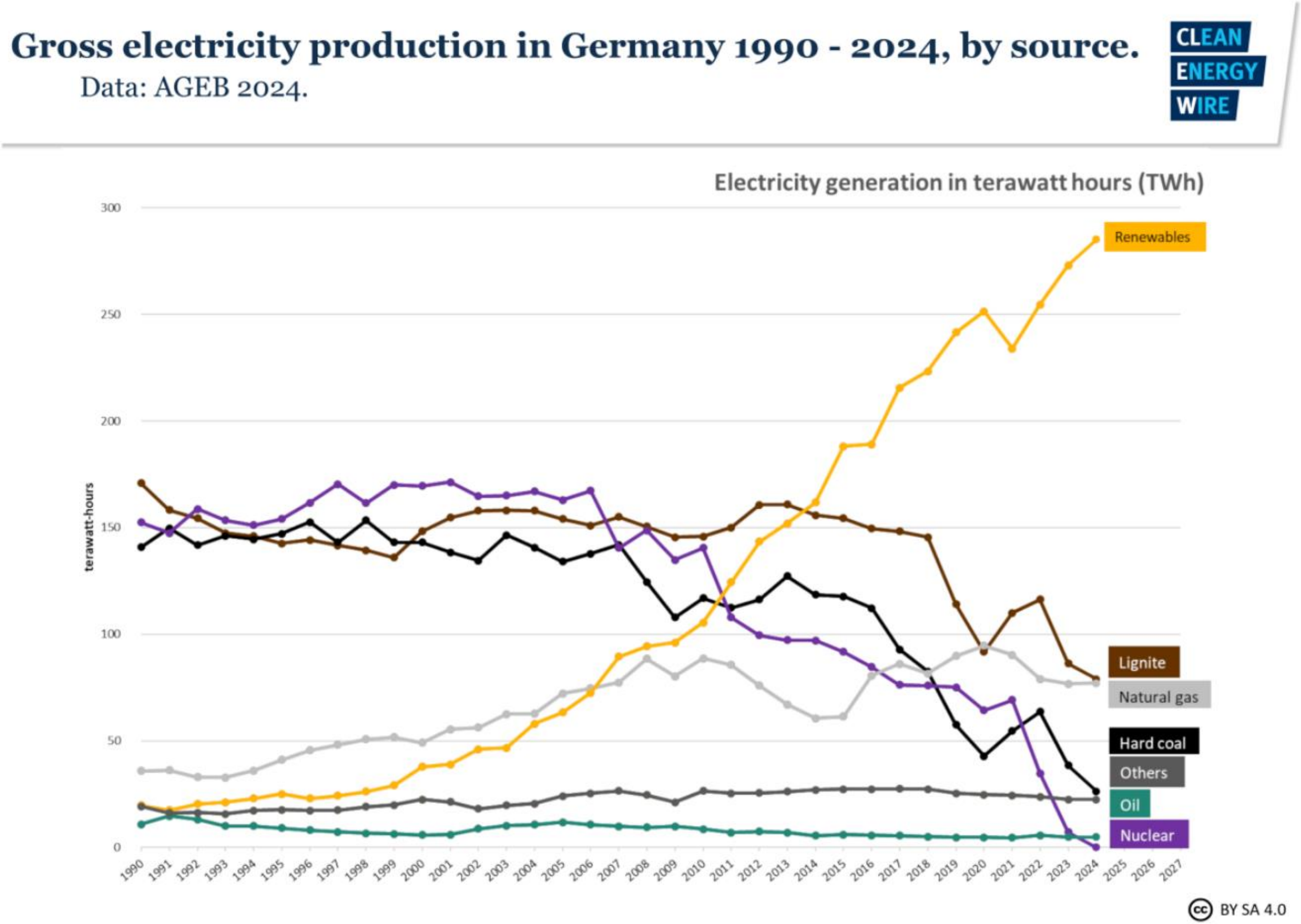
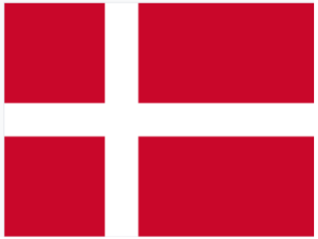
Christophe Ballif / Philippe Thalmann / Claudia Binder

# Germany increased share of nrew renewables in Electricity

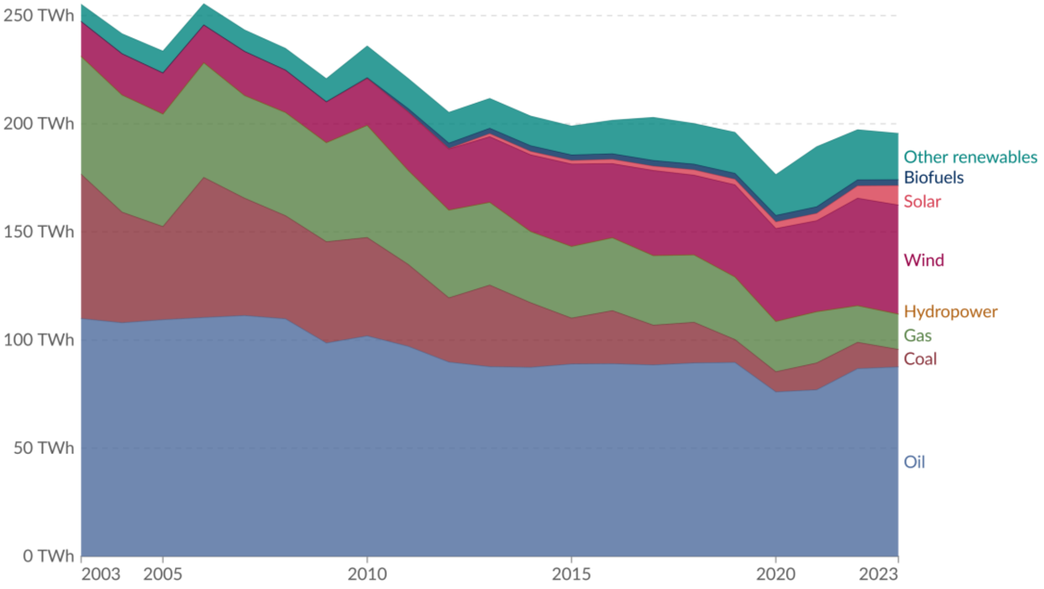



Germany's energy consumption and power mix in charts | Clean Energy Wire



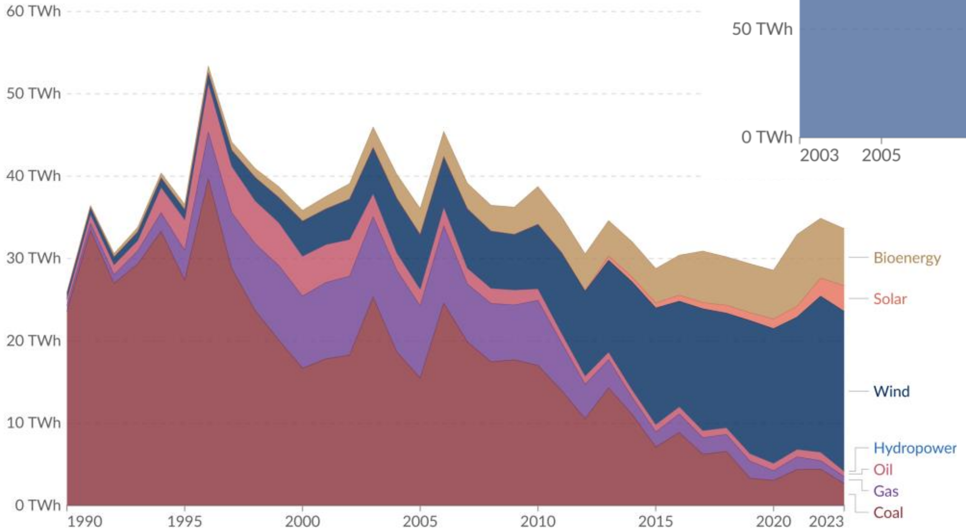
## Energy consumption by source, Denmark

Measured in terms of primary energy[1] using the substitution method[2].




## Electricity production by source, Denmark

Measured in terawatt-hours[1].




From 300 to 200 TWh
Primary energy (substituion method)

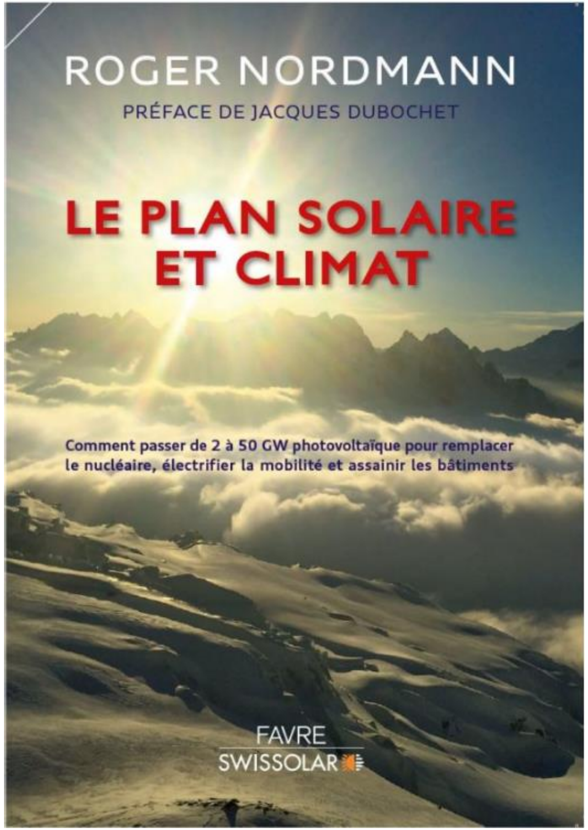
https://ourworldindata.org/energy/country/denmark

# The Swiss case



Prof. Christophe Ballif

What it really takes to decarbonize? The example of Switzerland




Scenario for a partially decarbonised Switzerland: Typically 50 GW (by 2050) PV, working in conjunction with hydro + wind (~ 5-7TWh) + biomass (e.g. distance heat, biogas)

- Efficiency (save 12 TWh electricity)
- Electric cars
- Heat-pumps

→ 86-100% $CO_2$ reduction

In book: worst case Keeps $CO_2$ emissions for 9 TWh winter (not enough solar), e.g. gas power plant

**or use $H_2$ (import or local), or produce/import wind electricity.**
**Upsides: more hydro, delay dam emptying, more solar in high altitude, more wind, keep biomass/biofuel……**

To be discussed in Final lecture

OBJECTIF D'UNE SUISSE NEUTRE POUR LE CLIMAT EN 2050


Study
Of Swiss
Federal office
For Energy
26.11.2020

37 GW PV
(not much
wind)
For 9 millions
people
By 2050
(n.b. 50 GW in
Nordman
scenario)

Now 45 TWh
new renewable
in gov plan for
2045. To be
voted on in
June

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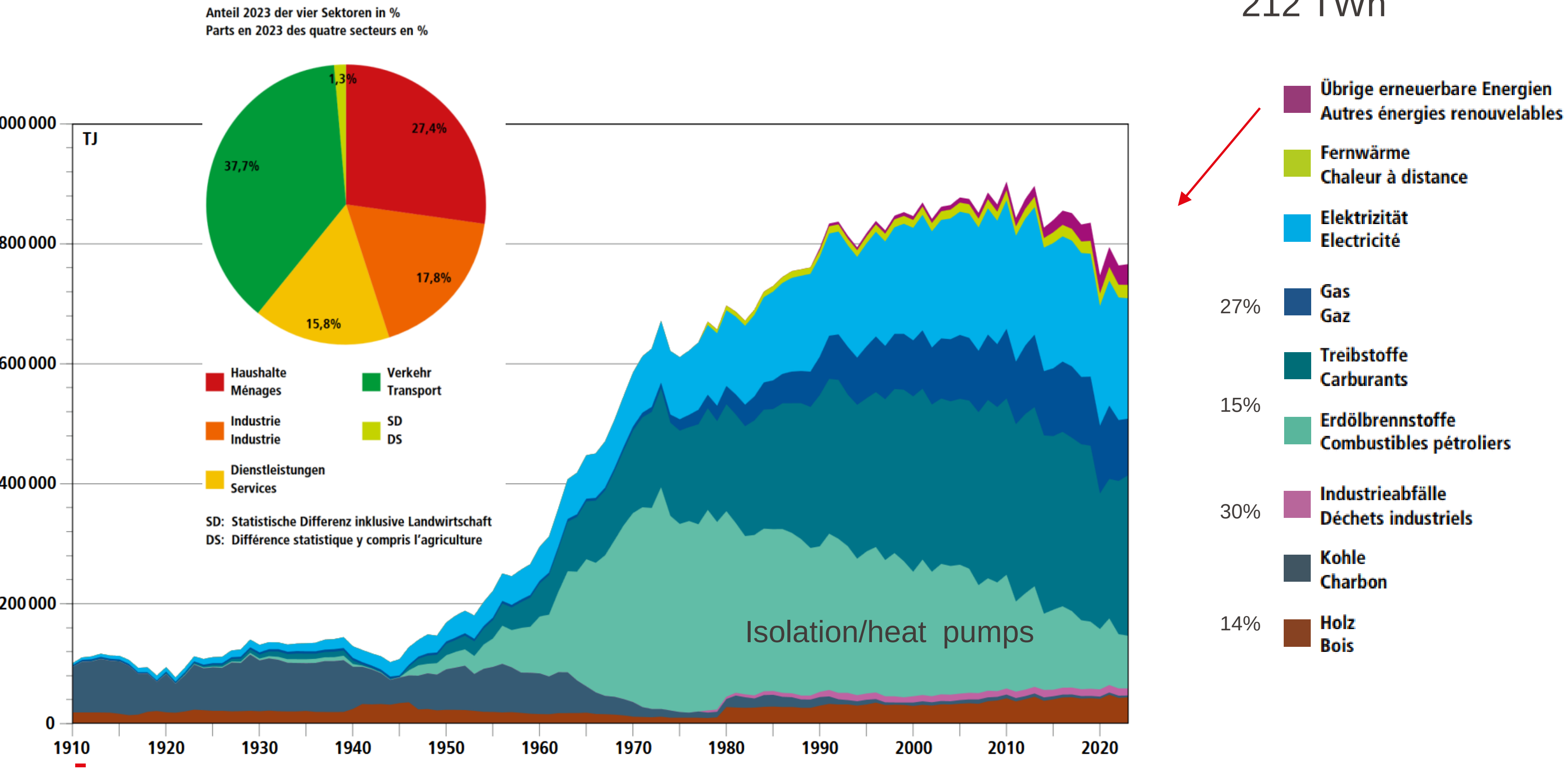
# Swiss final energy consumption up to 2023

212 TWh



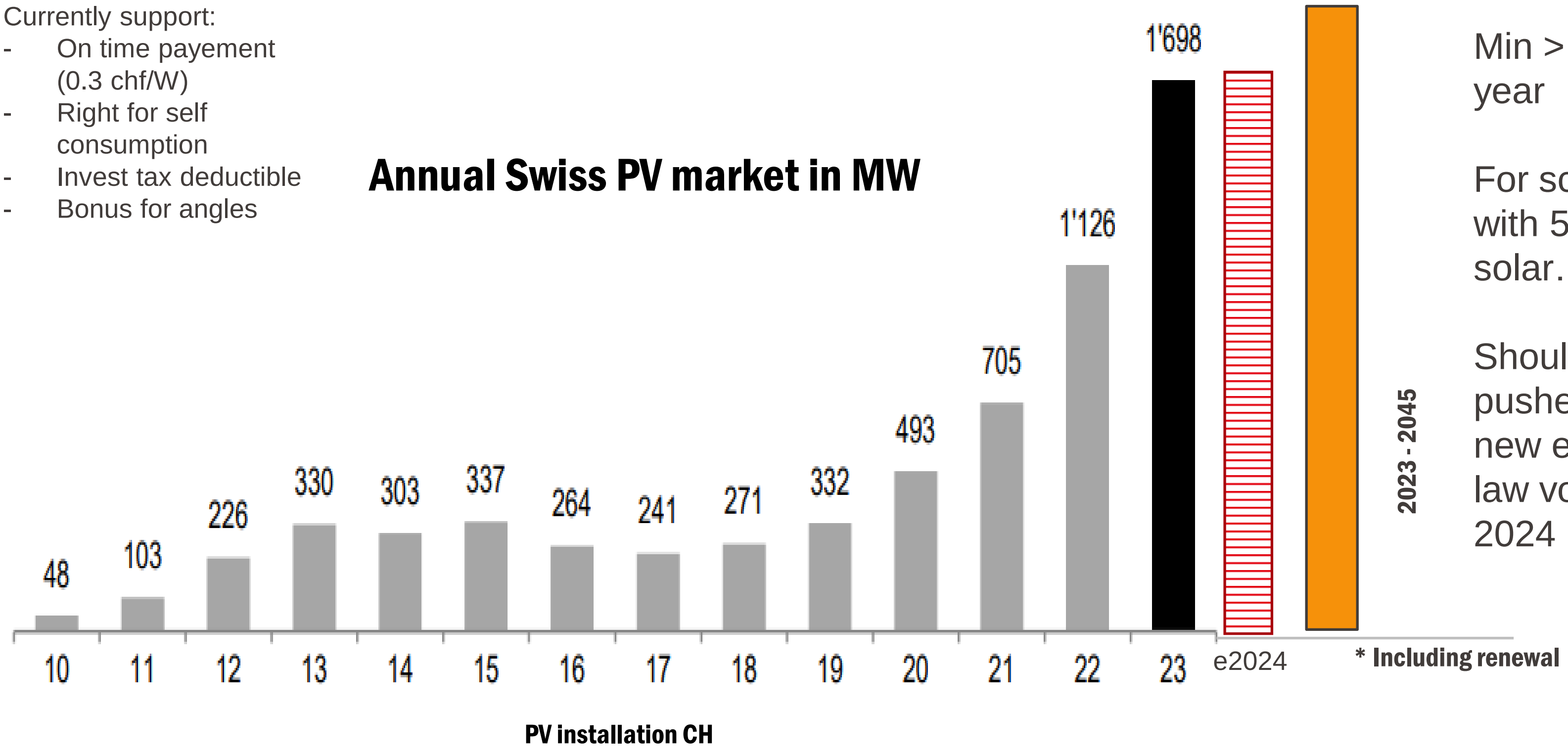

https://www.bfe.admin.ch/bfe/en/home/supply/statistics-and-geodata/energy-statistics/overall-energy-statistics.html

Christophe … Claudia Binder

# SWISS PV Market

End 2024: 7.7 GW installed
~11 % of annual CH electricity consumption of 2024

Currently support:
- On time payement (0.3 chf/W)
- Right for self consumption
- Invest tax deductible
- Bonus for angles




Orders of magnitudes starts to be ok !

Min > 1.7 GW year

For scenarios with 50 GW solar….

Should be pushed with new electricity law voted in 2024 !

*Source: Swissolar/internal data*

Prof. Dr. Christophe Ballif

# Quiz

1. **In the current EU electricity mix, renewable energies generate more than fossil fuels.**
   a) True.
   b) False.
   c) I'm not sure…

2. **From IRENA's 2022 estimations, by 2050 these will be the main contributors to the electricity generation (in order from most to least).**
   a) Solar, wind and Nuclear.
   b) Hydropower, wind and solar.
   c) Wind, solar and hydropower.

3. **By a fully decarbonized 2050, which one of the renewable technologies will grow most?**
   a) Wind and solar
   b) Geothermal
   c) Nuclear

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# Quiz

1. **In the current EU electricity mix, renewable energies generate more than fossil fuels.**
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   - **a) Wind and solar**
   - b) Geothermal
   - c) Nuclear



Christophe Ballif / Philippe Thalmann / Claudia Binder

# Fighting global warming: «what should happen» globally

- **Develop massively wind and solar**

Other sources: biomass, hydro, geothermal

Maintain (or develop)  nuclear base to facilitate transition

Keep and optimise fossile fuel assets for flexibility (but low capacity factor)

Capitalise on electrochemical storage (batteries) and synergies with mobility

Necessary amount of power-to-gas… (industry, heat, peak power). Keep small !

Keep biofuels mostly for peaks, air and maritime transport where difficult to replace

**Agriculture**

Sequestration through biomass and soils

Less cattle emitting $CO_2$

**Strategy**

Local production (including of energy products)

Ressources (metals, lithium, …)

Manpower: educate, prioritize and pay better

Intelligence: control and flexibility of energy systems

- **Energy efficiency**

Switch to electrical (transport, heat pumps)
Isolate building
Track losses (ventilation pumps),…

**Sufficiency**

Rethink consumption (smaller room, no flight, less or no red meat,…). Accept less in critical period (e.g. lower heating T of buildings)

Reduce ciment and capture CO2 Long term: Sequestrate carbon (from the air)

# Mitigating $CO_2$ Emissions and Scenarios



Christophe Ballif / Philippe Thalmann / Claudia Binder

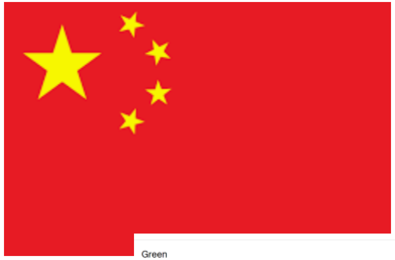
**But energy transition will require huge amount of solar panels, batteries, windturbines, electric cars, electrolysers**

**And huge investiment in manufacturing plants**

**(e.g. > 120 billions to make the production lines (equipements and building) to make 1000 GW of PV)**

EPFL

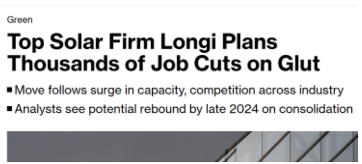
# Impact of China ultra-fast developments



▪ China has done it during COVID

During the 3 years of COVID, chinese companies have invested massively in

PV, batteries, electric cars and Wind.
(>> 100 billions $ invests)



Green

**Top Solar Firm Longi Plans Thousands of Job Cuts on Glut**

- Move follows surge in capacity, competition across industry
- Analysts see potential rebound by late 2024 on consolidation

Overcapacity (factor 2.5 to 3 for 2024)
→ Ultra-harsh competition

▪ **In PV close to 1400 GW** of production capacity are online (500 GW PERC, 800 GW topcon, 100 GW SHJ and IBC.

▪ For batteries, soon capacity for 4800 GWh or 100 millions car per year equivalent

- PV at 10 cts
- Battery cell at 50$/kWh
- Windturbine at 40 cts/W
- Inverters at 3cts/W
- Electrolysers systems at 30 cts/W


002459

# In a Nutshell

- Ultra-low price should push renewables, electric mobility everywhere
- China will be in competition with oil and gas producer and try to export its technologies (good for mankind !) : a new geopolitac paradigm
- Installation numbers for renewables likely to explose in 2024-2028, and will start a strong substitution of fossilefuel
- Challenge will be to push wind everywhere !

- But of course challenges and reaction to ultra-dominance of china and risk to destroy remaining industry
  → Inflation reduction act in usa, NZIA in Europe (too slow) …, trade barrier, $CO_2$ border tax
- Some challenges linked to most grid-connected power electronics controlled from china

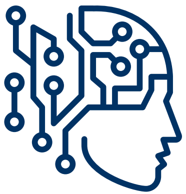

esmc
EUROPEAN SOLAR MANUFACTURING COUNCIL

Press Release

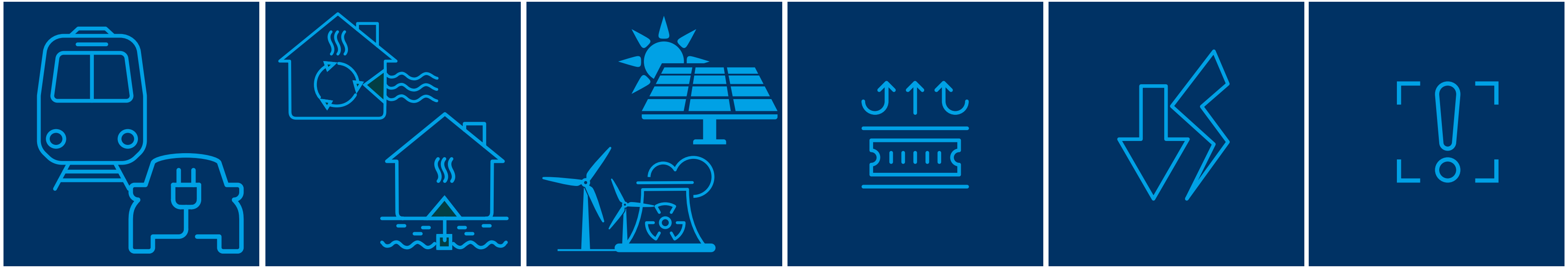
Press release: A Plea for Survival: ESMC Urges Swift Emergency Measures to support European PV manufacturing

January 17, 2024

# TO SUMARIZE: MAJOR TECHNOLGICAL ROUTES FOR THE ENERGY TRANSITION



**Flexibility** and **intelligence**



Public transport or **electric cars**
**+**
**batteries**

**Heat pumps**
(air, geothermal water, CO2)

**Solar,** Hydro, **Wind, Biomass** (Nuclear)

**Insulation, efficiencey**

**Tracking losses**

**+ many small** (but important)

**+ H2 ….**

**+ ships and plane**

# Mitigating $CO_2$ Emissions and Scenarios: summary





- Energy transition could be made at World, European and Swiss level
- Primarily by switching to renewable energies in all forms, cheaper in terms of LCOE, and keeping part of fossile fuel assets as reserve
- Costs saving on LCOE to adapt the system (grid, storage)
- Global investments acceptable, nothing if one considers external costs of fossile (impact of global warm, health isssues and biodiversity…)
- Improve effort at efficiency, consumption reduction
- Carbon storage at best in reforestation and ground management, can contribute to mitigate
- A greener agriculture, with less meat will also help
- Going fast is possible (see the German case) without damaging the economics… borrow money to invest for tomorrow

**But energy transition will require huge amount of solar panels, batteries, windturbines, electric cars, electrolysers**