

**Jonas SCHNDIRIG**

**ENV-421**  
**Introduction to Energy Systems**

**Week 2**

**- 24'004 YEARS**

**- 24'004 YEARS**

**- 1809 M**

**BRIG**

**- 1502 M**

**SION**

**- 1199 M**

**Lausanne**

A scenic sunset over a Swiss town, likely Sion, with vineyards in the foreground, a town in the middle ground, and mountains in the background. The sky is filled with warm orange and yellow hues.

2024

+7.8°C  
in 24'004 years

A dramatic image of a glacier calving into a deep blue lake, with a massive wall of ice in the background.

2024

+7.8°C

in 24'024 years

A scenic view of a Swiss town at sunset, with vineyards in the foreground and mountains in the background.

2050

**+1.5°C - +2.5°C**

in 60 years?!

**+7.8°C**

in 24'004 years

# Energy Systems

## Agenda

	Week 2	Week 4	Week 7	Week 9
Lectures	Energy System Fundamentals	Energy Conversion Technologies	Technologies' Impacts	Climate Impact on Energies
Applications & Exercises	The Swiss Energy System Evolution & Perspectives	Efficiencies & Classification	Conference <i>Is it all about renewable energies?</i>	Closing the Balance & Defining Compromises Powerplay Game

Project: Addressing Contemporary Challenges to the Swiss system  
Energy-independent and carbon-neutral Switzerland 2050



Week 2



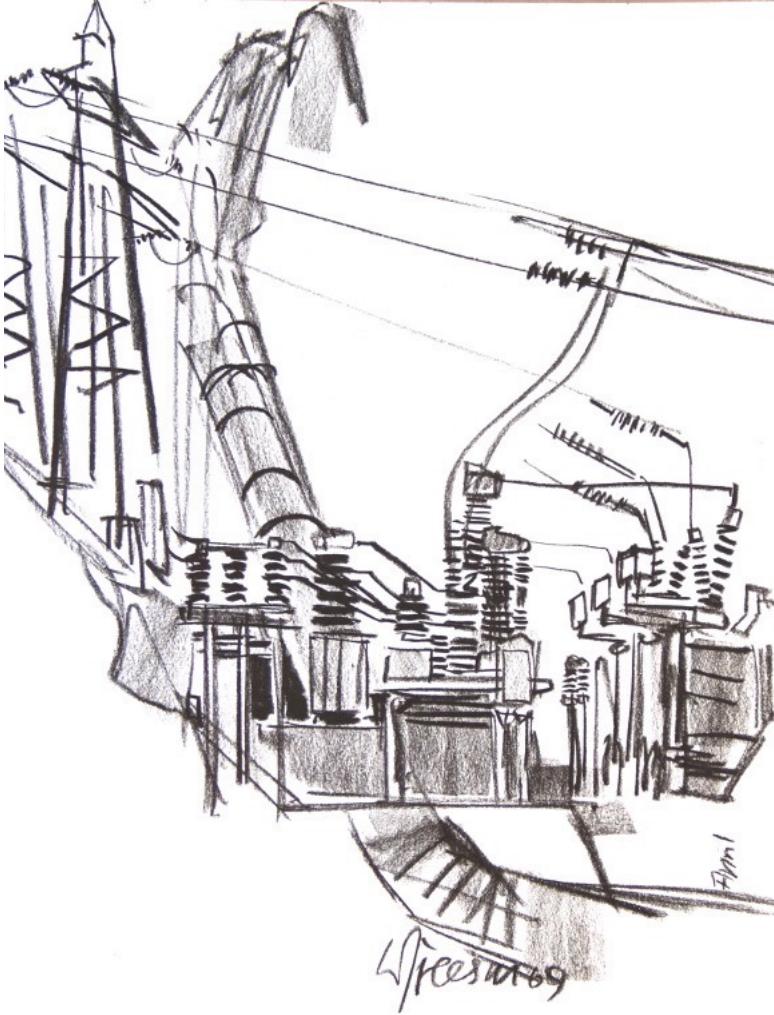
Lectures

Energy System  
Fundamentals

- Introduction to Energy Systems and Key Concepts
- Energy Balance Fundamentals
- Analysis and Evaluation of Energy Systems

Applications &amp; Exercises

The Swiss Energy  
System  
Evolution  
&  
Perspectives



## A G E N D A

### Introduction to Energy Systems

Energy Balance Fundamentals

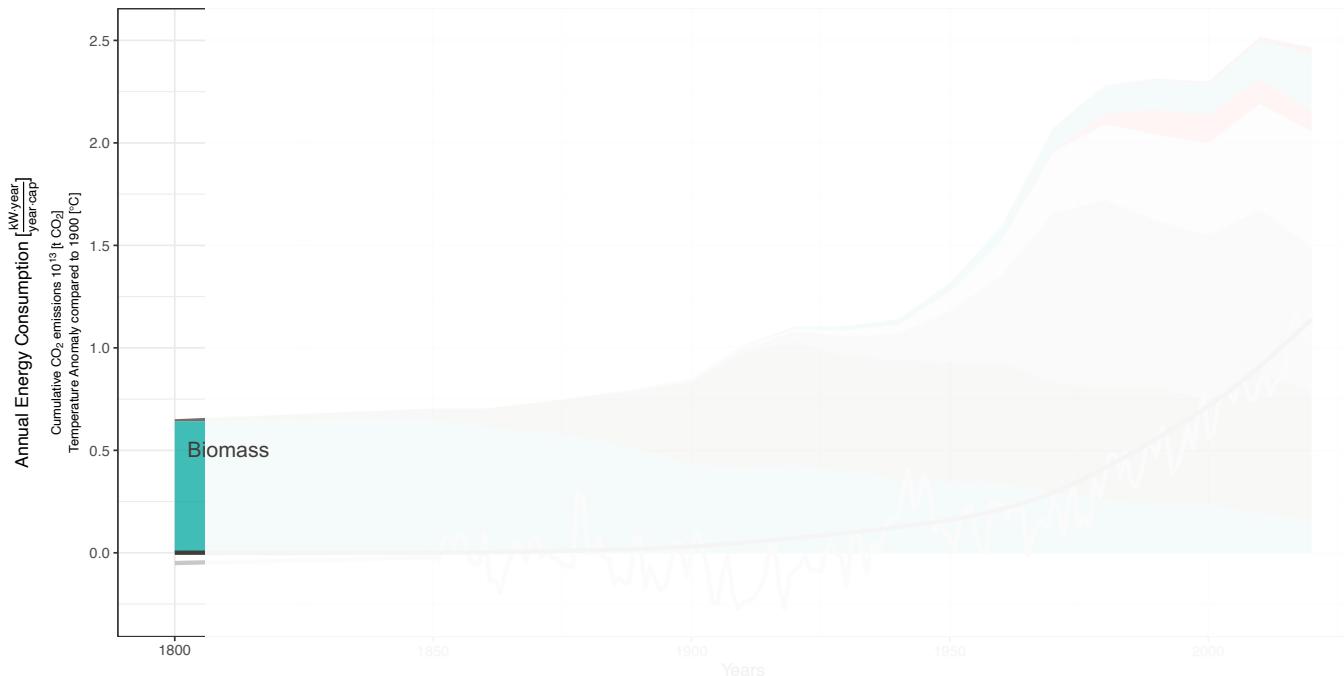
Analysis and Evaluation of Energy Systems



# A brief history of time

## The Foundation of Ingenuity and Survival

- Mastery of fire improved **warmth, protection, and cooking**, altering human interaction with nature [2–5].
- Fire use enhanced living conditions and enabled **migration** [2–5].



■ Global energy consumption per capita and temperature evolution.

The temperature anomaly was calculated using the reference year 1900 by [49]. The specific energy use is determined as the ratio between annual energy consumption [50] [ W·year ] and the respective population [51]. The CO<sub>2</sub> emissions are calculated as the cumulative sum of year emissions since 1800 [52].

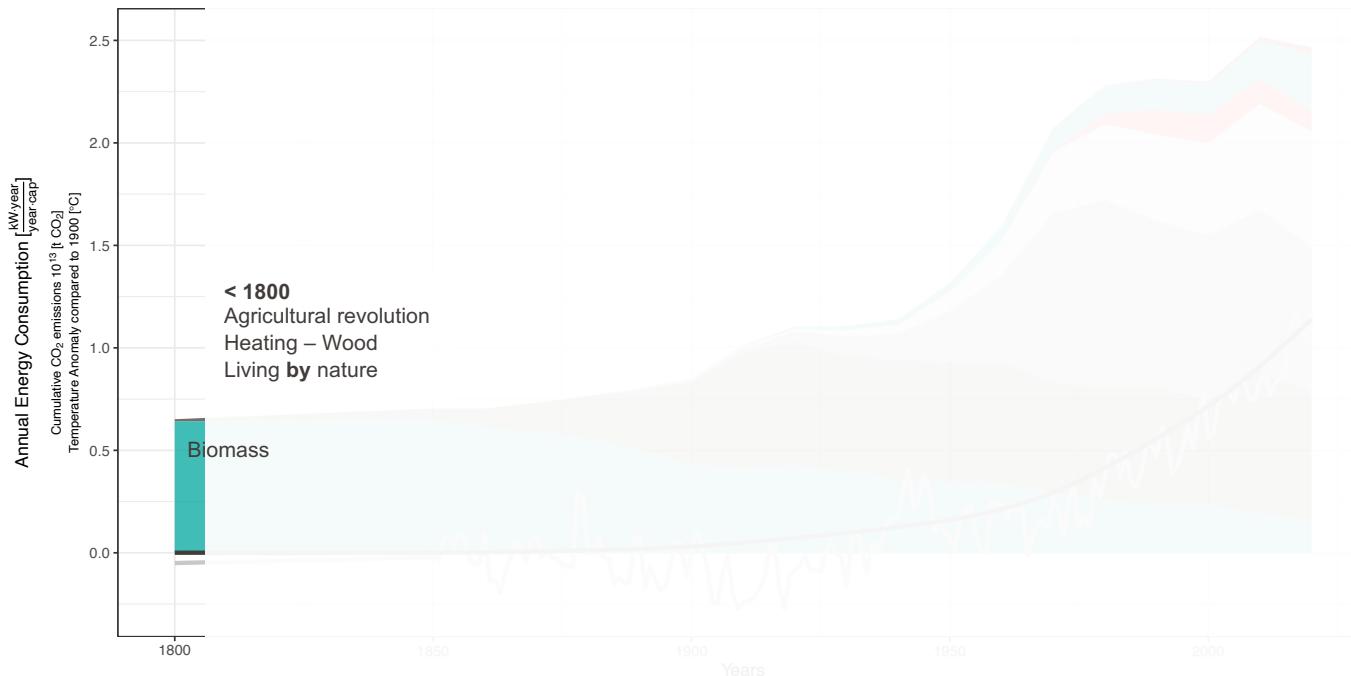
Population	0.8 billion
Energy [W·year/year-cap]	400
CO <sub>2</sub> emissions [10 <sup>9</sup> t]	0.12
ΔT <sub>1800</sub> [°C]	0



# A brief history of time

## Symbiosis with Nature

- Agricultural Revolution began with **glacier retreat**, changing human-nature relations. [6–9]
- **Wood biomass** dominated energy use, meeting demands of 600  $\frac{\text{W}\cdot\text{year}}{\text{year cap}}$ . [10,11]
- **Crop cultivation and animal domestication** improved efficiency and understanding of nature. [12, 13]



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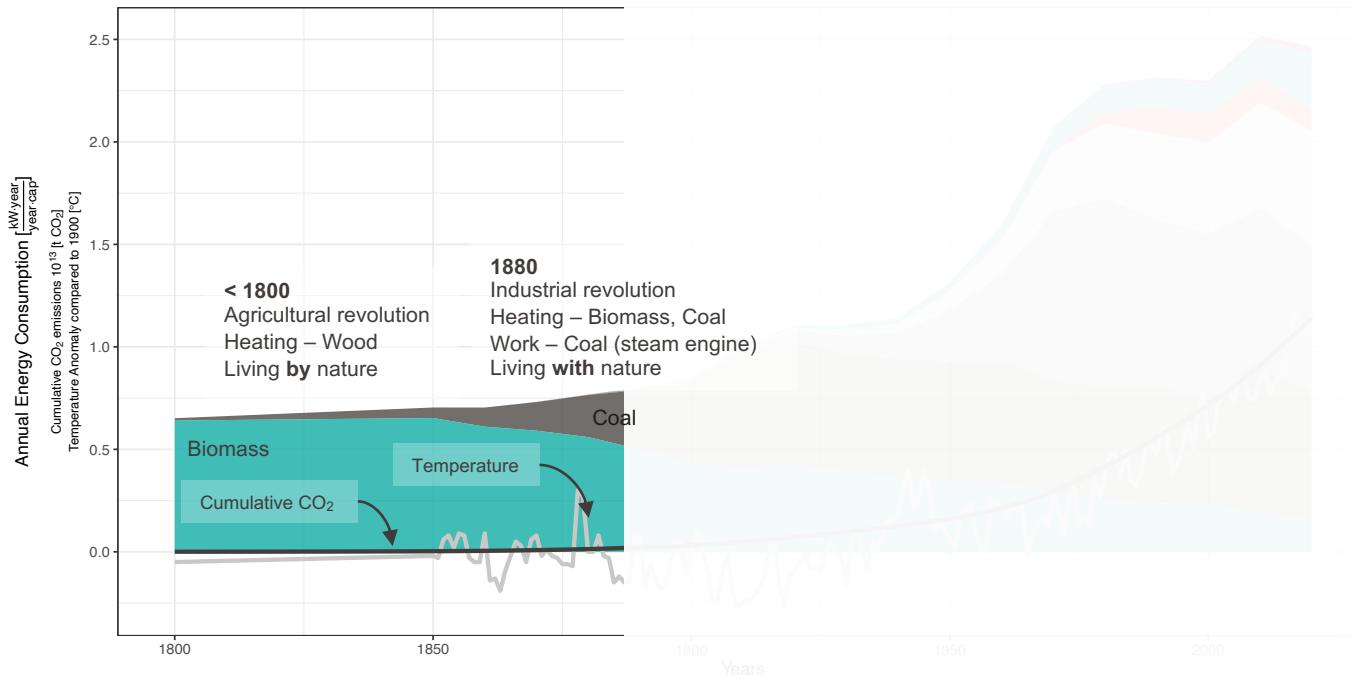
Population	1 billion
Energy $\frac{\text{W}\cdot\text{year}}{\text{year cap}}$	656
$\text{CO}_2$ emissions $[10^9 \text{ t}]$	0.19
$\Delta T_{1800} \text{ [}^{\circ}\text{C}]$	0



# A brief history of time

## Harnessing Power

- **Industrial Revolution** increased energy use per capita, raising CO<sub>2</sub> levels. [14–17]
- **Water and steam power** innovations drove technological progress and urbanization. [18–20]
- **Coal** became a major energy source, fueling steam engines. [21]
- Industrialization (1850) doubled the **population** to 2.5 billion; energy consumption reached 27.2 GJ/year per capita. [13,22]



■ Global energy consumption per capita and temperature evolution.  
The temperature anomaly was calculated using the reference year 1900 by [49]. The specific energy use is determined as the ratio between annual energy consumption [50] [ $\text{W-year}$ ] and the respective population [51]. The CO<sub>2</sub> emissions are calculated as the cumulative sum of year emissions since 1800 [52].

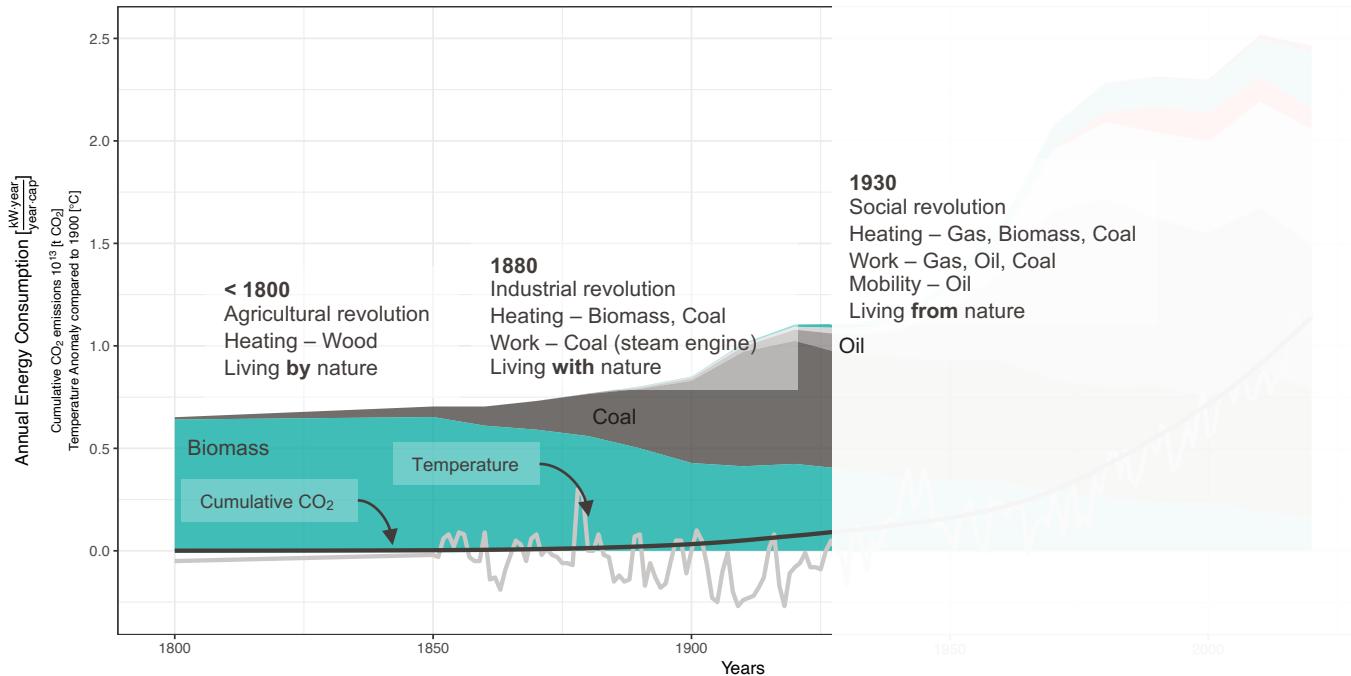
Population	1.4 billion
Energy [ $\text{W-year/year-cap}$ ]	766
CO <sub>2</sub> emissions [ $10^9 \text{ t}$ ]	6.41
$\Delta T_{1800}$ [ $^{\circ}\text{C}$ ]	0.05



# A brief history of time

## Growth and Consequences

- Oil and electricity discovery enabled **technological** advancements. [10,23,24]
- **Energy services diversified**: coal for electricity, oil for mobility, natural gas for heating. [25–27]
- Fossil fuels raised CO<sub>2</sub> levels to 415 ppm and temperatures by 0.9°C post-1950. [13,28,29]
- **Oil crises** and conflicts influenced energy patterns. [25–27]



■ Global energy consumption per capita and temperature evolution.  
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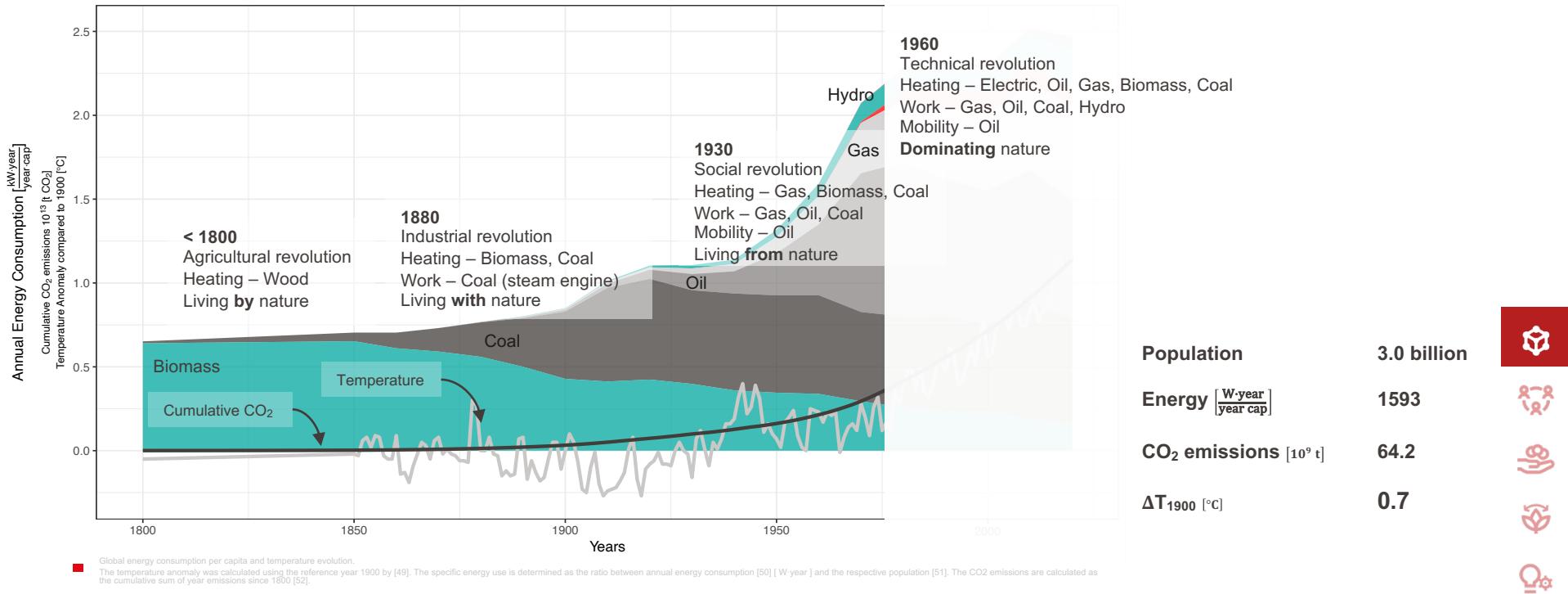
<b>Population</b>	2.1 billion
<b>Energy</b> [ $\text{W-year/year-cap}$ ]	1086
<b>CO<sub>2</sub> emissions</b> [ $10^9 \text{ t}$ ]	27.3
$\Delta T_{1800}$ [ $^{\circ}\text{C}$ ]	0.12



# A brief history of time

## The Nuclear Dilemma and Environmental Awakening

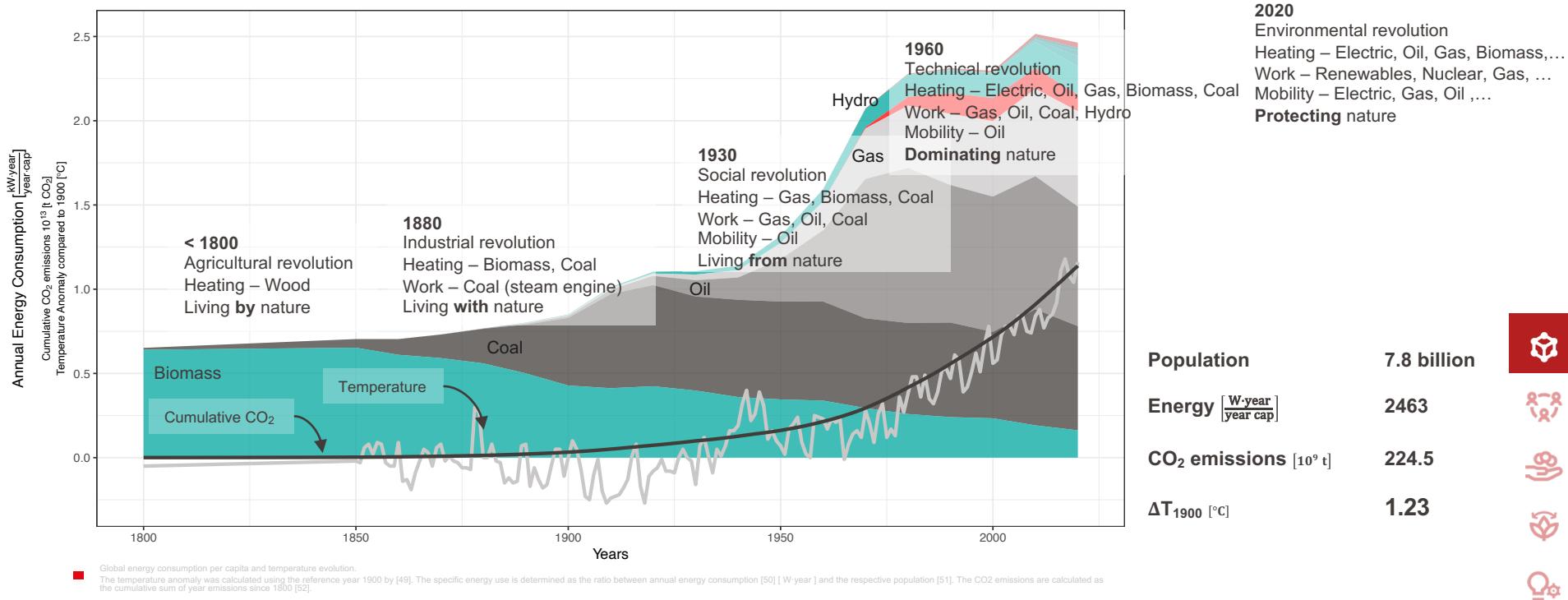
- Nuclear energy exploration driven by Cold War and physics advances. [30–34]
- Incidents highlighted environmental and safety concerns. [35–39]



# A brief history of time

## The environmental turning point

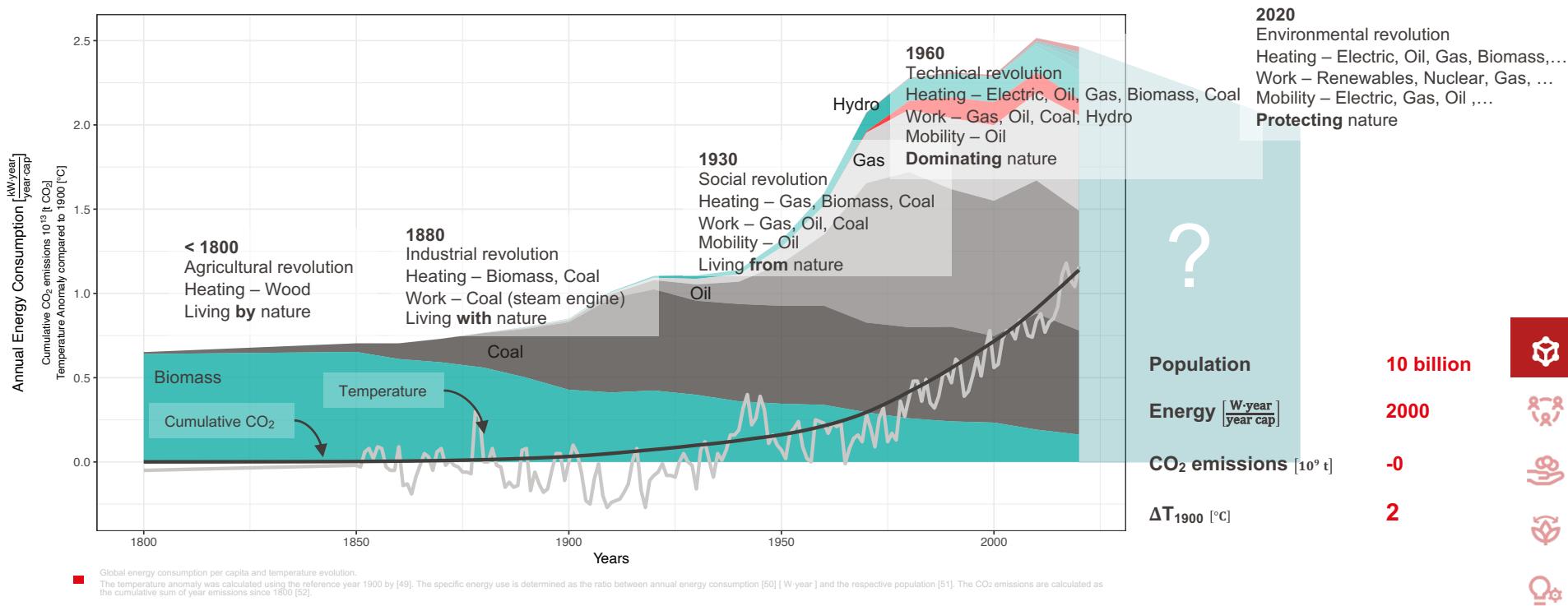
- By 2015, population reached 7.4 billion, energy consumption marked departure from **Holocene**. [13,27,40,41]
- Environmental awakening emphasized balancing energy development with ecological preservation. [42–47]



# The big question of the future

And now → 2050?

- Crossroad is both an **opportunity and a challenge**, requiring courage to abandon old patterns and enter a new era. [55,56]
- **Multiple sustainable pathways** exist, necessitating comprehensive modeling and quantification. [53,54]
- Equip **decision-makers with tools** to address the greatest challenge of the 21<sup>st</sup> century. [53,54]



# What is an energy system

## A question of balance

“The energy system comprises all components related to the production, conversion, delivery, and use of energy” (where energy is defined as “the power of ‘doing work’ possessed at any instant by a body or system of bodies”)

*O. Edenhofer, Climate change 2014: mitigation of climate change, volume 3, Cambridge University Press, 2015.*

“It is important to realize that the use of energy is no end but is always directed to satisfy human needs and desires. Energy services are the ends for which the energy system provides the means.”

*H. Groscurth, T. Bruckner, R. Kümmel, Modeling of energy-services supply systems, Energy 20 (1995) 941–958.*

“The combined processes of acquiring and using energy in a given society or economy”

*J. Keirstead, M. Jennings, A. Sivakumar, A review of urban energy system models: Approaches, challenges and opportunities, Renewable and Sustainable Energy Reviews 16 (2012) 3847–3866.*

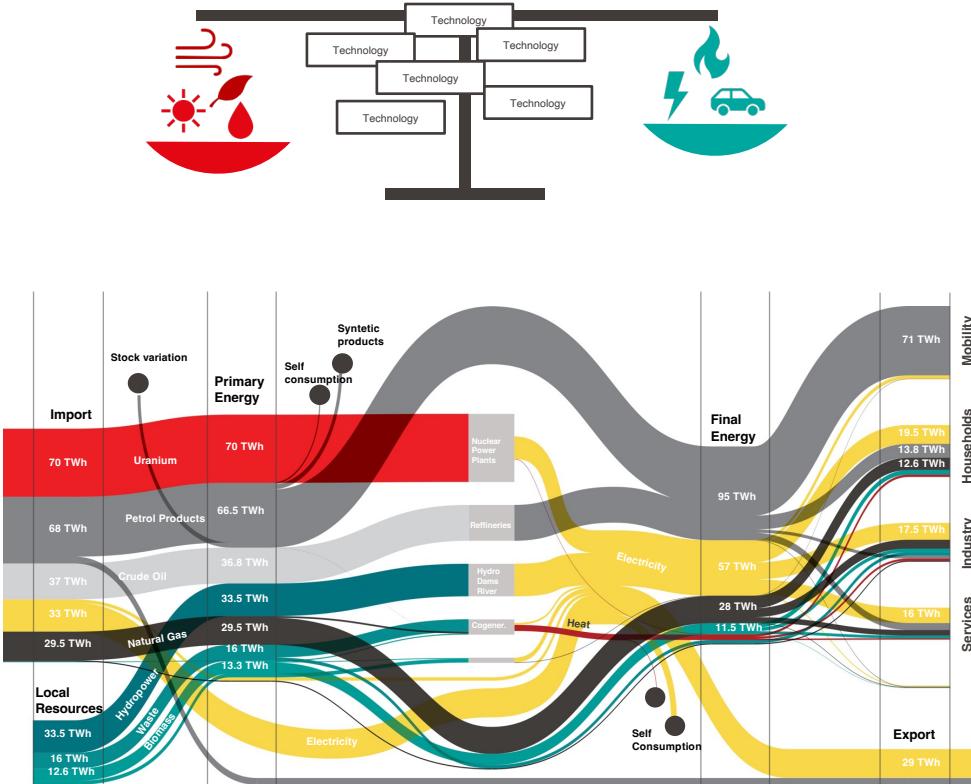
“energy systems are usually defined as technical and economic systems meeting the energy demand”

*T. B. Johansson, A. P. Patwardhan, N. Nakicenovic, L. Gomez-Echeverri, Global energy assessment: toward a sustainable future, Cambridge University Press, 2012.*



# What is an energy system

## A question of balance



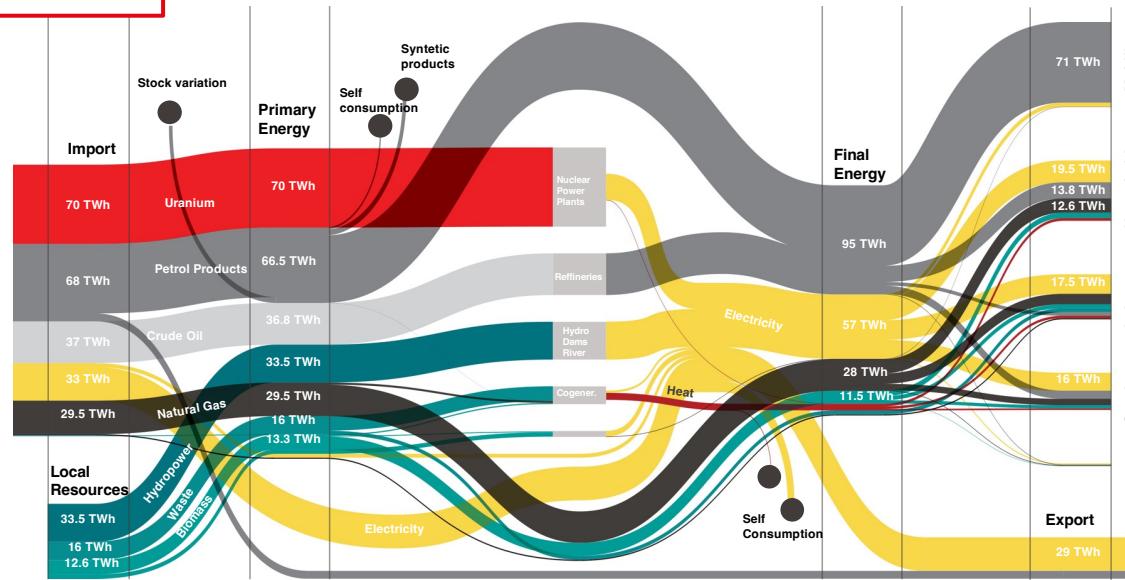
# The energy system

## Definitions

**Primary energy** is any extraction of energy products in a useable form from natural sources. This occurs either when natural sources are exploited (for example, in coal mines, crude oil fields, hydro power plants) or in the fabrication of biofuels.

**Final energy** consumption is the total energy consumed by end users, such as households, industry and agriculture. It is the energy which reaches the final consumer's door and excludes that which is used by the energy sector itself.

**End-use energy demand**, or useful energy, is the last measurable energy flow before the delivery of energy services.



# Demands

Mobility



Housing

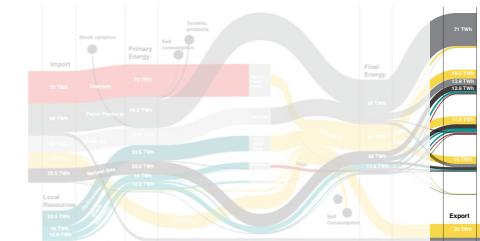


Sectors



Industry & Agriculture

Services



Low Temperature



End-Uses



Passenger [pkm/year]



Transportation



Freight [tkm/year]

# Demands

## Mobility



14030 p km



3970 t km



41 W



101 W



147 W



## Industry



10 W

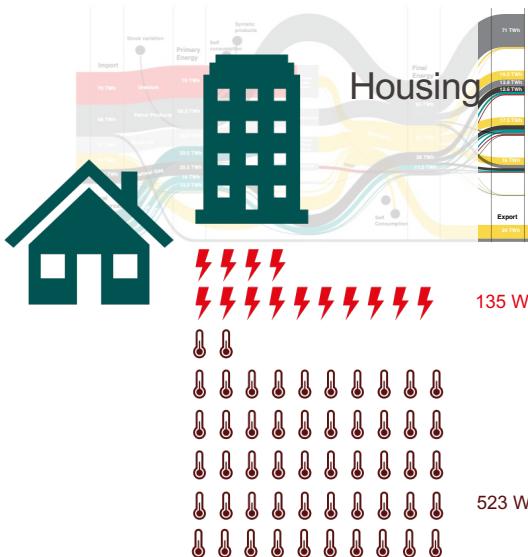
139 W



199 W

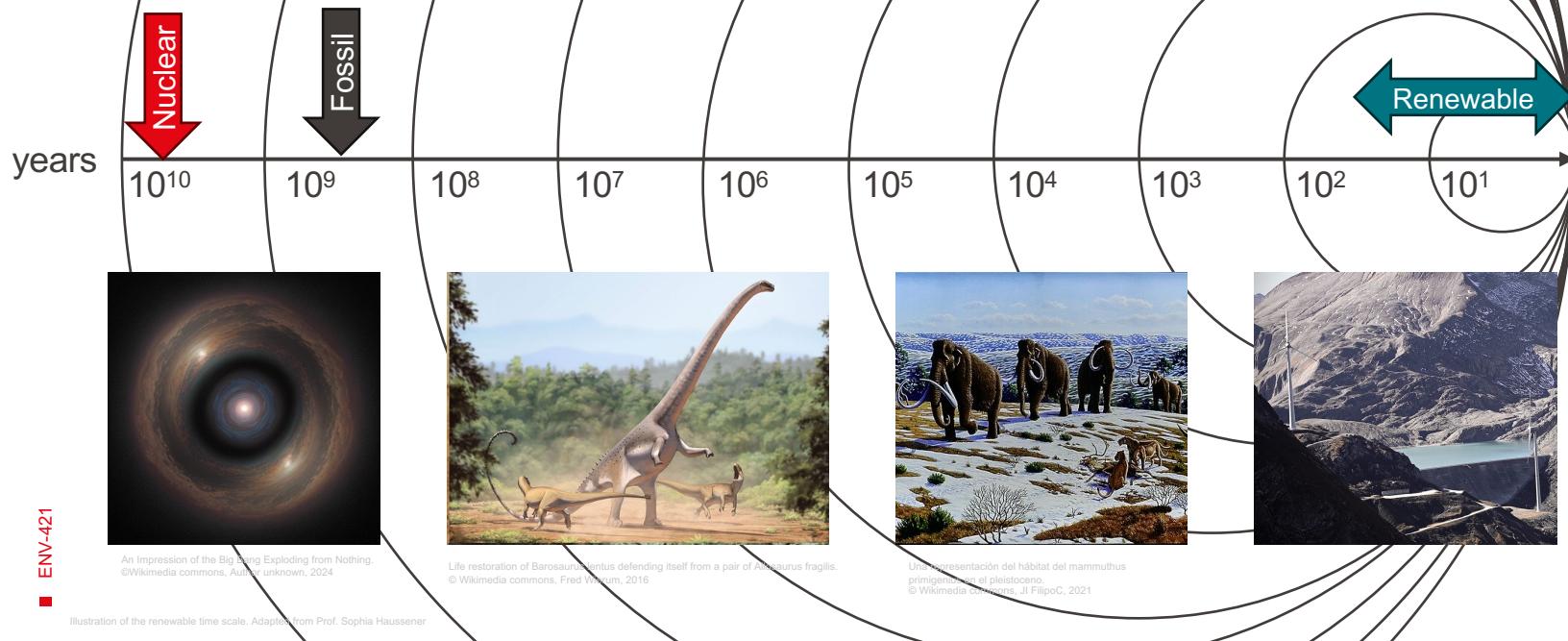


## Services

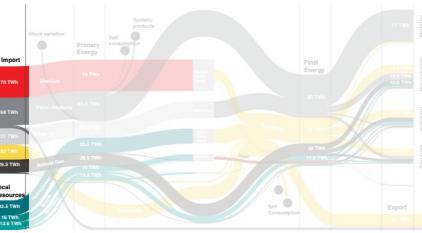
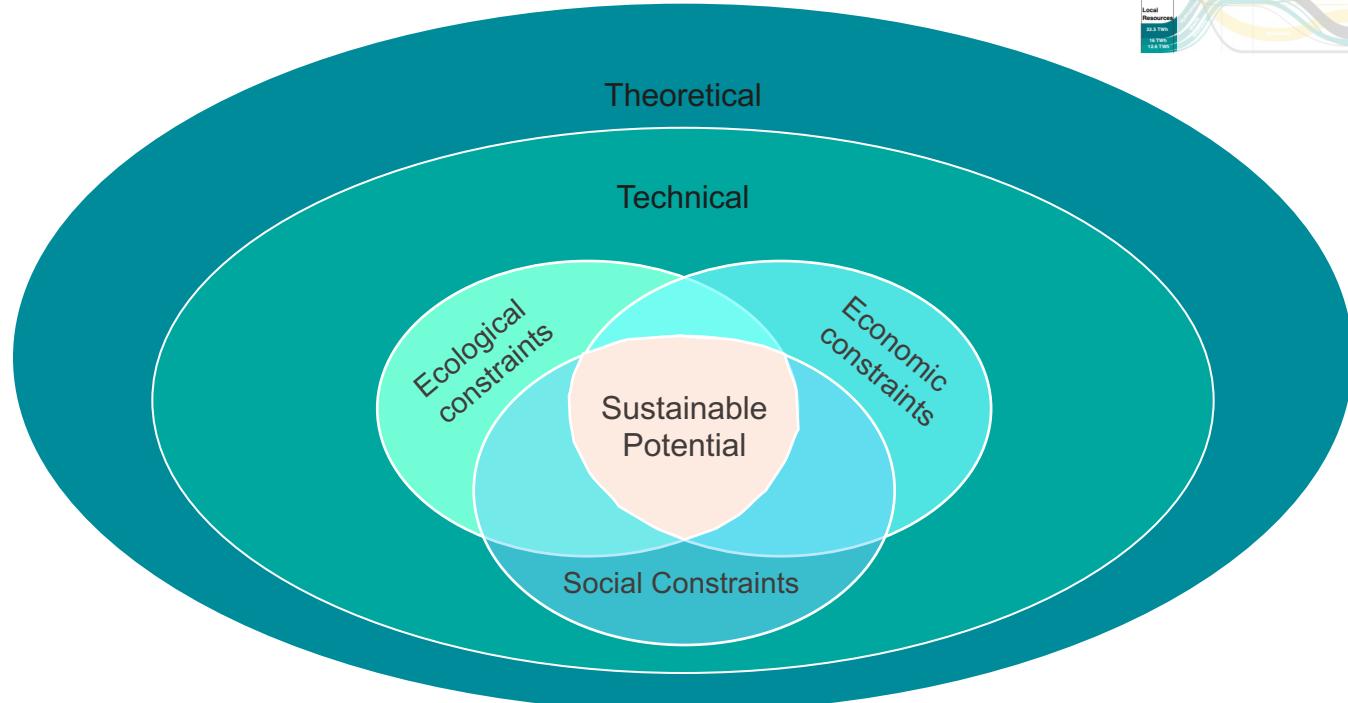


# Resources

## Renewable vs non-renewable

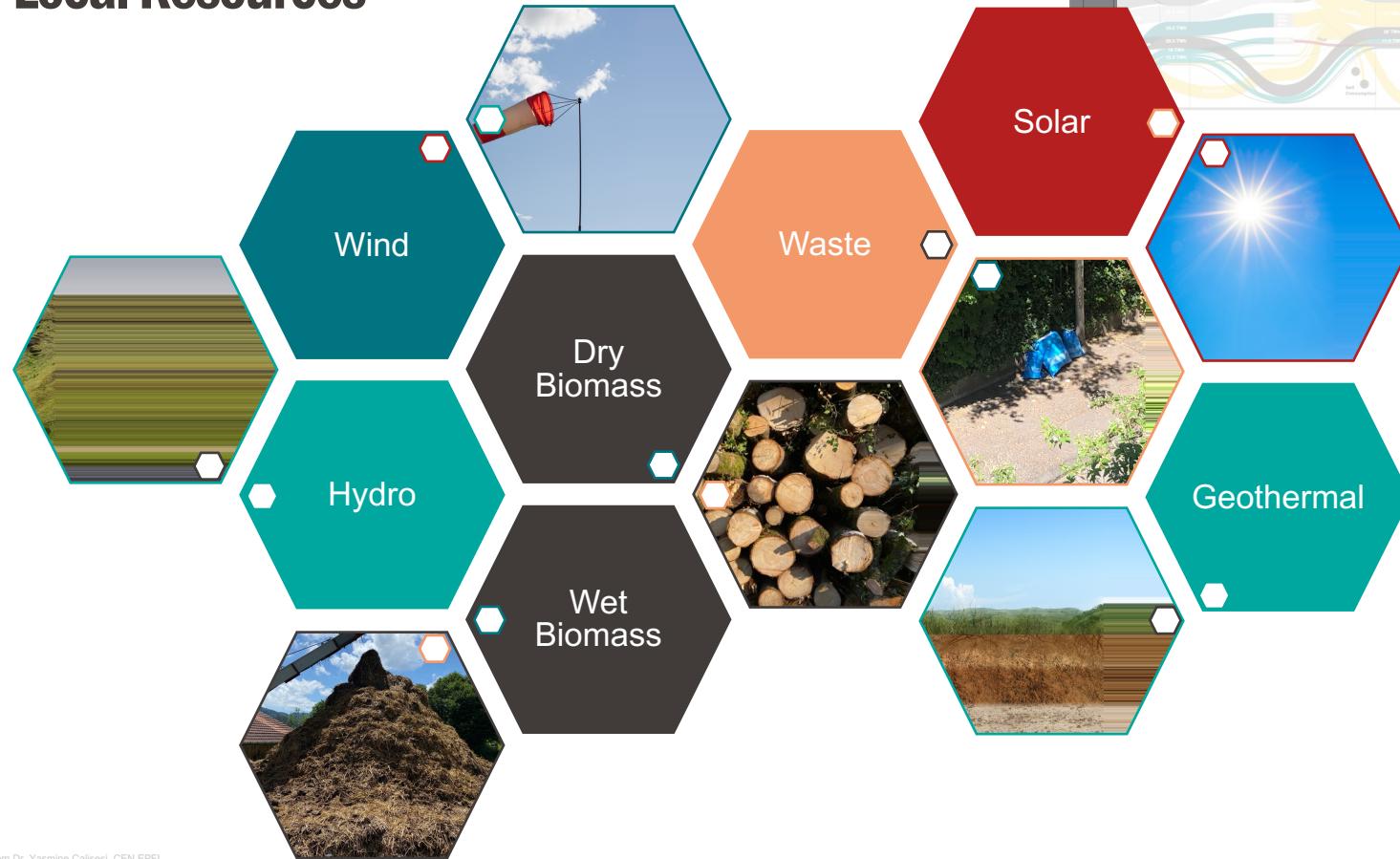


# Resources Potentials



# Resources

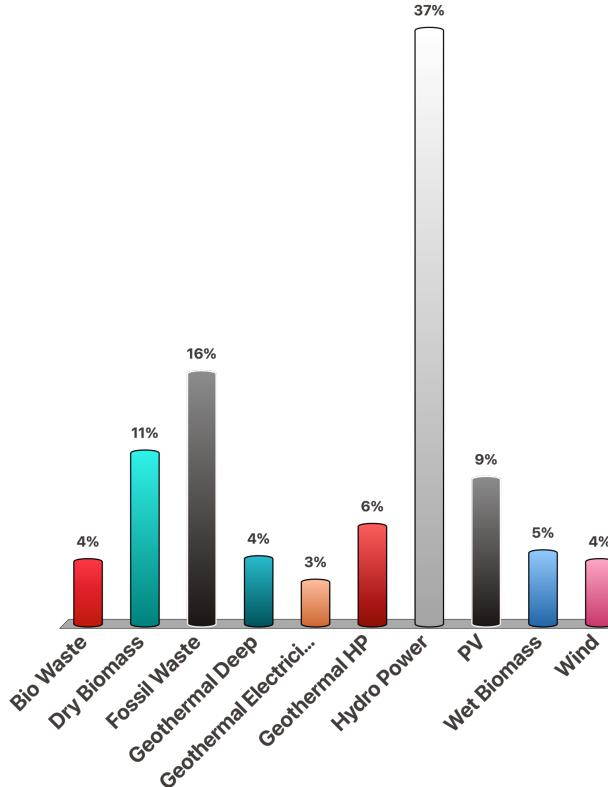
## Local Resources



# Resources Potential & Used

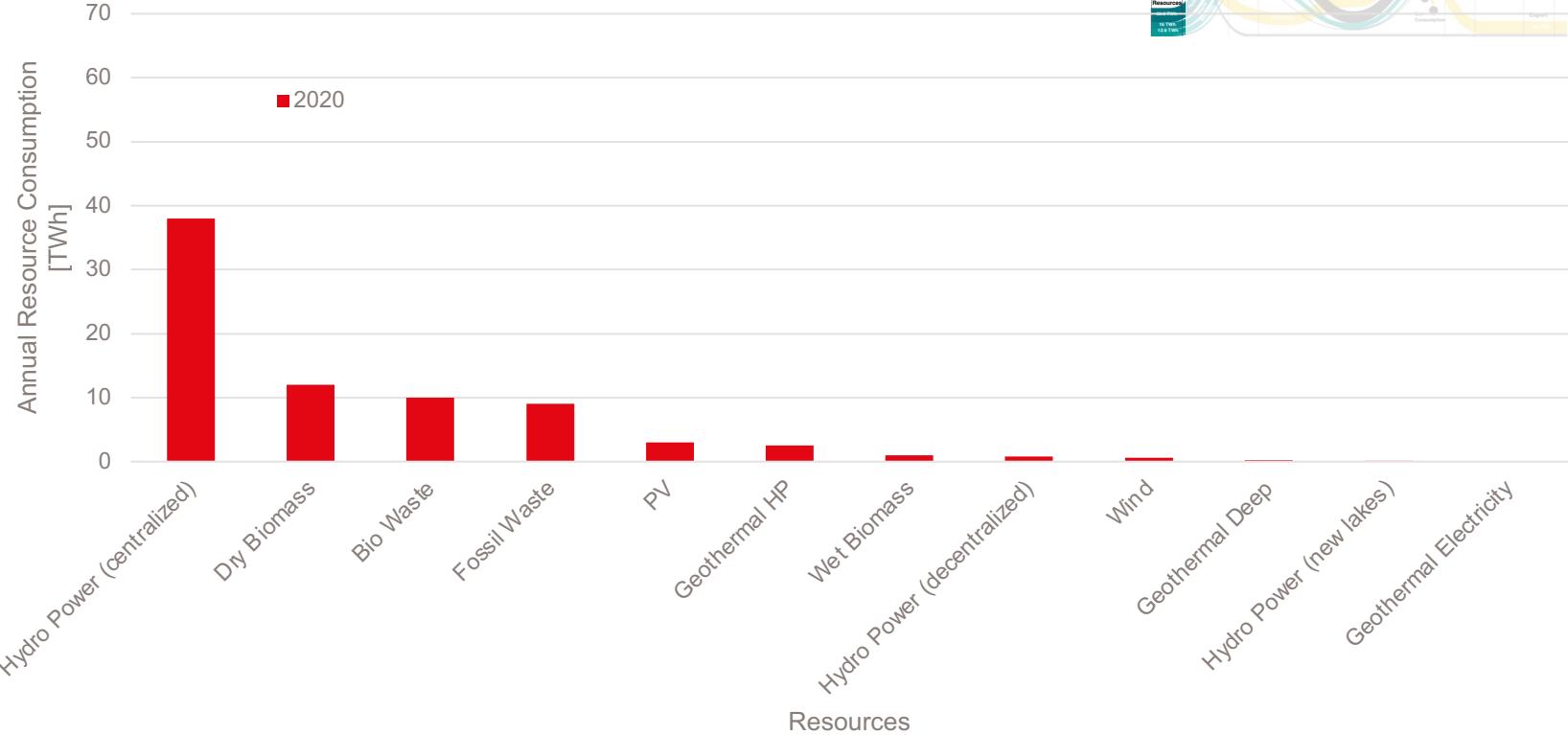
Class the following resources by  
Used Energy in 2020 in Switzerland

- A. Bio Waste
- B. Dry Biomass
- C. Fossil Waste
- D. Geothermal Deep
- E. Geothermal Electricity
- F. Geothermal HP
- G. Hydro Power
- H. PV
- I. Wet Biomass
- J. Wind



# Resources

## Potential & Used



# Resources

## Potential & Used

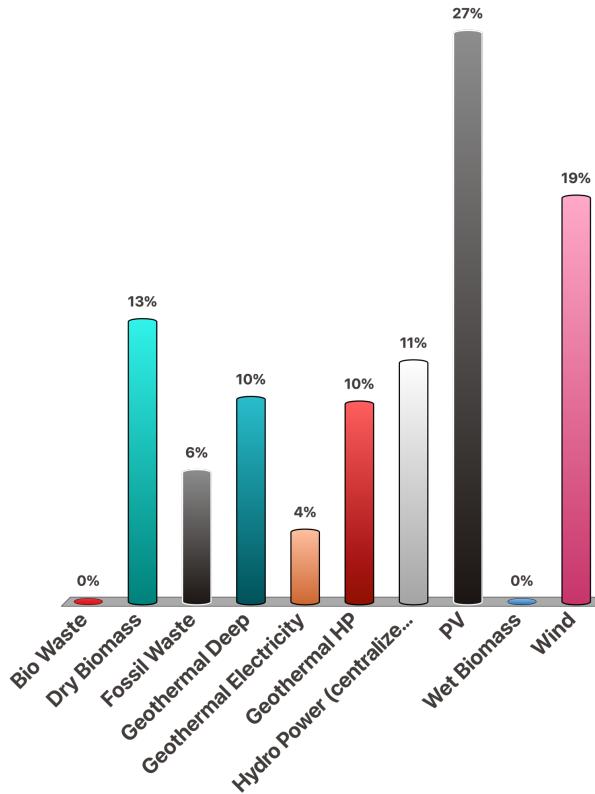
- Class the following resources by
  - Technical Potential in Switzerland
  
- Bio Waste
- Dry Biomass
- Fossil Waste
- Geothermal Deep
- Geothermal Electricity
- Geothermal HP
- Hydro Power (centralized)
- Hydro Power (decentralized)
- Hydro Power (new lakes)
- PV
- Wet Biomass
- Wind



# Resources Potential & Used

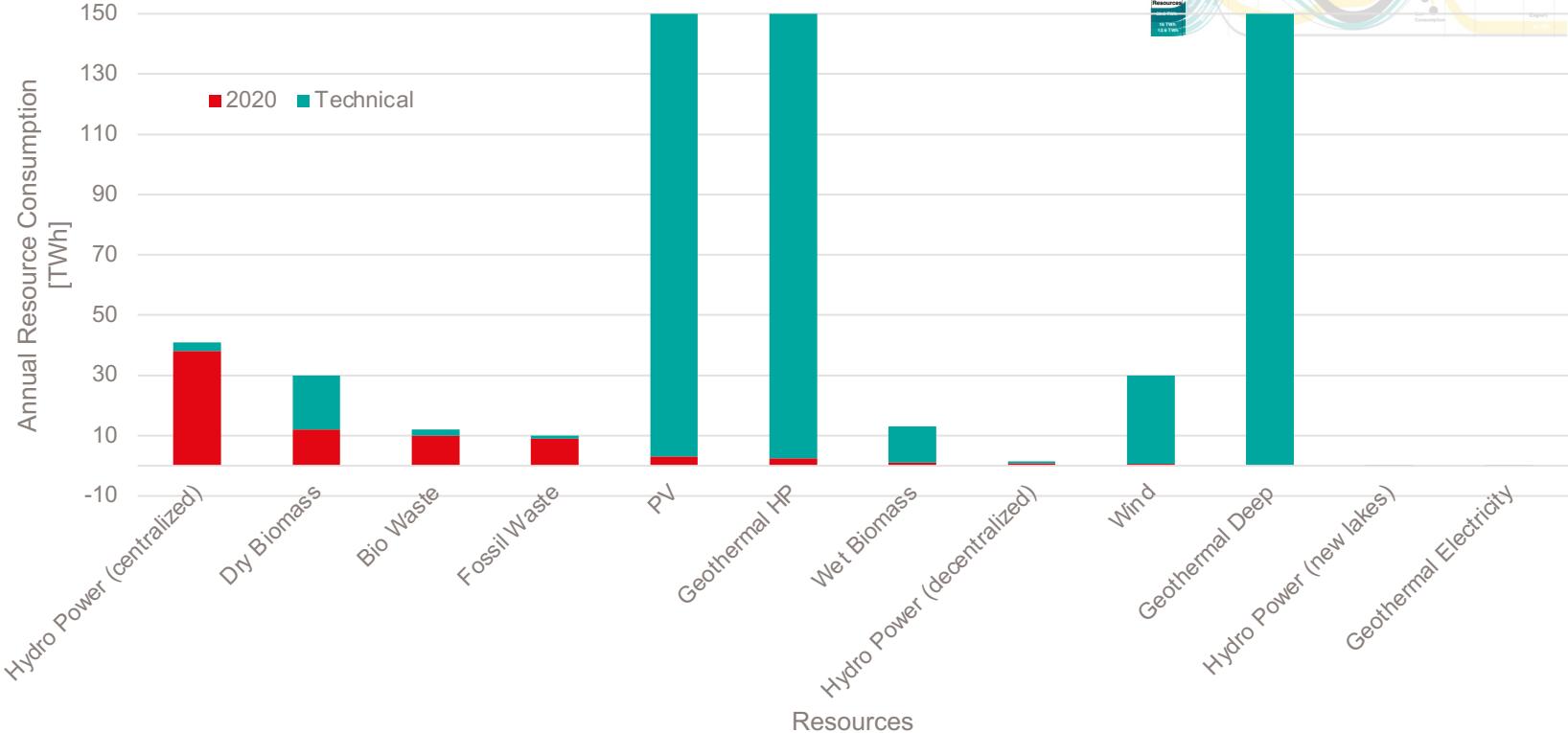
- A. Bio Waste
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- G. Hydro Power (centralized)
- H. PV
- I. Wet Biomass
- J. Wind

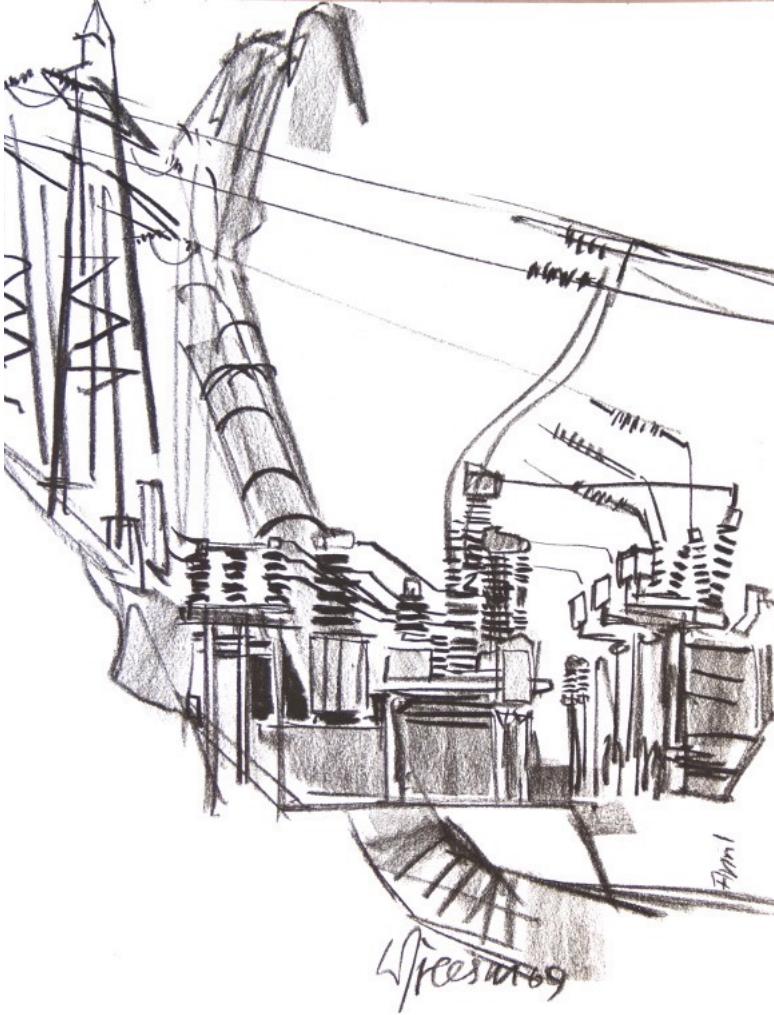
Class the following resources by  
Technical Potential in Switzerland



# Resources

## Potential & Used





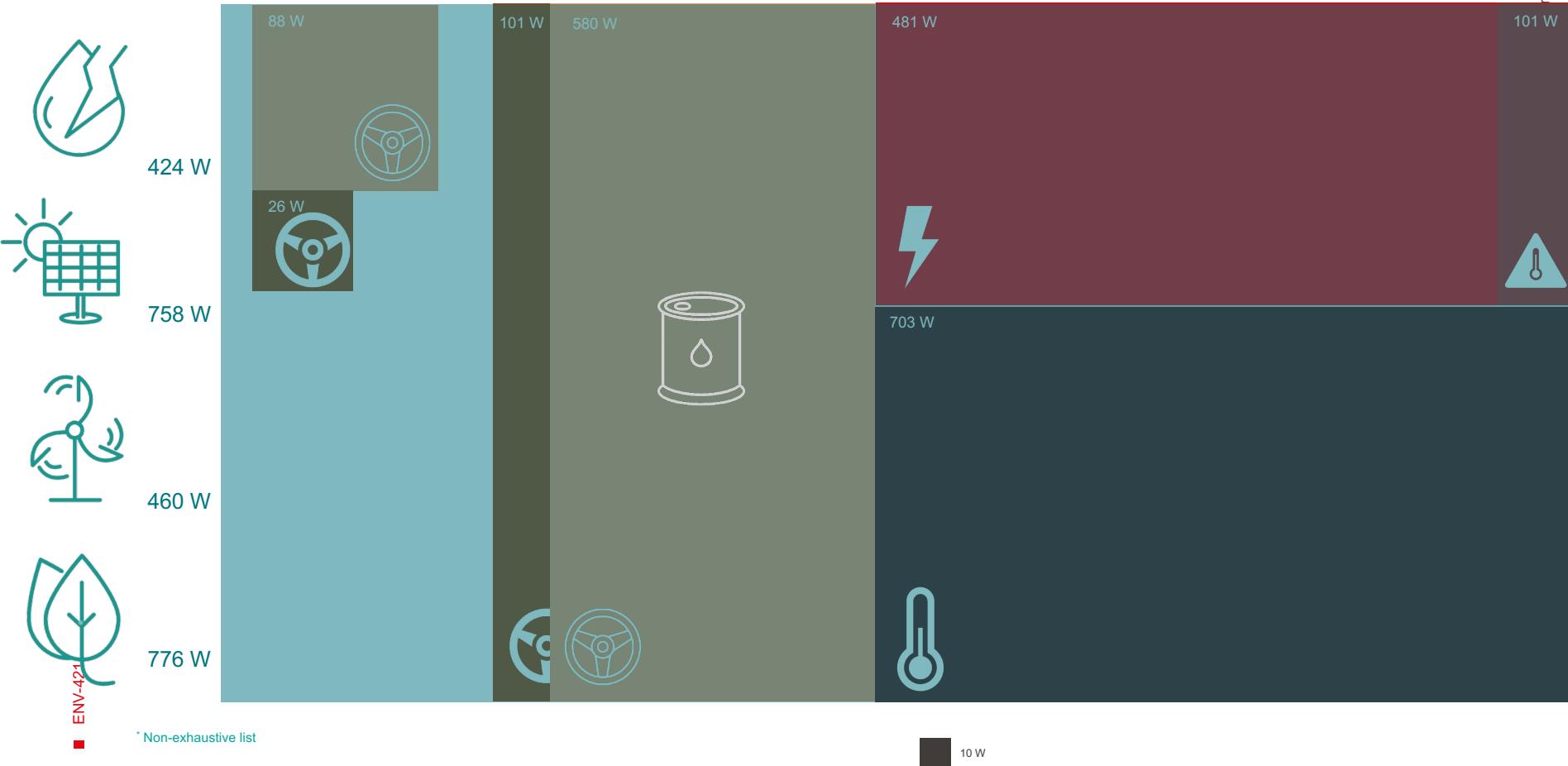
## AGENDA

Introduction to Energy Systems

## Energy Balance Fundamentals

Analysis and Evaluation of Energy Systems





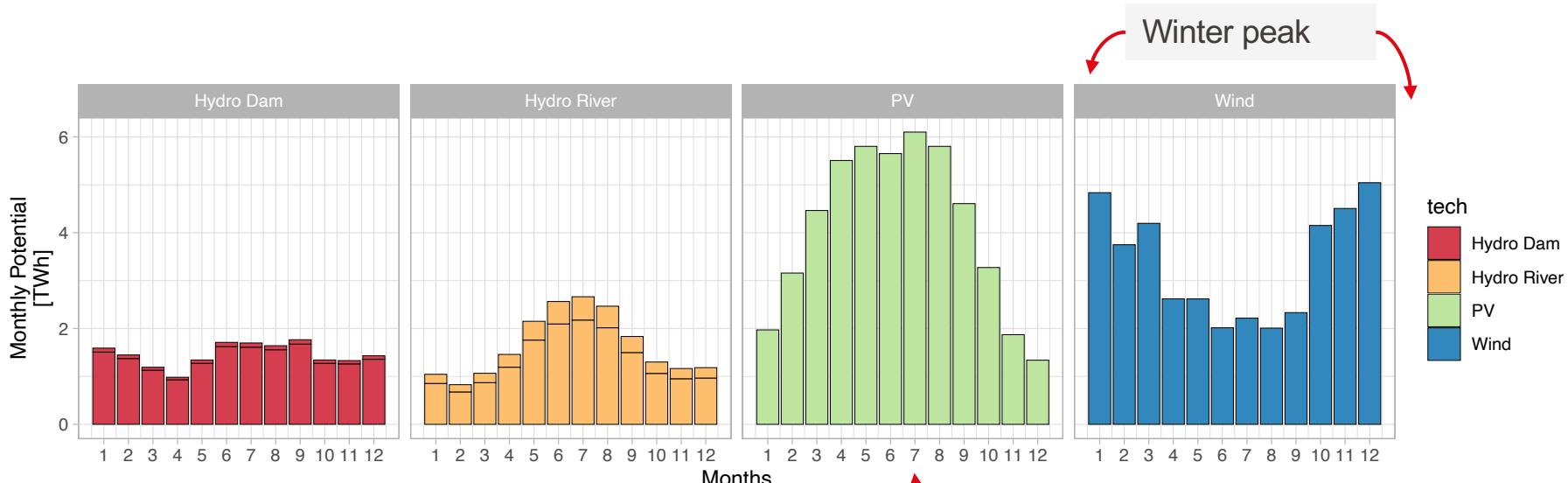
# The Systemic Approach

## The intermittency Challenge



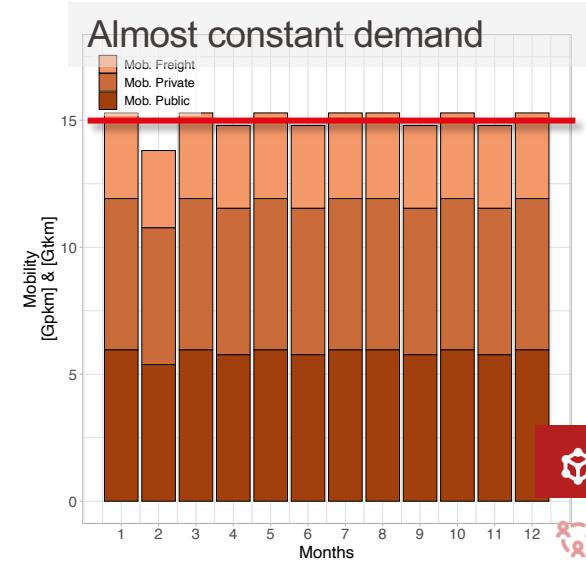
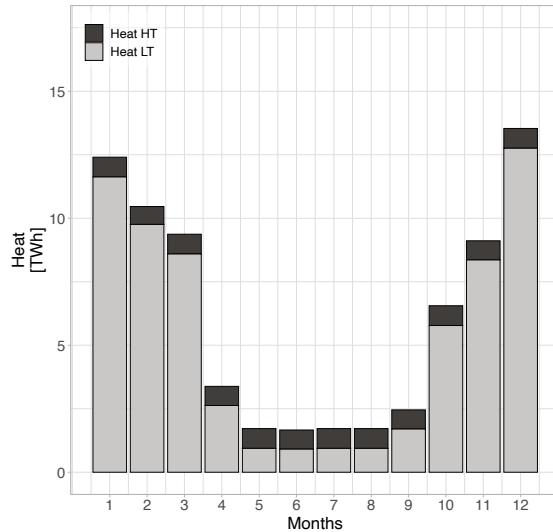
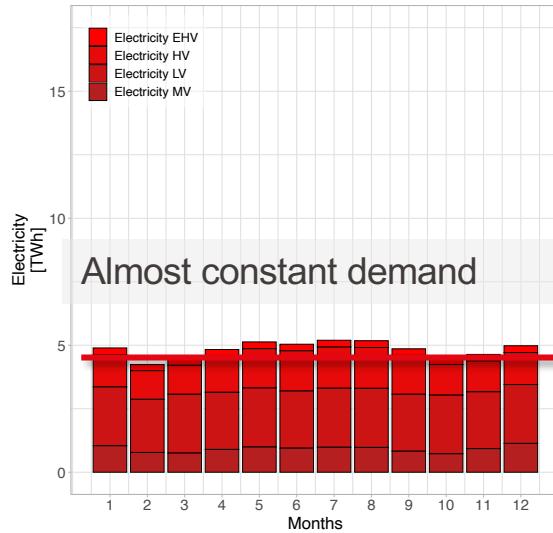
# The Systemic approach

## Intermittency of Resources



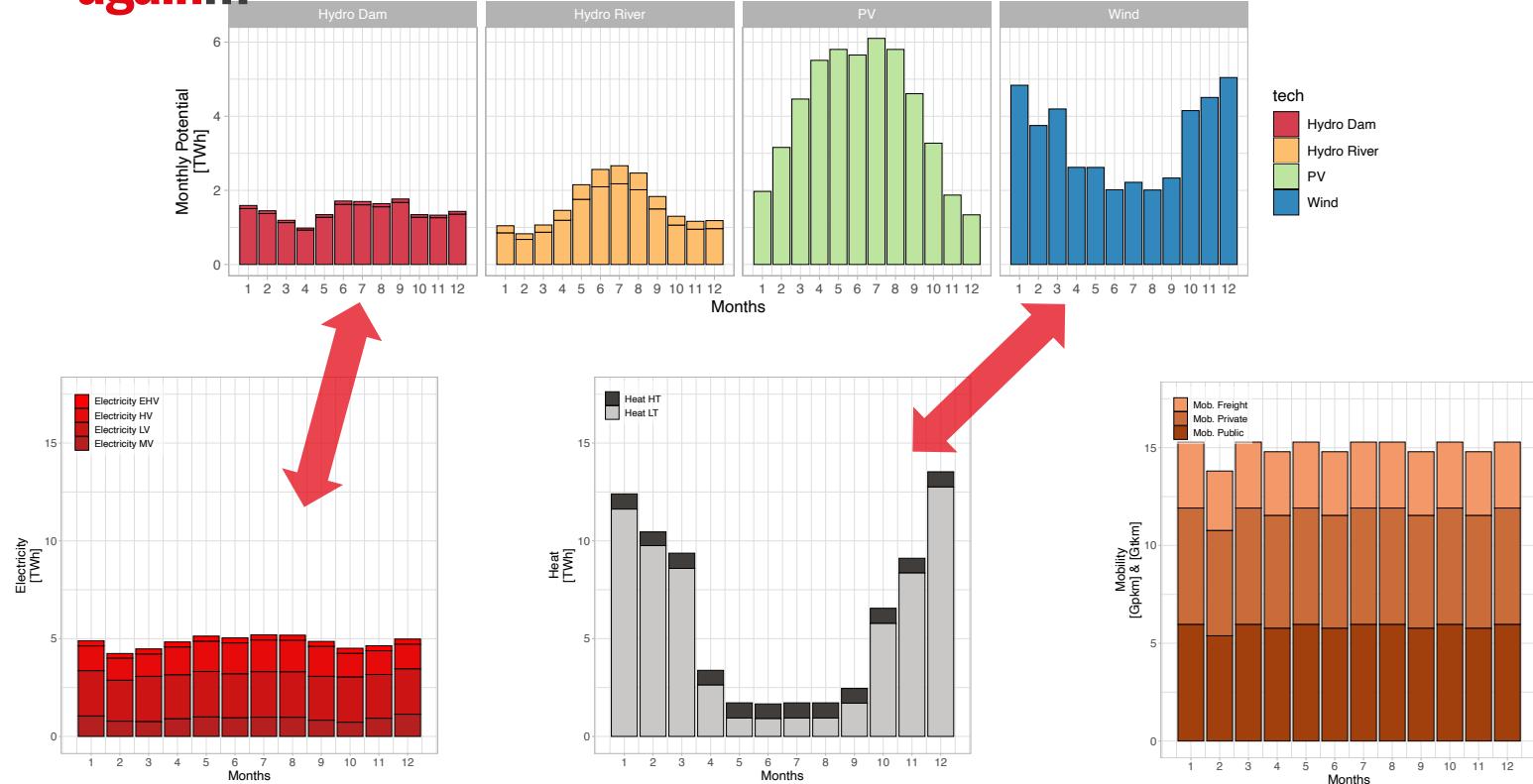
# The Systemic approach

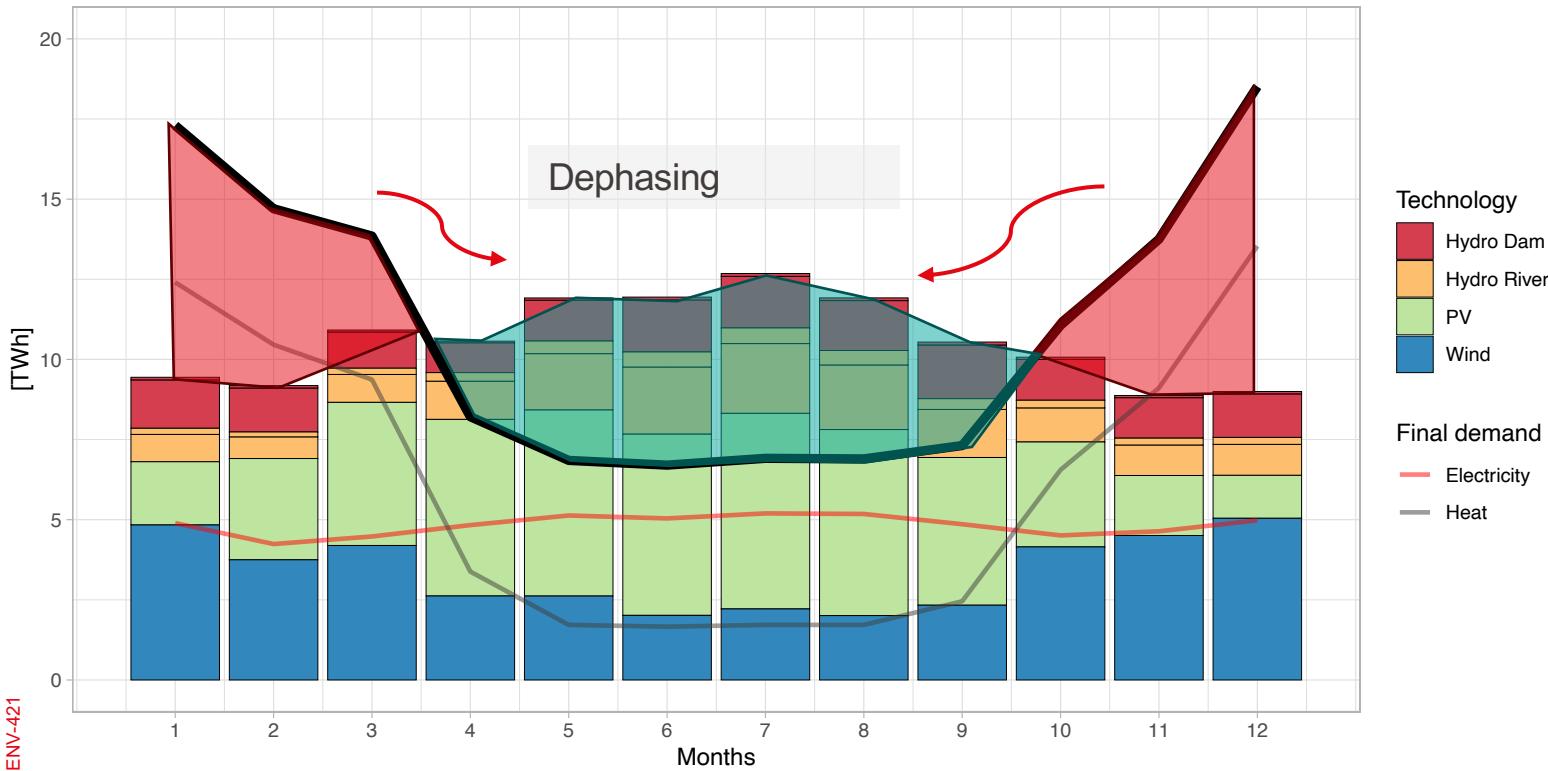
## Intermittency of demands



# The Systemic approach

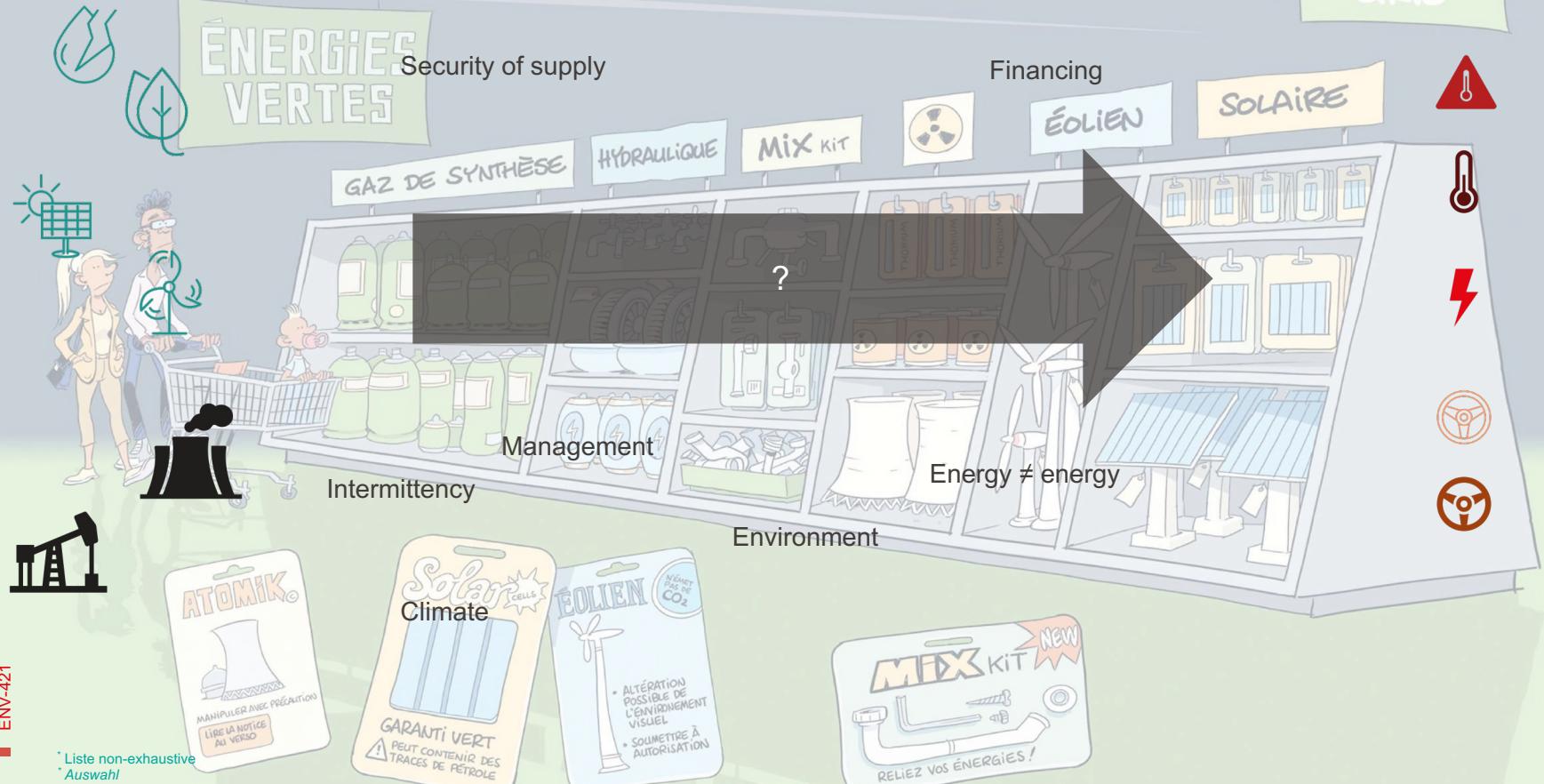
## A question of equilibrium – again...



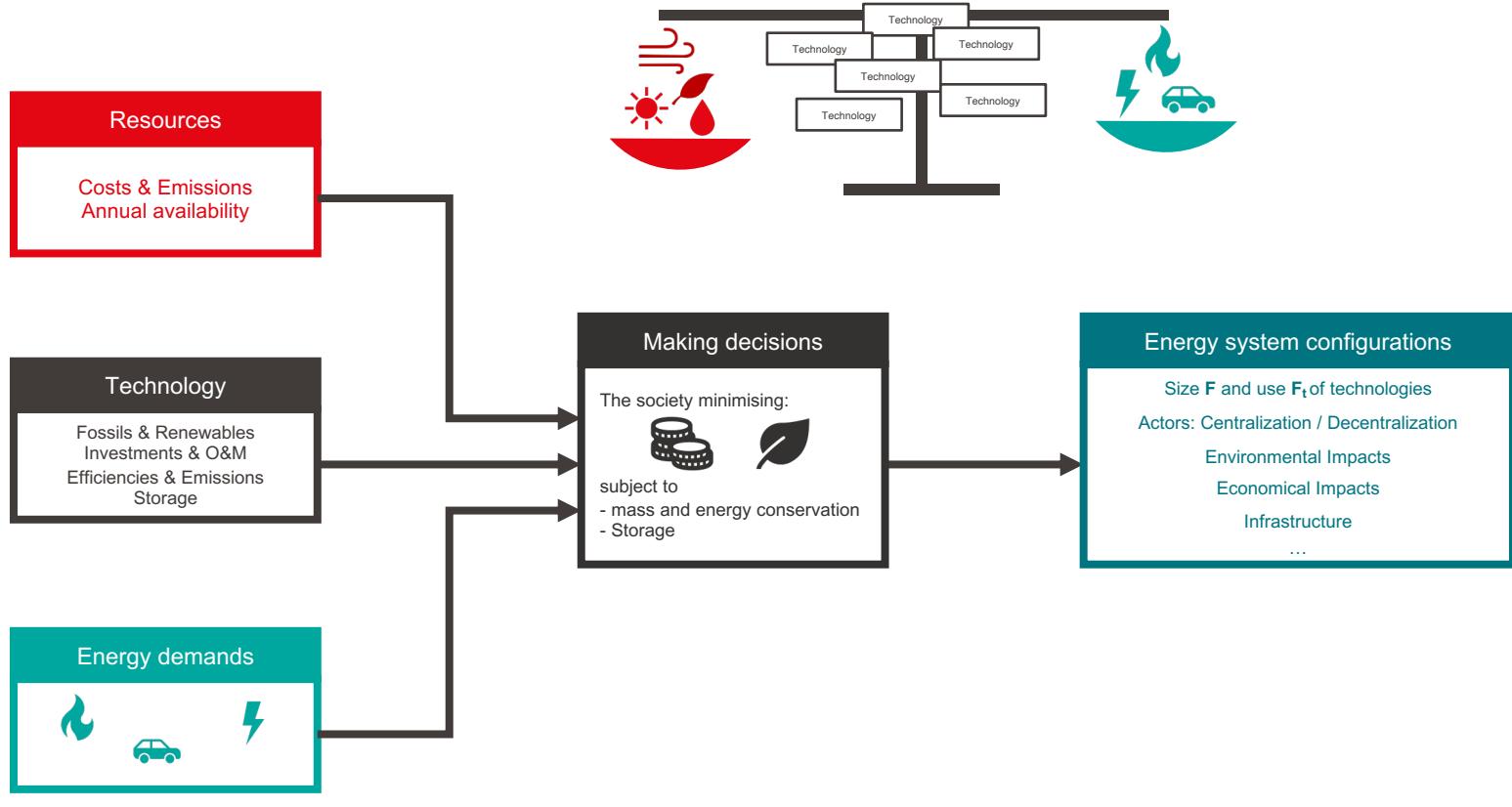


Distribution

POUR  
UN AVENIR  
Demand  
MOINS  
GRIS

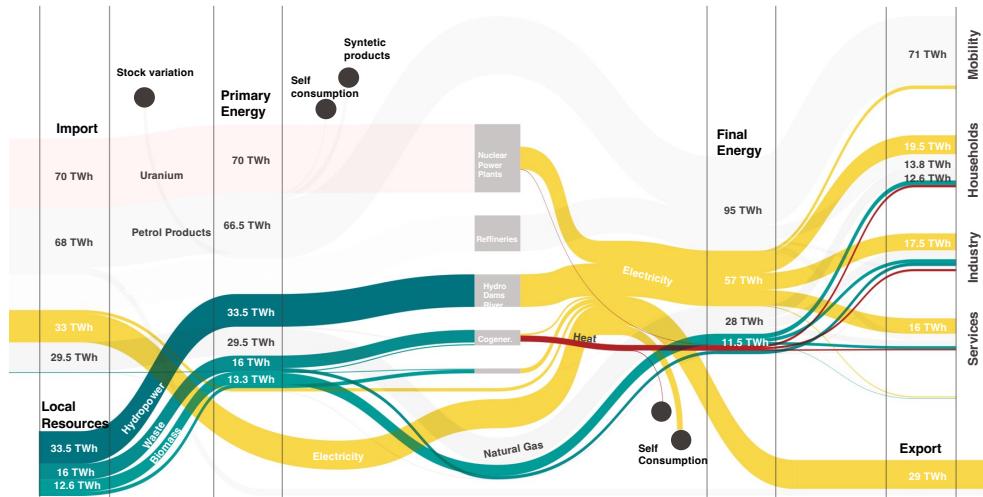


# Energy system modeling - EnergyScope



# The Swiss Challenge

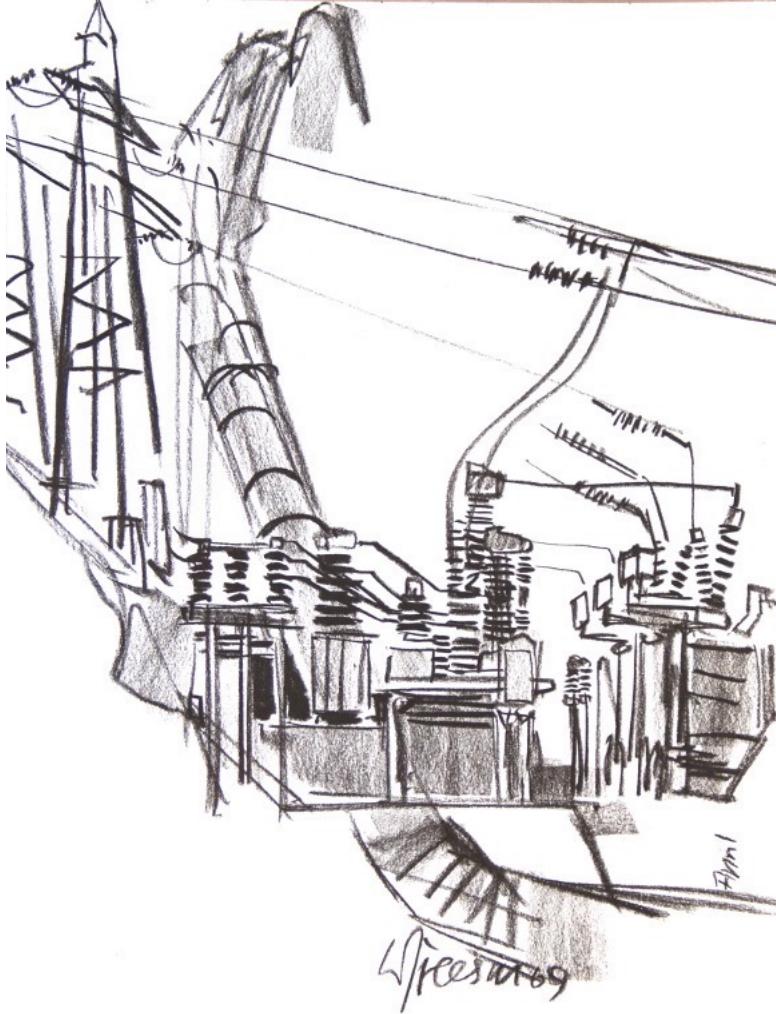
## In the Heart of Europe



Sankey Diagram Global Swiss Energy System Statistic 2022 [63]. Switzerland imports 79 % of its PE, of which 57 % is of fossil origin. The electricity share in the final energy amounts to 30 %: with 33 TWh of electricity import and 29 TWh export due to seasonal intermittency and transit. Local resources are dominated by hydropower, while waste incineration is used in cogeneration units to generate heat and electricity. The remaining renewable energy shares are negligible (1.2 %). Illustration adapted from Sébastien Fasel (Emphase Sàrl) [78].

- **Strategic Geographic Position**
  - Bridge of European energy network<sup>[57]</sup>.
  - linking **diverse energy systems**, including Austria's, France's nuclear energy, Germany's renewable and fossil-based power, and Italy's energy imports from North Africa<sup>[58-60]</sup>.
- **Pioneering Renewable Energy Integration**
  - Historical reliance on **hydroelectric power**<sup>[63-65]</sup>
  - play with **market fluctuations** foundation for expanding renewable energy capacity<sup>[63,66,87]</sup>.
- **Decentralized Energy Potential**
  - Potential for **decentralized renewable energy** sources, such as photovoltaics, small hydropower, and wind<sup>[64,66,67]</sup>.
  - **Existing centralized renewable energy** as opportunity for energy management and distribution<sup>[69,70-73]</sup>.
- **Economic and Environmental Synergy**
  - Environmental imperatives and economic goals, aiming for **sustainability, efficiency, and reliability**<sup>[61,78]</sup>.
  - Imperatives on sustainability for **unique landscape and tourism reasons**<sup>[68,70-73, 84-86]</sup>.





## A G E N D A

Introduction to Energy Systems

Energy Balance Fundamentals

**Analysis and Evaluation of Energy Systems**



# The systemic perspective

## Conversion – some formulas

- Energy conversion efficiency

$$\eta = \frac{\text{useful Energy}}{\text{required Energy}} = \frac{\text{useful Power}}{\text{required Power}}$$

- Thermal efficiency

$$\eta_{th} = \frac{\text{useful Energy}}{\text{required heat/fuel Energy}} = \frac{\text{useful Power}}{\text{required heat/fuel Power}}$$

- Combination of efficiencies

$$\eta_{tot} = \prod_i \eta_i$$



# The systemic perspective

## Conversion – some formulas

- Primary Energy

$$E_{primary} = \sum_{r \in Resources} E_r$$

- Secondary Energy

$$E_{secondary} = E_{primary} \cdot \eta_{conversion} = E_{primary} - L_{conversion}$$

- Final Energy

$$E_{Final} = E_{secondary} \cdot \eta_{distribution} = E_{secondary} - L_{distribution}$$

- End-Use Demand

$$E_{demand} = E_{Final} \cdot \eta_{end-uses} = E_{final} - L_{end-use}$$



# The systemic perspective

## Conversion – some more formulas

### Annual perspective

- Conversion efficiency

$$\eta_{conv} = \frac{E_{secondary}}{E_{primary}}$$

- Distribution efficiency

$$\eta_{dist} = \frac{E_{final}}{E_{secondary}}$$

- End-use efficiency

$$\eta_{end-use} = \frac{E_{end-use}}{E_{final}}$$

- Combination of efficiencies

$$\eta_{system} = \eta_{conv} \cdot \eta_{dist} \cdot \eta_{end-use}$$

### Seasonality

- Conversion efficiency

$$\eta_{conv}(t) = \frac{E_{secondary}(t)}{E_{primary}(t)}$$

- Distribution efficiency

$$\eta_{dist}(t) = \frac{E_{final}(t)}{E_{secondary}(t)}$$

- End-use efficiency

$$\eta_{end-use}(t) = \frac{E_{end-use}(t)}{E_{final}(t)}$$

- Combination of efficiencies

$$\eta_{system}(t) = \eta_{conv}(t) \cdot \eta_{dist}(t) \cdot \eta_{end-use}(t)$$

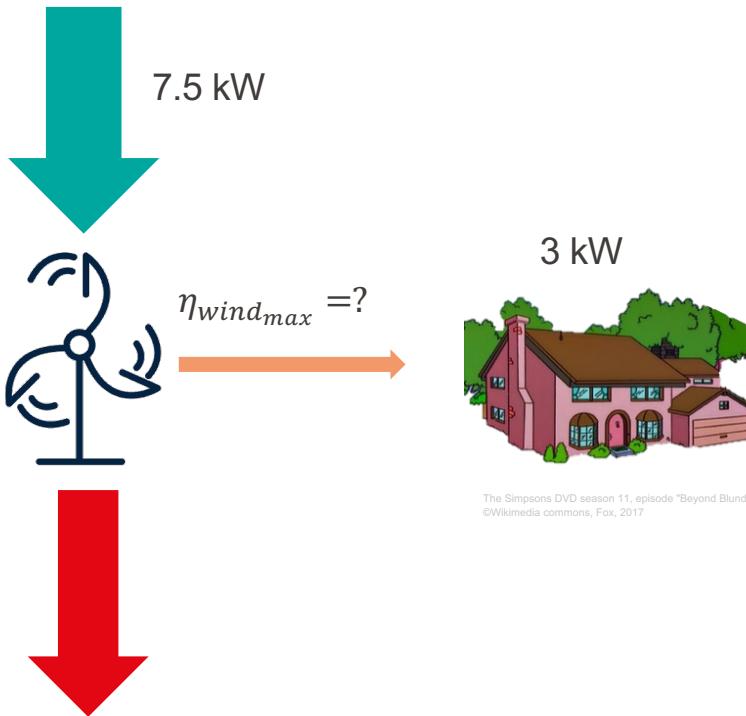


# The systemic perspective

## Conversion – the Simpsons live intermittently

Case 1: Full Wind

$$\eta_{full-wind} = ?$$



The Simpsons DVD season 11, episode "Beyond Blunderdome"  
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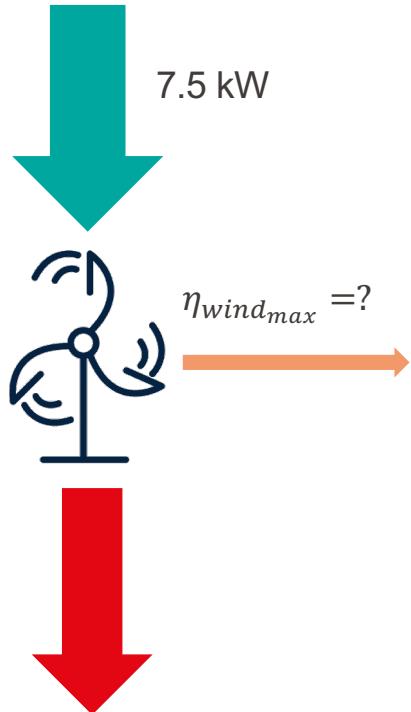
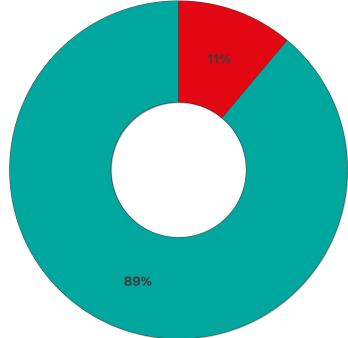


# The systemic perspective

## Conversion – the Simpsons live intermittently

Case 1: Full Wind

$$\eta_{full-wind} = ?$$



Calculate the electricity conversion system efficiency  $\eta_{full-wind}$  to cover the Simpson's electricity demand

- A. 2.5%
- B. 40%
- C. 25%
- D. 0.4%

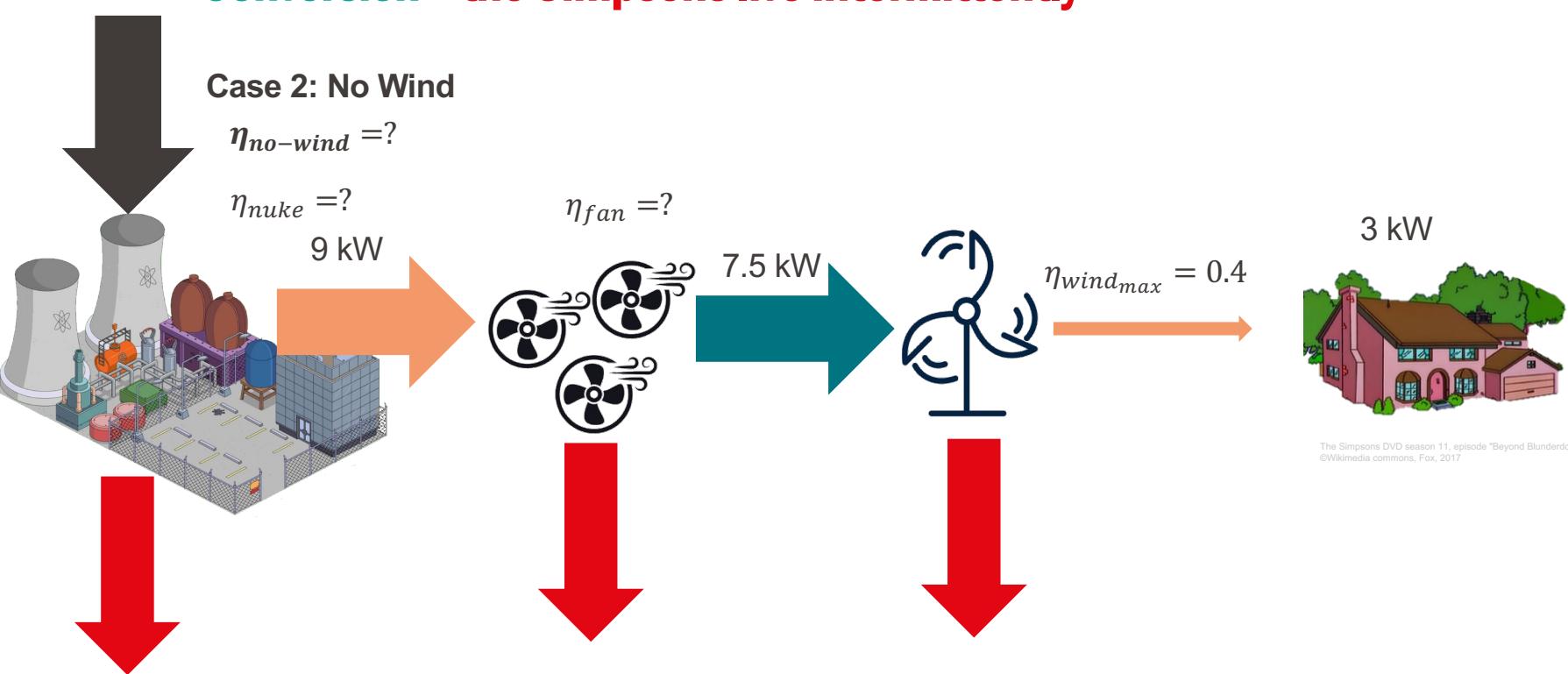


The Simpsons DVD season 11, episode "Beyond Blunderdome"  
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# The systemic perspective

## Conversion – the Simpsons live intermittently

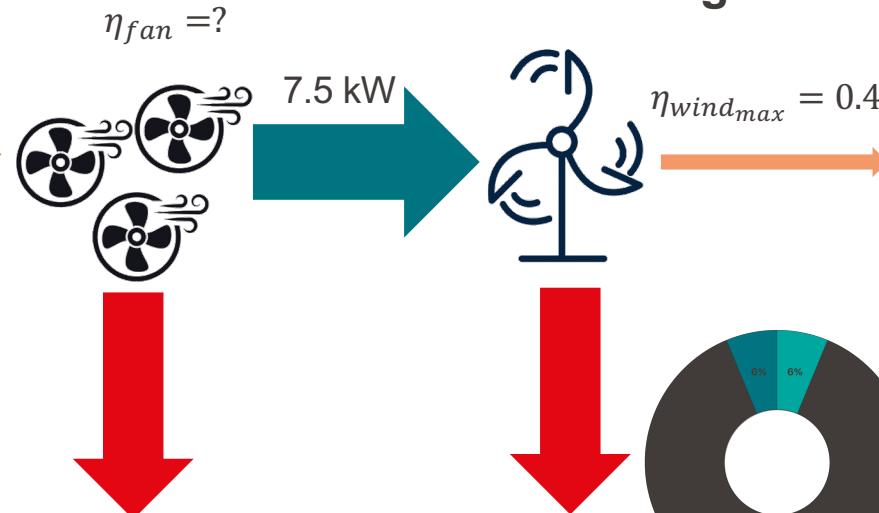
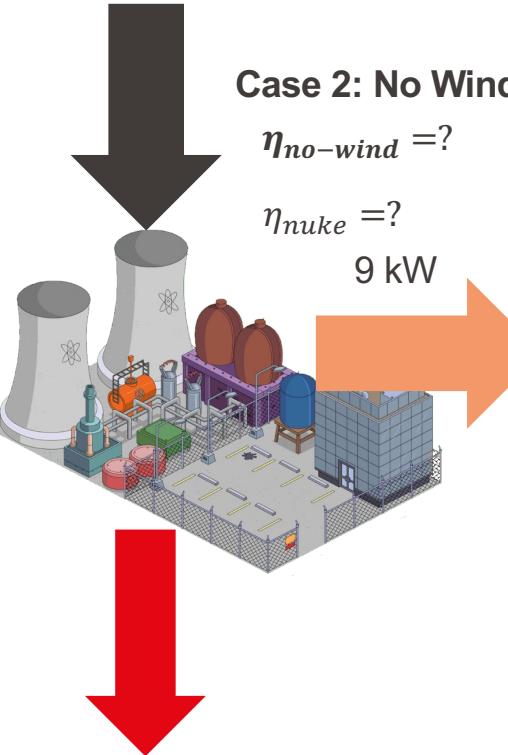


The Simpsons DVD season 11, episode "Beyond Blunderdome"  
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# The systemic perspective

## Conversion – the Simpsons live intermittently



Calculate the electricity conversion system efficiency  $\eta_{no-wind}$  to cover the Simpson's electricity demand when no wind is blowing



A. 40%

B. 25%

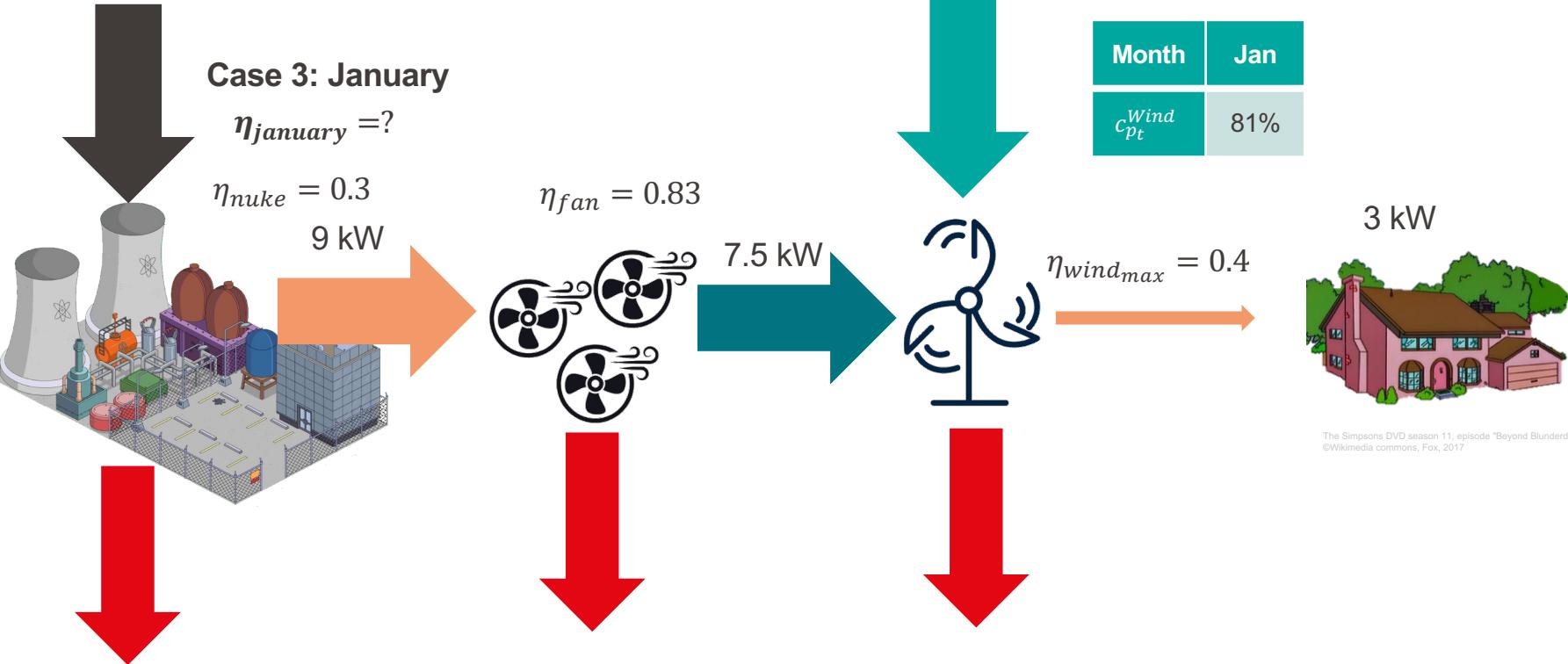
C. 10%

D. 4%



# The systemic perspective

## Conversion – the Simpsons live intermittently

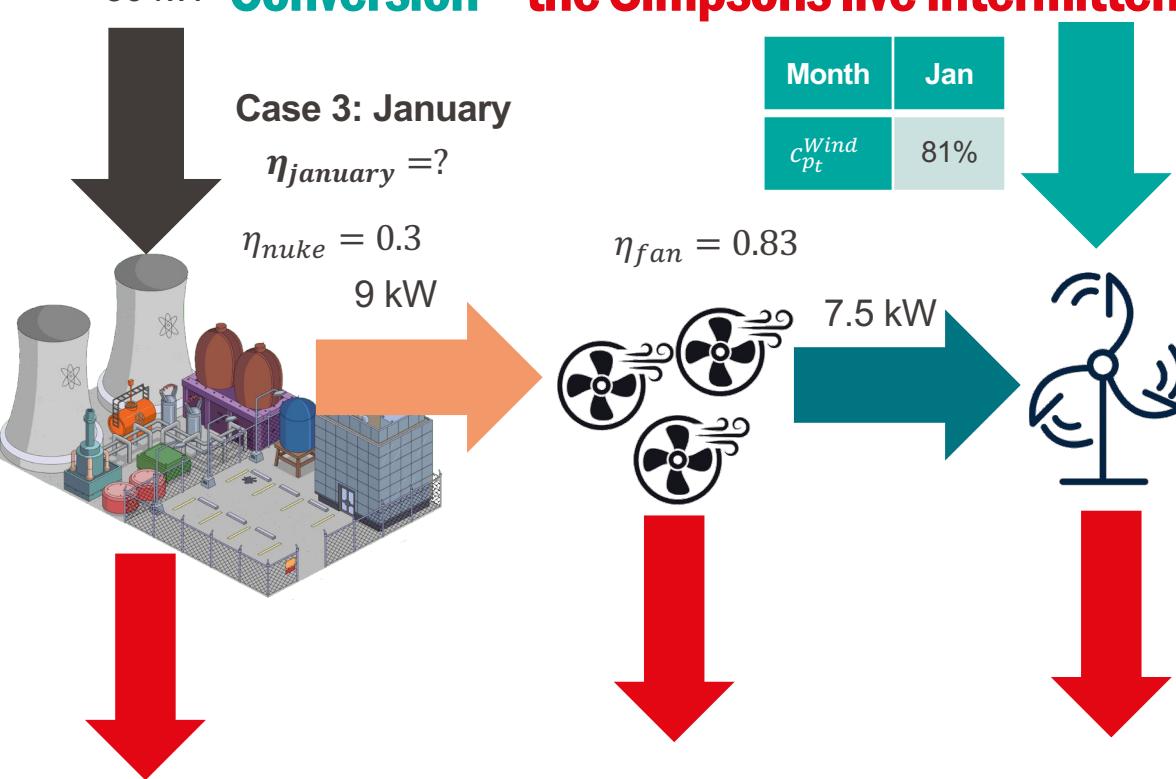


The Simpsons DVD season 11, episode "Beyond Blunderdome"  
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# The systemic perspective

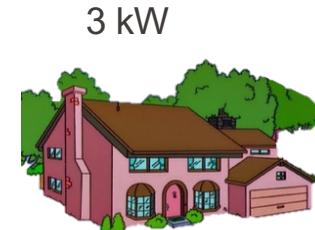
## Conversion – the Simpsons live intermittently



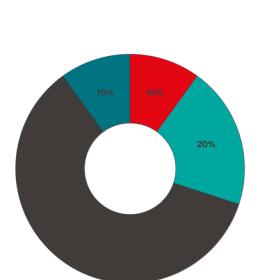
ENV-421

Calculate the electricity conversion system efficiency  $\eta_{January}$  to cover the Simpson's electricity demand with partial wind outages

- A. 11%
- B. 26%
- C. 34%
- D. 41%

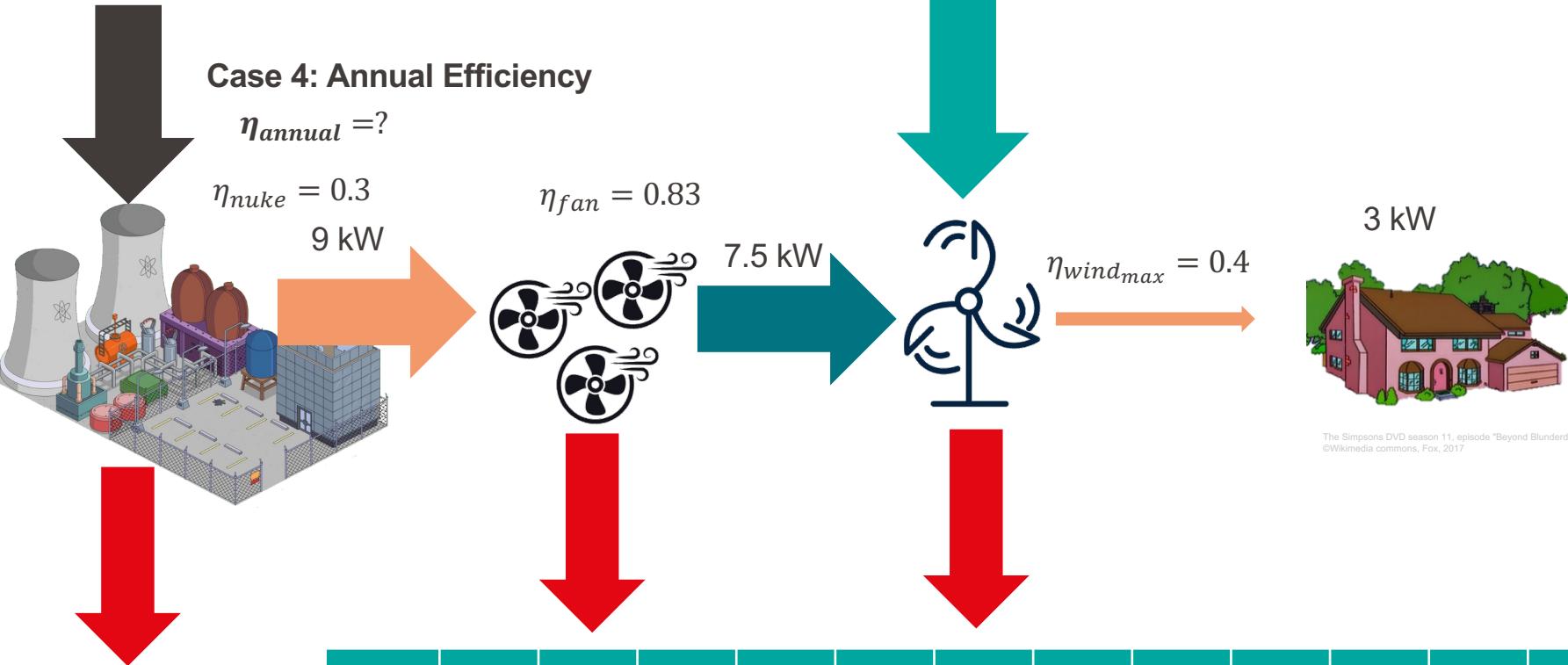


11% 26% 34% 41%



# 30 kW Conversion – the Simpsons live intermittently

30 kW



## Case 4: Annual Efficiency

$$\eta_{annual} = ?$$

$$\eta_{nuke} = 0.3$$

9 kW

$$\eta_{fan} = 0.83$$

7.5 kW

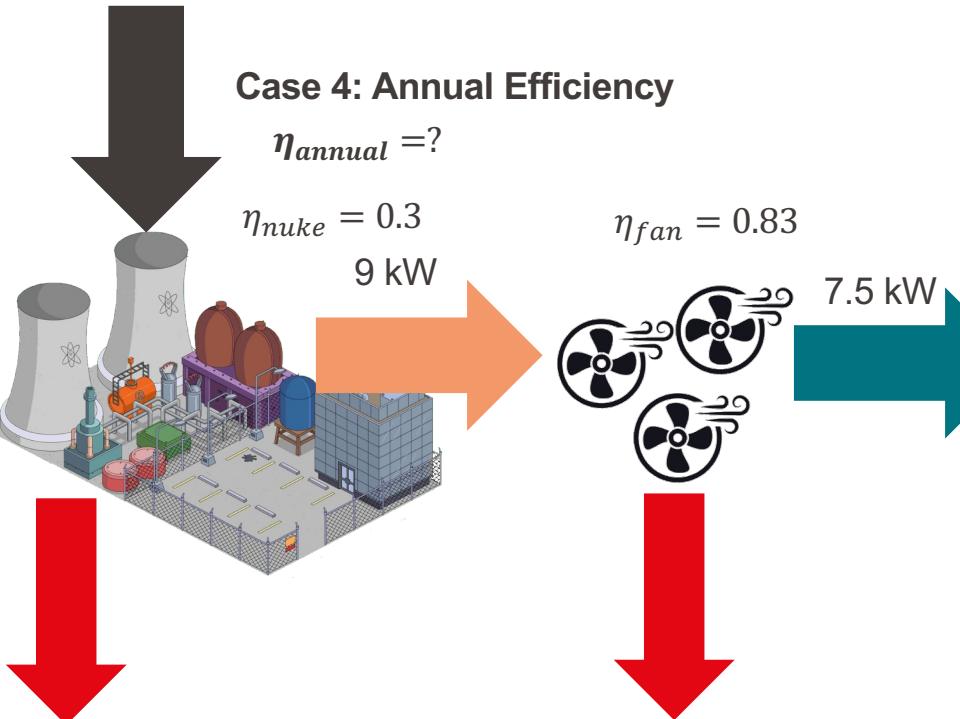
$$\eta_{wind_{max}} = 0.4$$

3 kW

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$c_{pt}^{Wind}$	81%	70%	71%	46%	45%	35%	37%	33%	40%	70%	78%	85%

# The systemic perspective

## Conversion – the Simpsons live intermittently



Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$c_{p_t}^{Wind}$	81%	70%	71%	46%	45%	35%	37%	33%	40%	70%	78%	85%

Calculate the annual electricity conversion system efficiency  $\eta_{annual}$  to cover the Simpson's electricity demand with partial wind outages



The Simpsons DVD season 11, episode "Beyond Blunderdome"  
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