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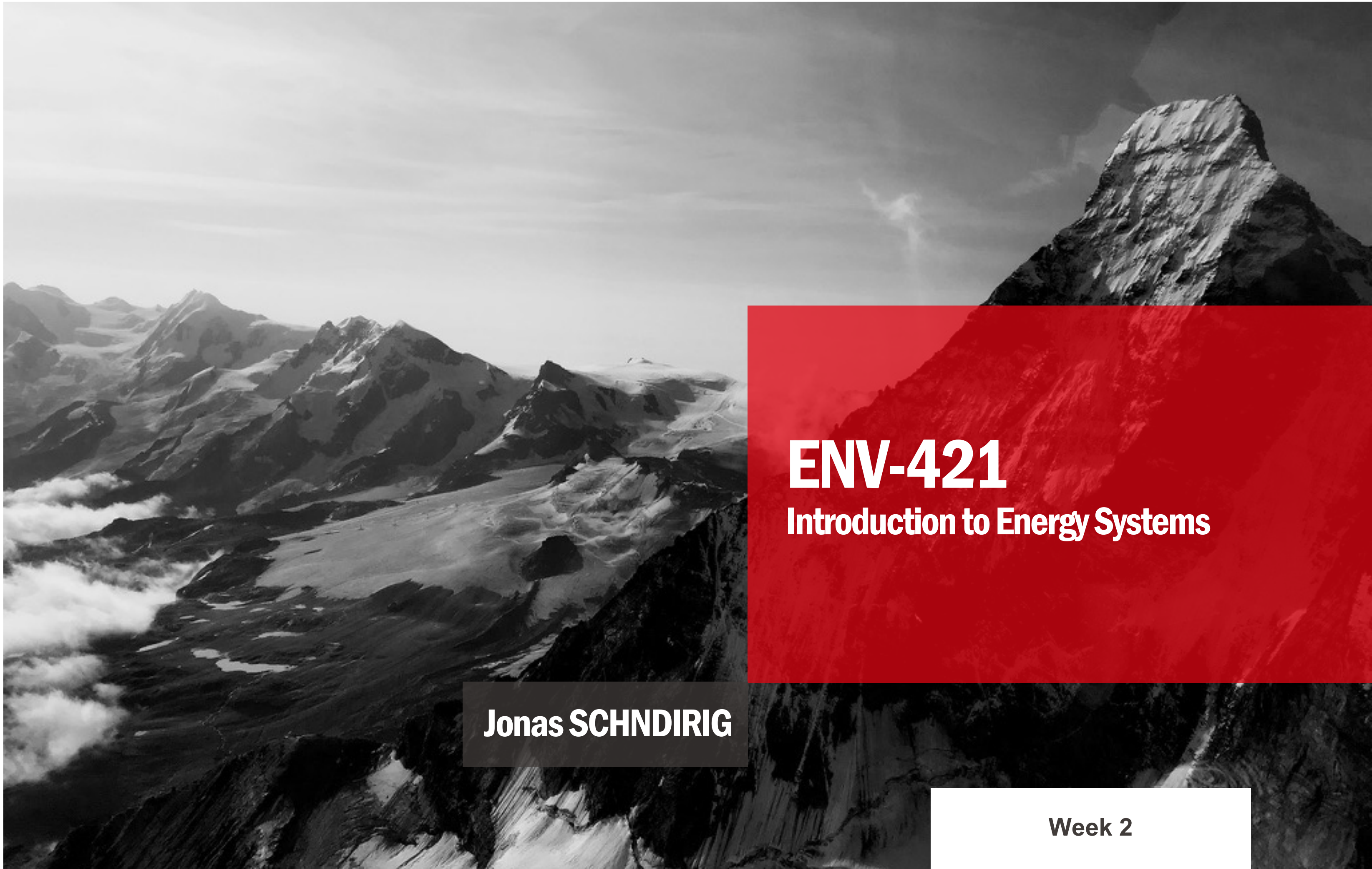
IPESE
Industrial Process
and Energy Systems
Engineering

Hes·so Valais Wallis
School of Engineering

CIRAIG



ENV-421
Introduction to Energy Systems

Jonas SCHNDIRIG

Week 2

École
polytechnique
fédérale
de Lausanne

- 24’004 YEARS

- 24’004 YEARS

- 1809 M

BRIG

- 1502 M

SION

- 1199 M

Lausanne

map.geoadmin.ch


2024
+7.8°C
in 24’004 years
ipcc report 2022
© Valais promotion


2024
+7.8°C
in 24’024 years


2050
+1.5°C - +2.5°C
in 60 years?!
+7.8°C
in 24’004 years
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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 & Excercises	The Swiss Energy System Evolution & Perspectives	Efficiencies & Classification	Conference *Is it all about renewable energies?* Closing the Balance & Defining Compromises	*Powerplay Game*

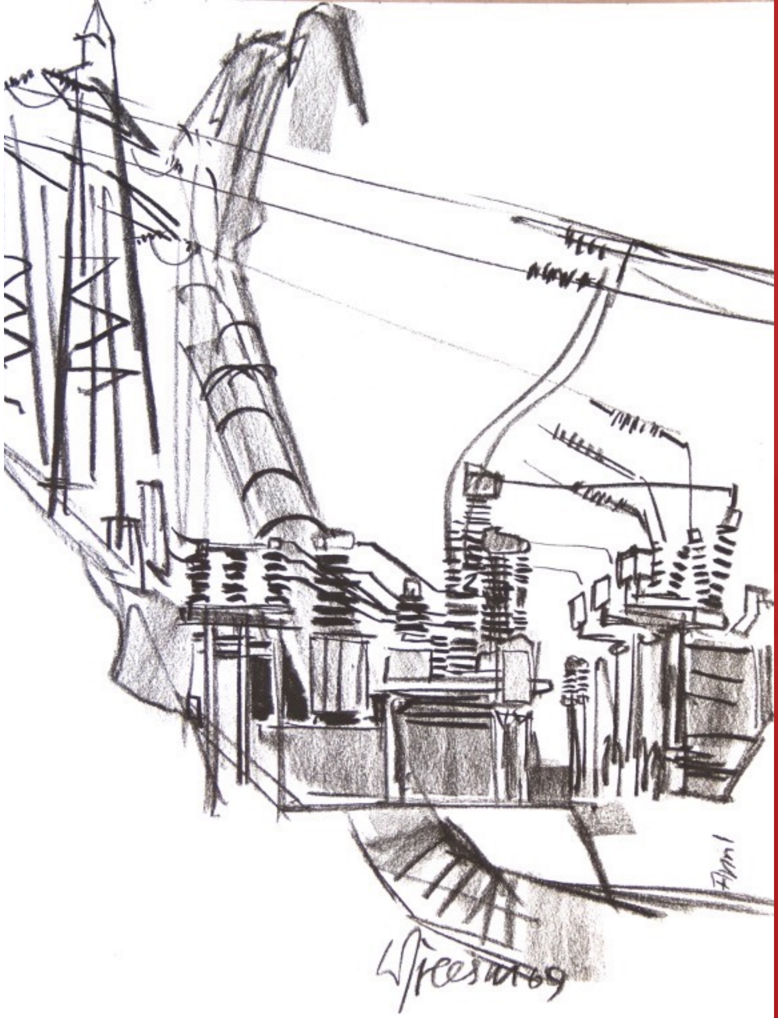
Project: Addressing Contemporary Challenges to the Swiss system
Energy-independent and carbon-neutral Switzerland 2050

This Week

Week 2

	Week 2
Lectures	Energy System Fundamentals
Applications & Excercises	The Swiss Energy System Evolution & Perspectives

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



A G E N D A

Introduction to Energy Systems

Energy Balance Fundamentals

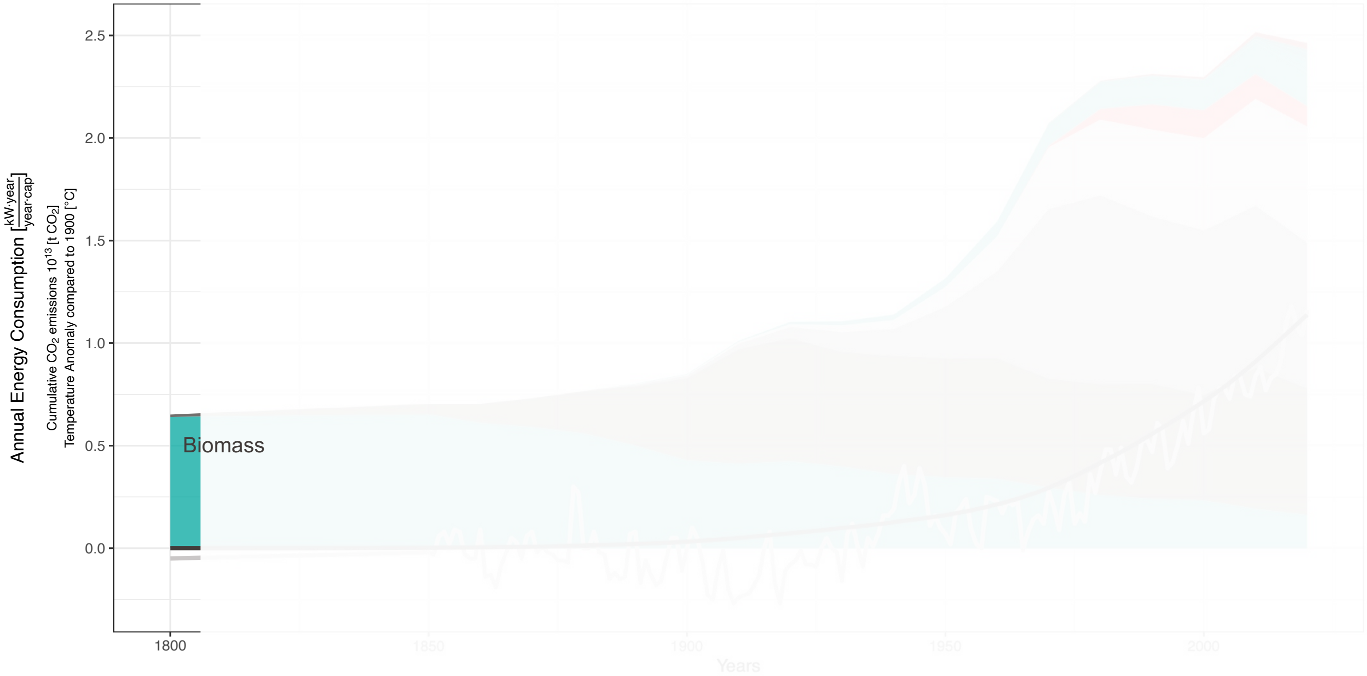
Analysis and Evaluation of Energy Systems

Jonas Schnidrig

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 CO2 emissions are calculated as the cumulative sum of year emissions since 1800 [52].

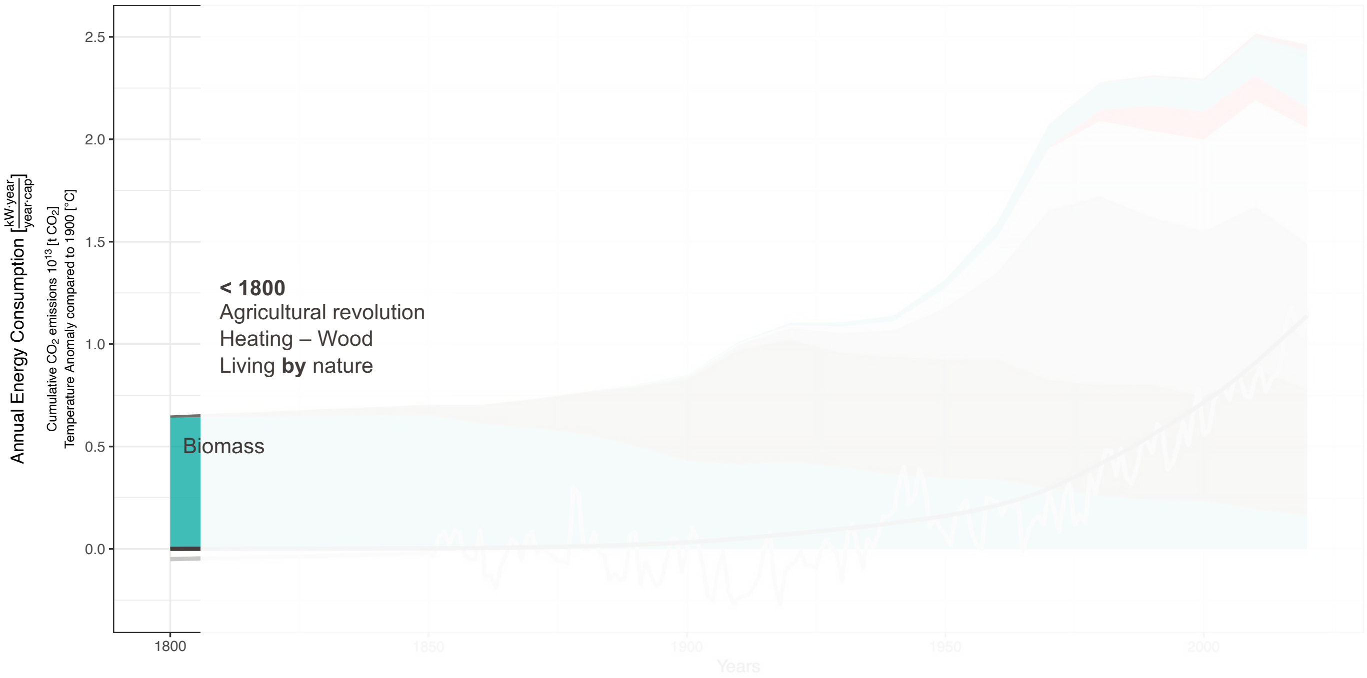
Population	**0.8 billion**
Energy $\left[\frac{W \cdot year}{year\ cap}\right]$	**400**
CO_2 emissions $[10^9\ t]$	**0.12**
ΔT_{1800} [°C]	**0**

A brief history of time

Jonas Schnidrig

Symbiosis with Nature

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



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Population	**1 billion**
Energy $\left[\frac{W \cdot year}{year\ cap}\right]$	**656**
CO_2 emissions $[10^9\ t]$	**0.19**
ΔT_{1800} $[°C]$	**0**

A brief history of time

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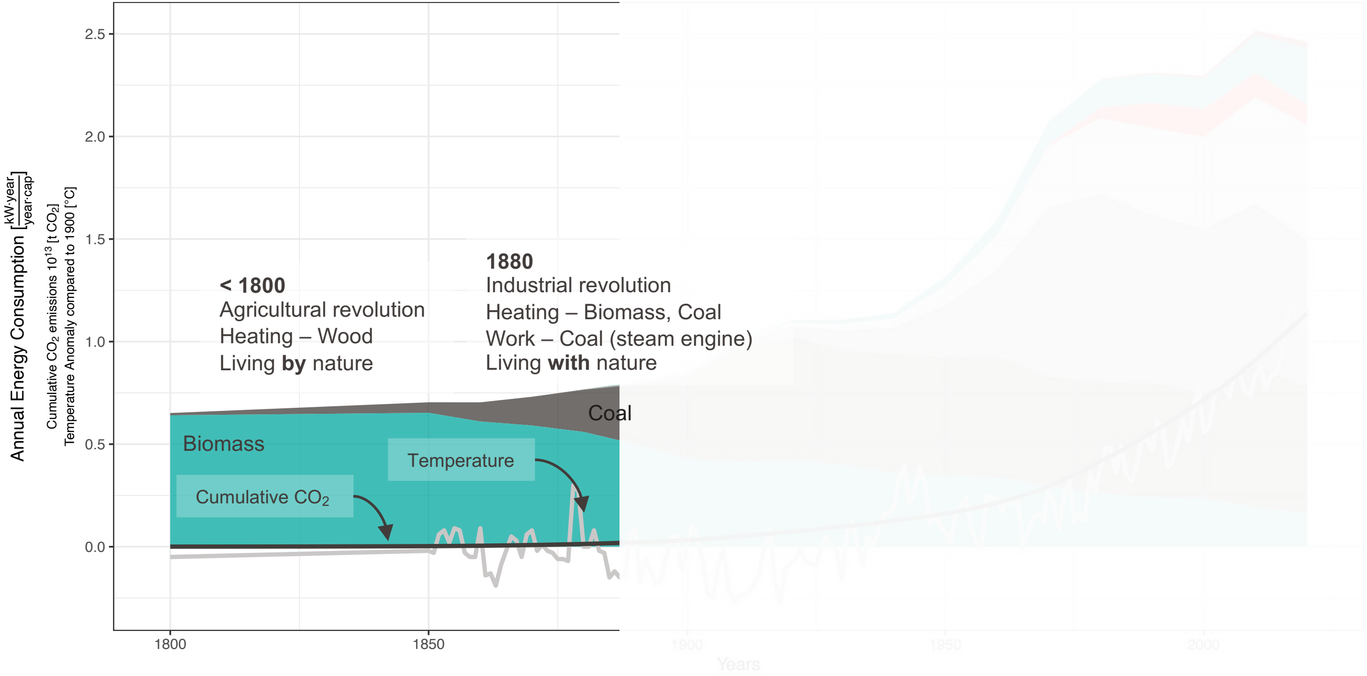
Harnessing Power

- **Industrial Revolution** increased energy use per capita, raising CO_2 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]



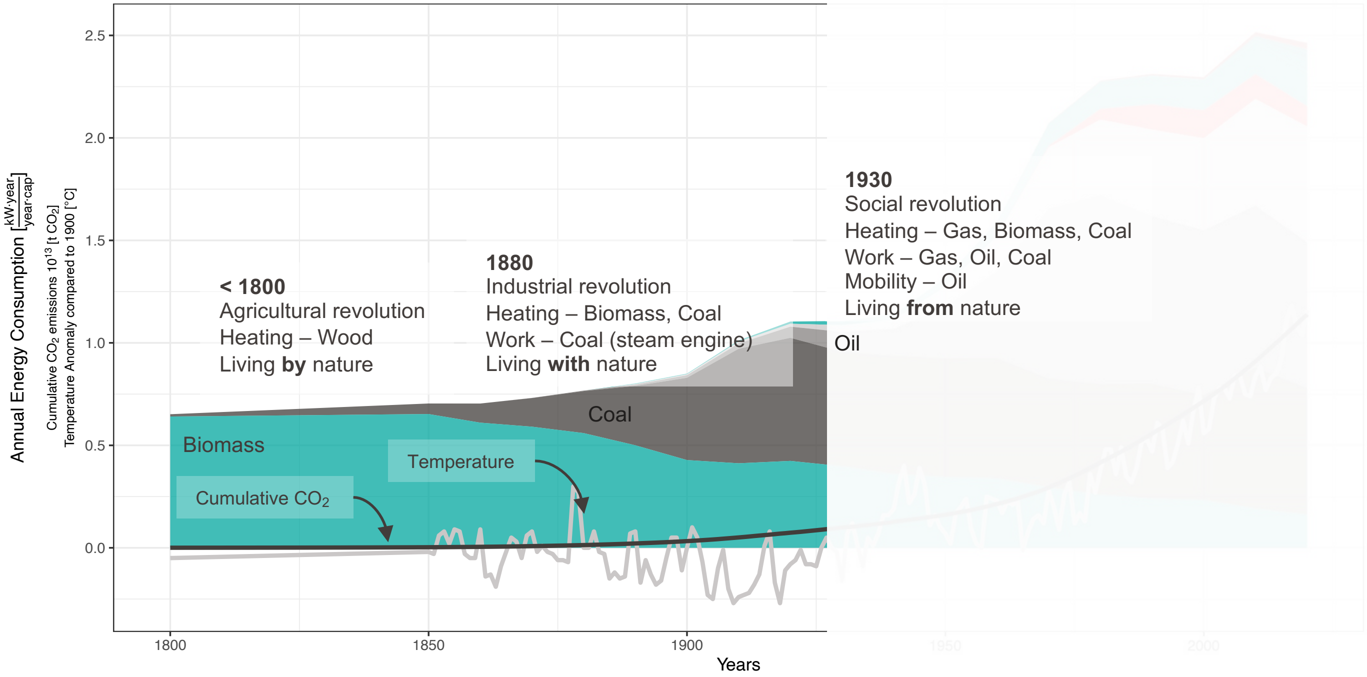
Population	**1.4 billion**
Energy $\left[\frac{W \cdot year}{year\ cap}\right]$	**766**
CO_2 emissions $[10^9\ t]$	**6.41**
ΔT_{1800} [°C]	**0.05**

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 CO2 emissions are calculated as the cumulative sum of year emissions since 1800 [52].

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_2 levels to 415 ppm and temperatures by 0.9°C post-1950. [13,28,29]
- **Oil crises** and conflicts influenced energy patterns. [25–27]



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Population	**2.1 billion**
Energy $\left[\frac{W\cdot year}{year\ cap}\right]$	**1086**
CO_2 emissions $[10^9\ t]$	**27.3**
ΔT_{1800} $[°C]$	**0.12**

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A brief history of time

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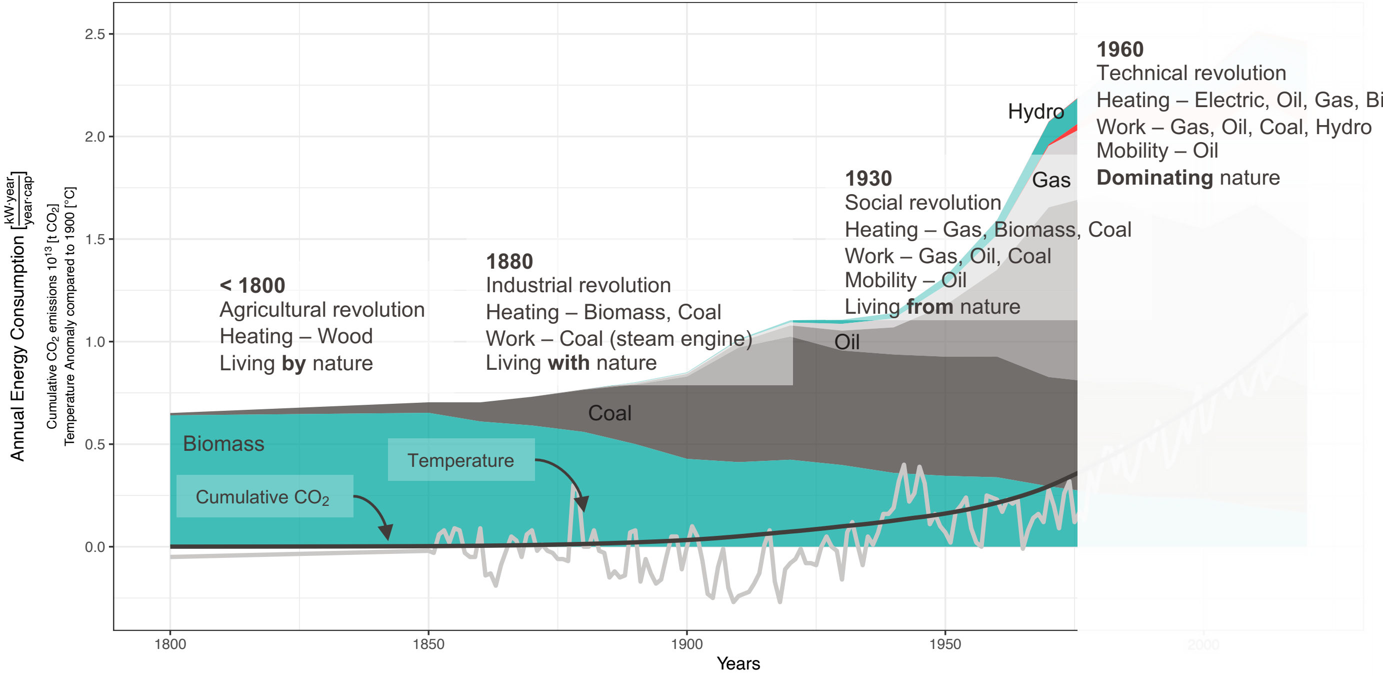
The Nuclear Dilemma and Environmental Awakening

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



Population	**3.0 billion**
Energy [W·year / year cap]	**1593**
CO_2 emissions [10^9 t]	**64.2**
ΔT_{1900} [°C]	**0.7**

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 CO2 emissions are calculated as the cumulative sum of year emissions since 1800 [52].

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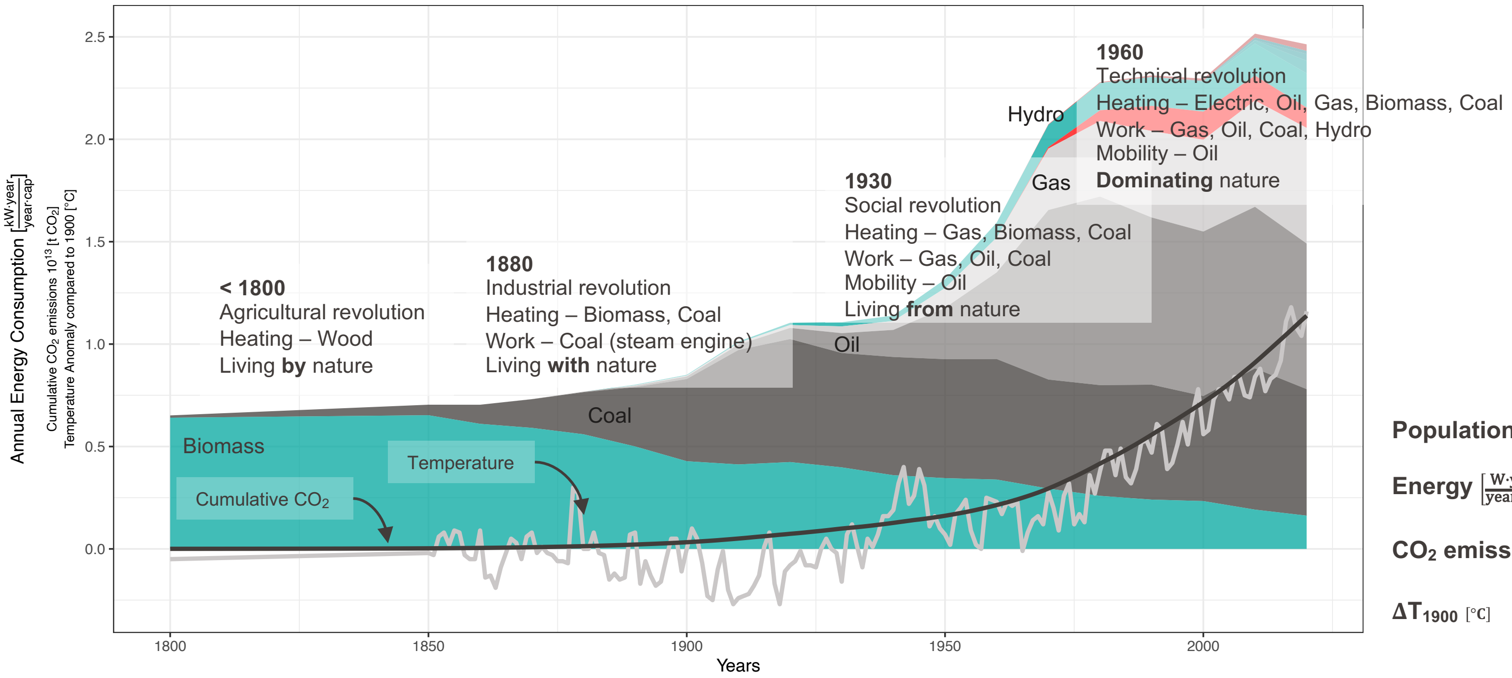
A brief history of time

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]



2020
Environmental revolution
Heating – Electric, Oil, Gas, Biomass,…
Work – Renewables, Nuclear, Gas, …
Mobility – Electric, Gas, Oil ,…
Protecting nature

Population	**7.8 billion**
Energy $\left[\frac{W \cdot year}{year\ cap}\right]$	**2463**
CO_2 emissions $[10^9\ t]$	**224.5**
ΔT_{1900} [°C]	**1.23**

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 CO2 emissions are calculated as the cumulative sum of year emissions since 1800 [52].

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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 21st century. [53,54]

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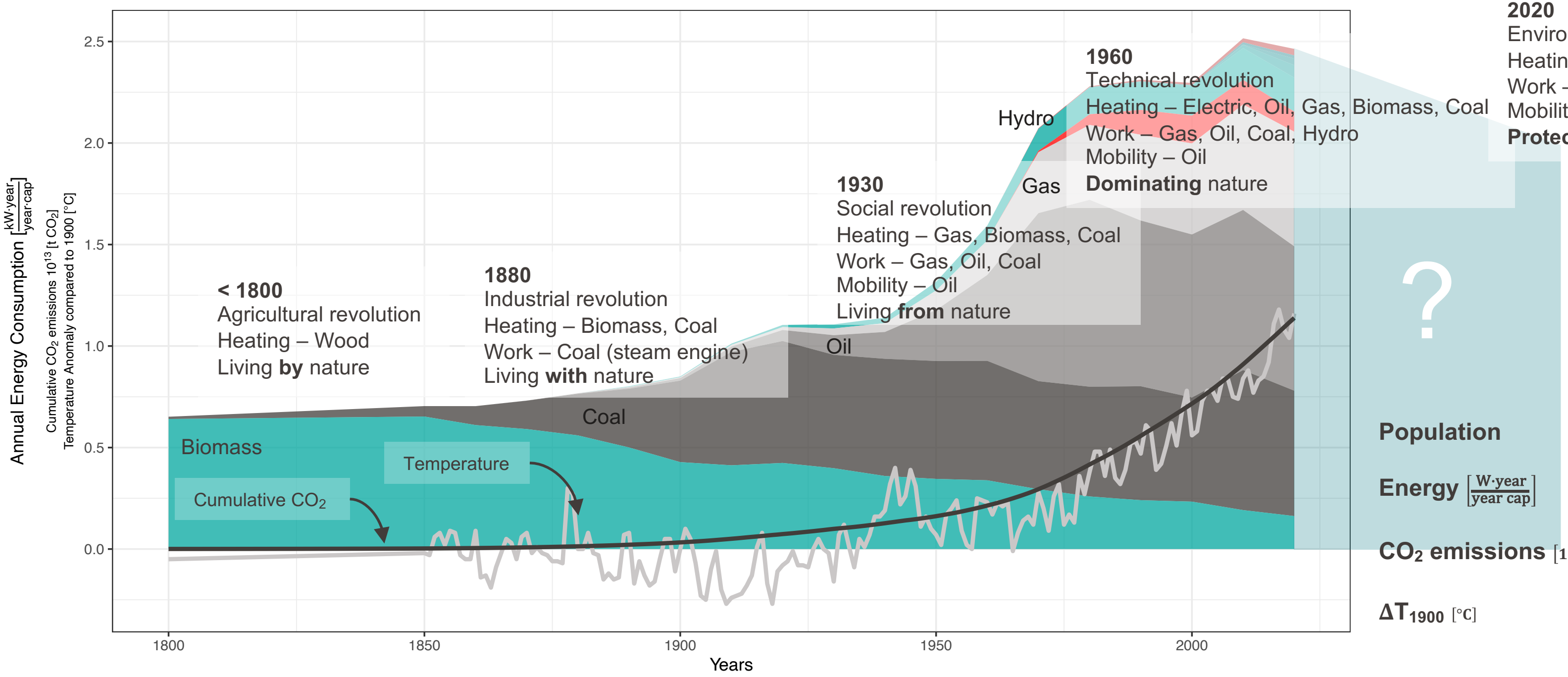

2020
Environmental revolution
Heating – Electric, Oil, Gas, Biomass,…
Work – Renewables, Nuclear, Gas, …
Mobility – Electric, Gas, Oil ,…
Protecting nature

Population	10 billion
Energy $\left[\frac{W\cdot year}{year\ cap}\right]$	2000
CO_2 emissions [10^9 t]	-0
ΔT_{1900} [°C]	2

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_2 emissions are calculated as the cumulative sum of year emissions since 1800 [52].

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

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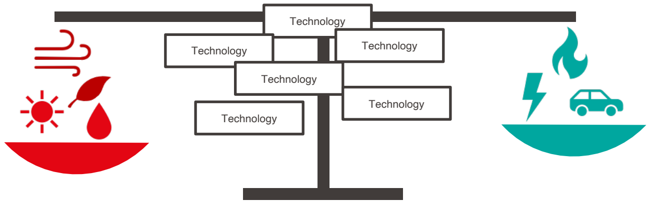

Resources

Costs & Emissions
Annual availability

Technology

Fossils & Renewables
Investments & O&M
Efficiencies & Emissions
Storage

Energy demands

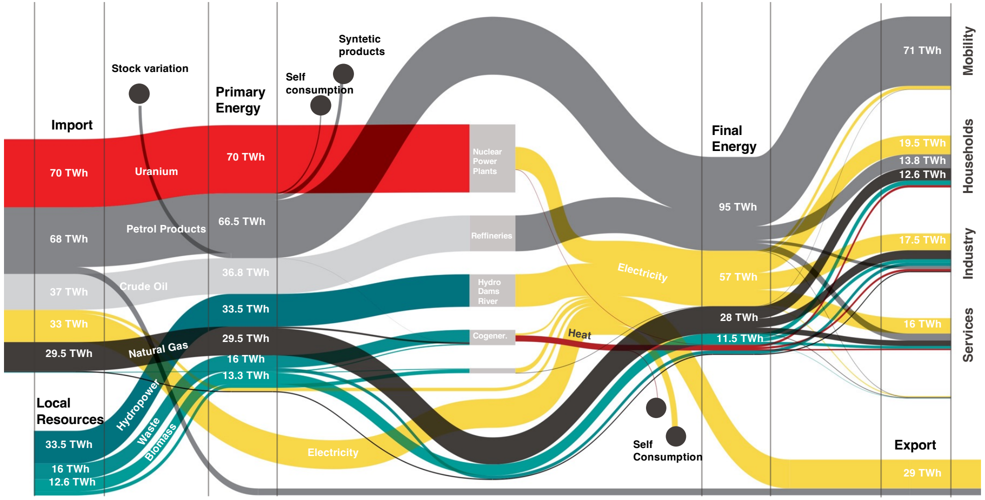

Illustration of the energy system modeling principle

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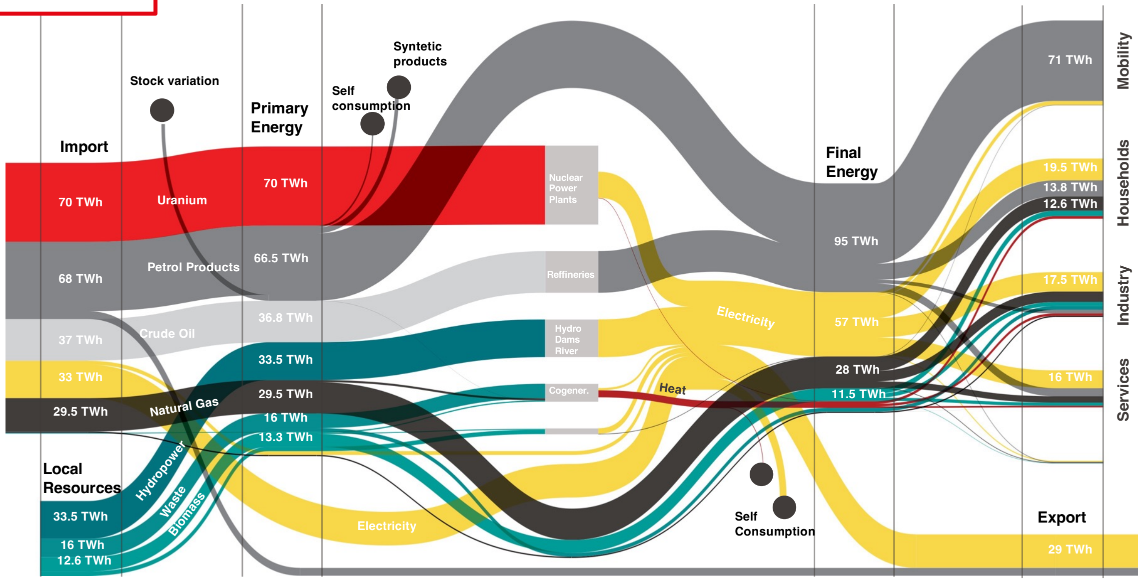
The energy system

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.



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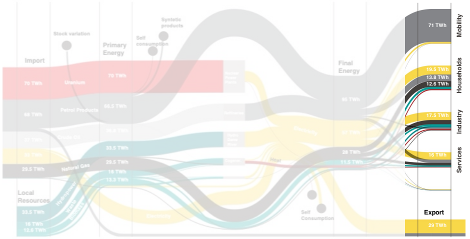
Demands



Sectors

Mobility

Housing

Industry
&
Agriculture

Services

End-Uses

Heat

Low Temperature

Process Heat

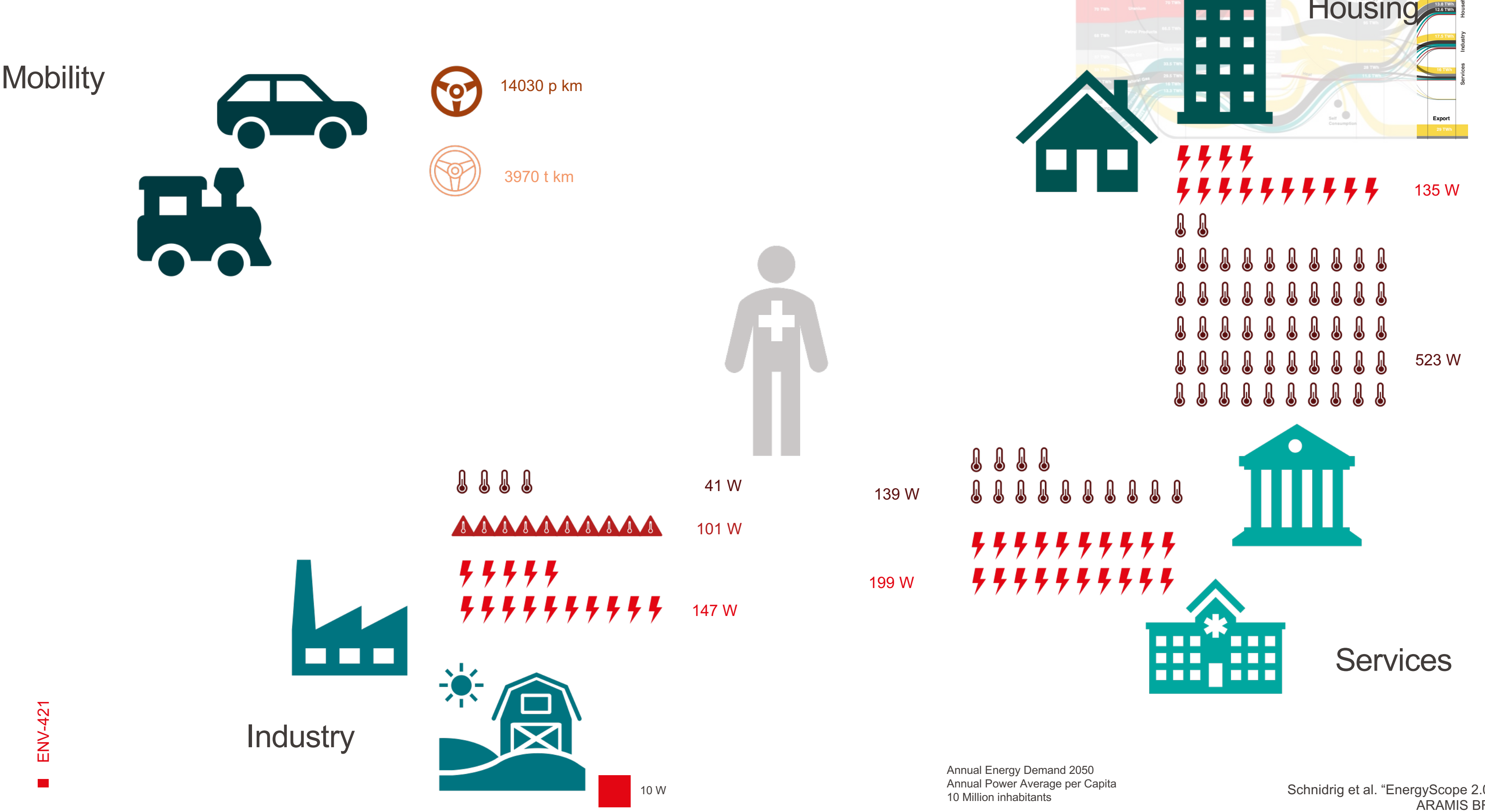
Electricity

Transportation

Passenger [pkm/year]

Freight [tkm/year]

Demands

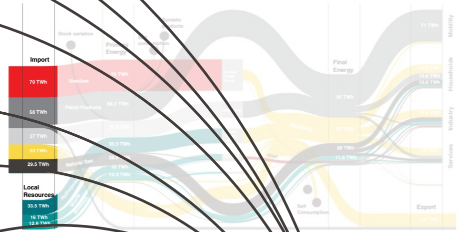


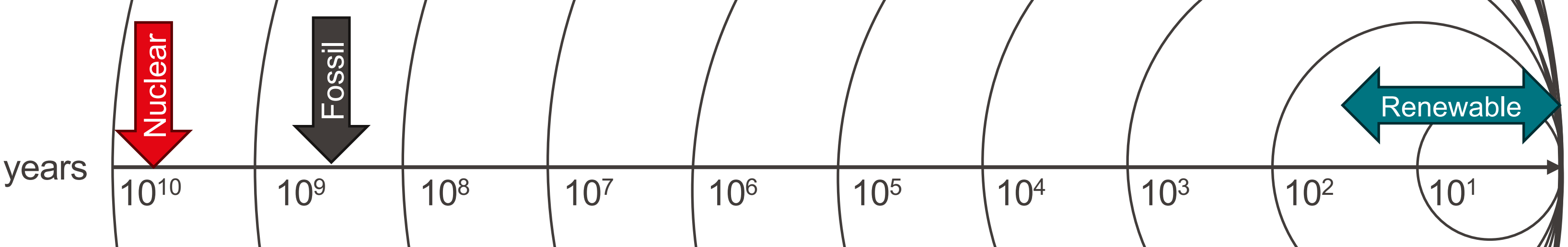
Annual Energy Demand 2050
Annual Power Average per Capita
10 Million inhabitants

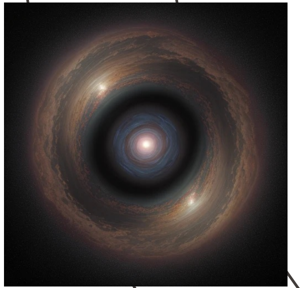
Schnidrig et al. “EnergyScope 2.0”,
ARAMIS BFE

Resources

Renewable vs non-renewable







An Impression of the Big Bang Exploding from Nothing.
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Life restoration of Barosaurus lentus defending itself from a pair of Allosaurus fragilis.
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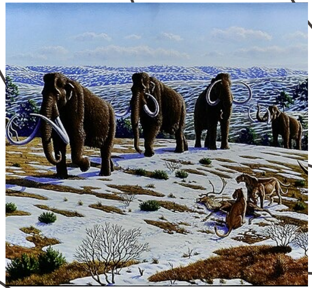

Una representación del hábitat del mammuthus primigenius en el pleistoceno.
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Illustration of the renewable time scale. Adapted from Prof. Sophia Haussener

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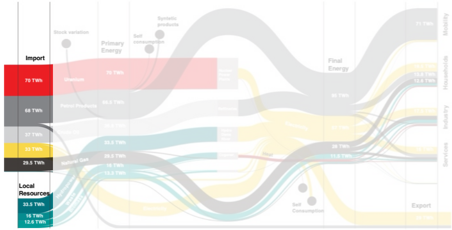
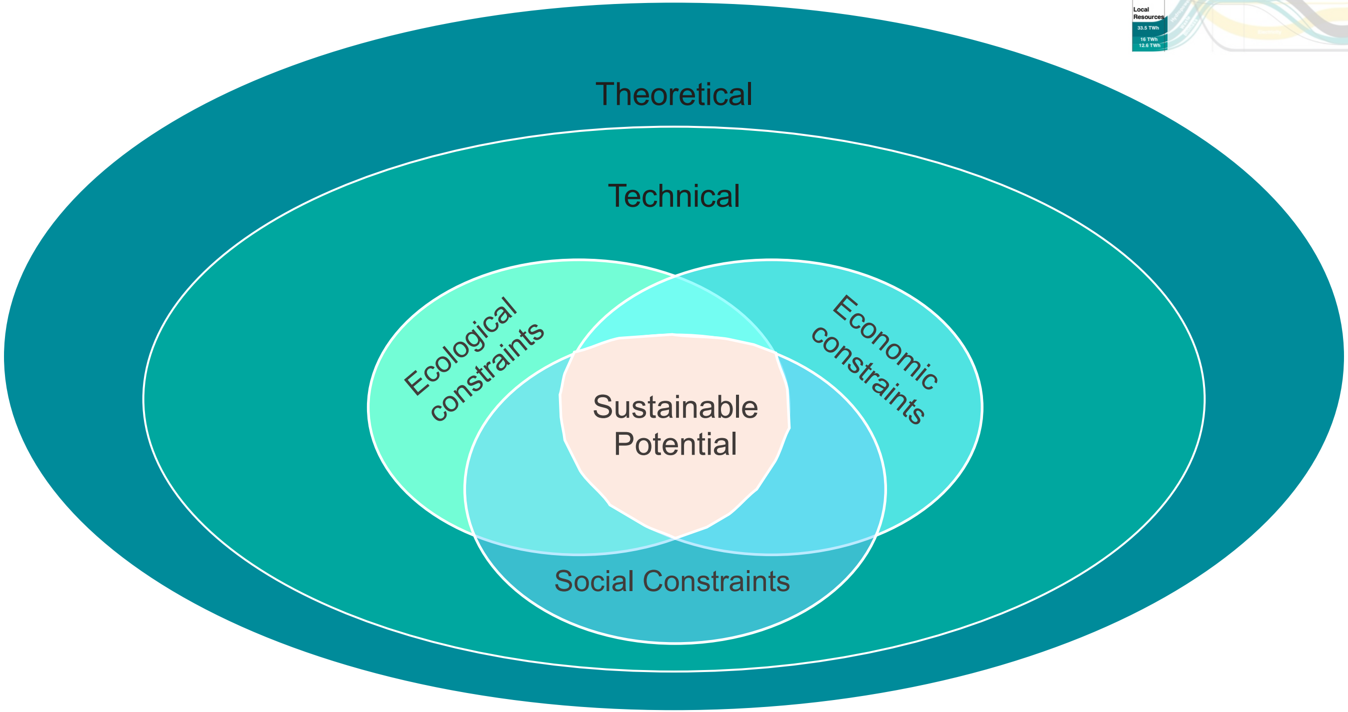
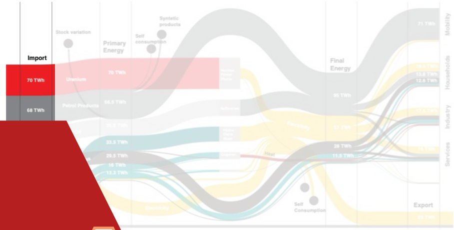
Resources
Potentials





Source: Adapted from Dr. Yasmine Calisesi, CEN EPFL

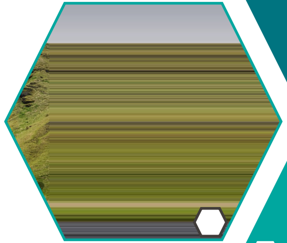
Resources
Local Resources



Wind

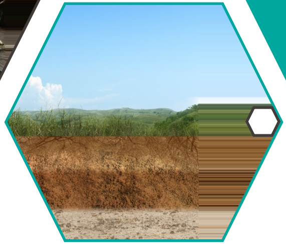
Waste

Solar



Dry Biomass

Hydro



Geothermal

Wet Biomass

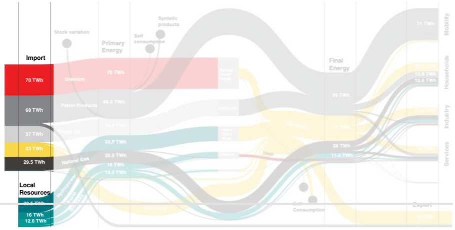
Source: Adapted from Dr. Yasmine Calisesi, CEN EPFL

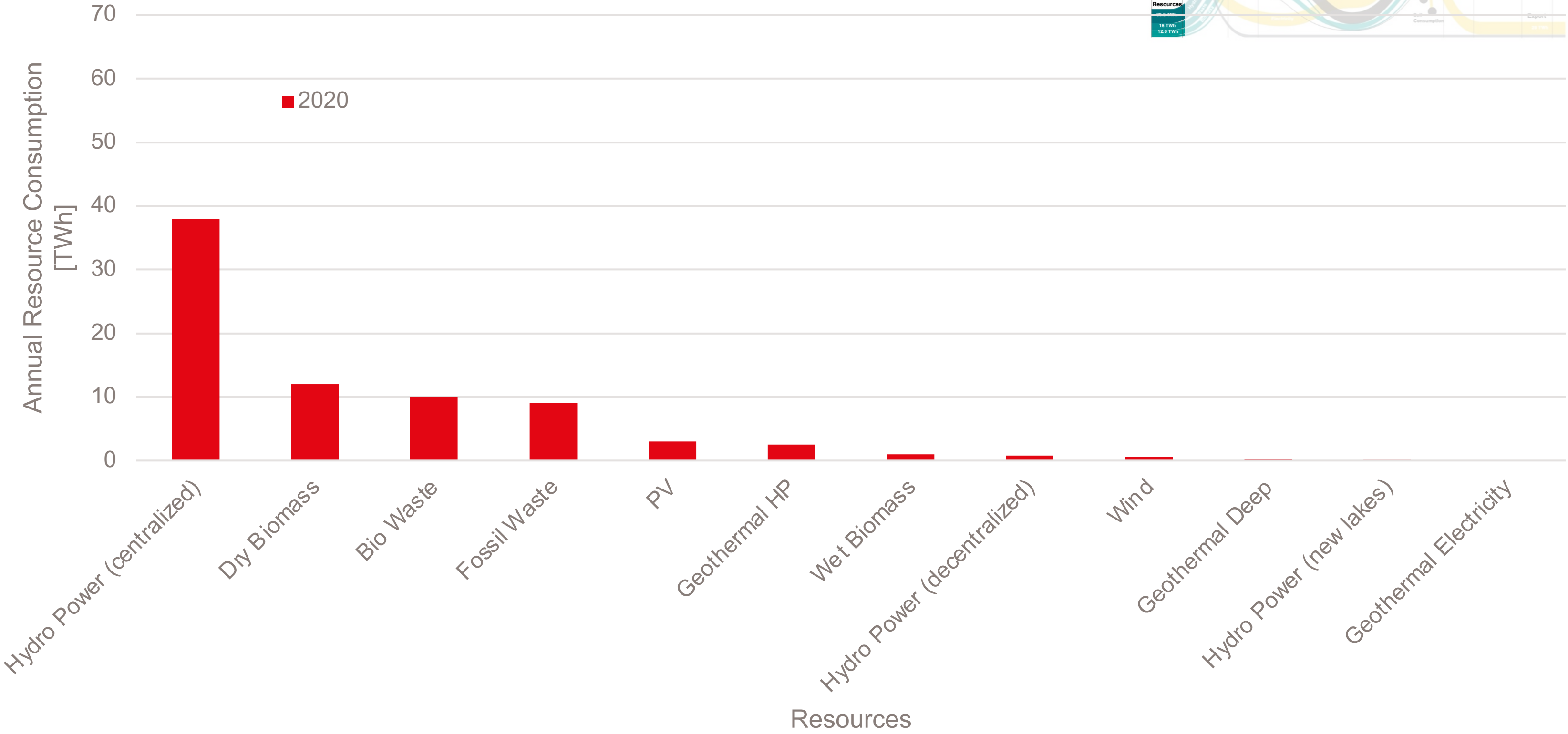
Resources Potential & Used

- Class the following resources by
  - Used Energy in 2020

- 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





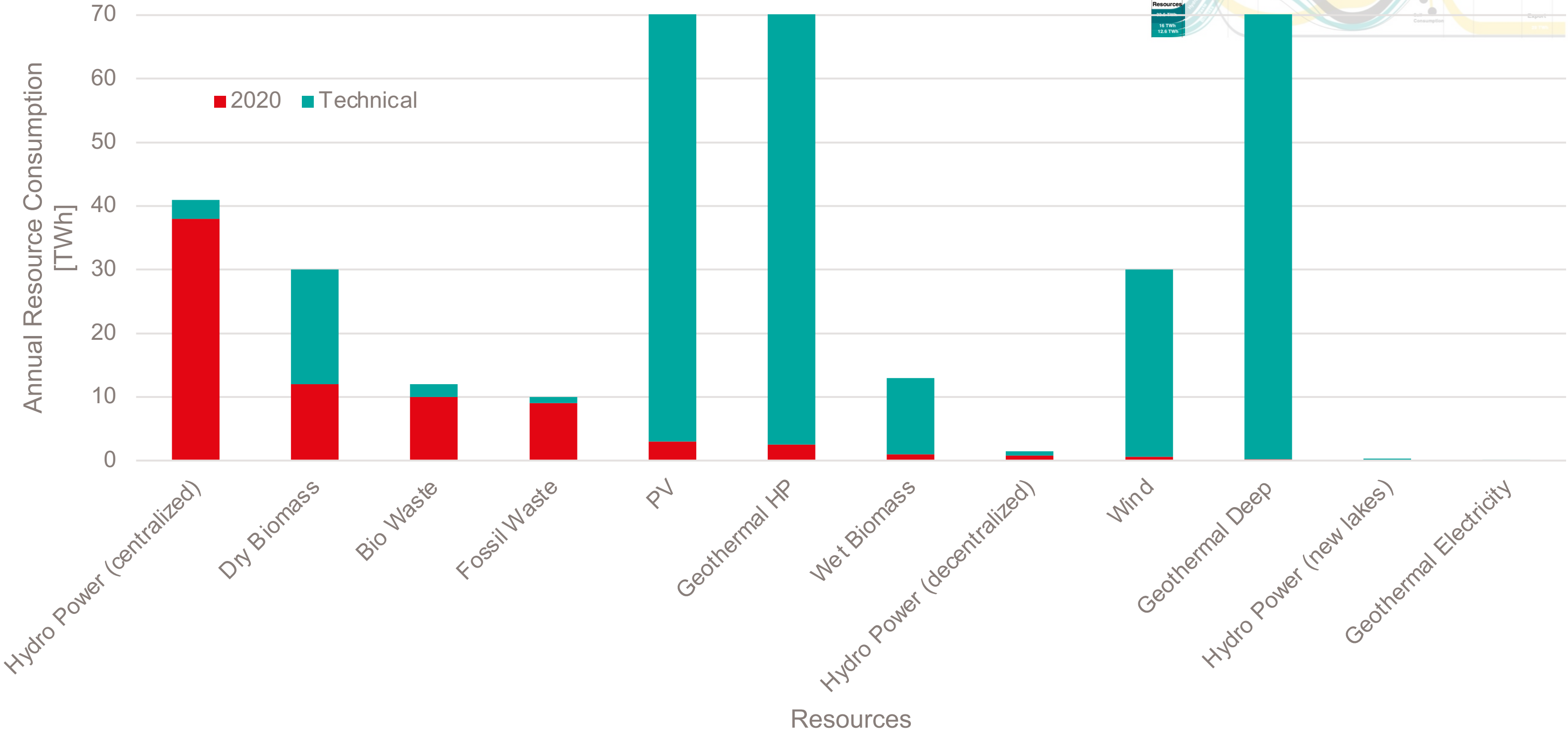
Source: Adapted from Dr. Yasmine Calisesi, CEN EPFL

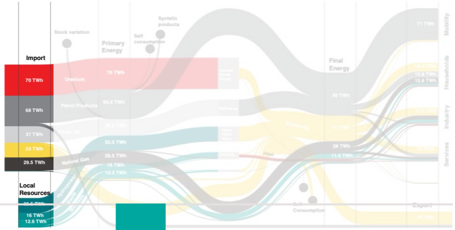
Resources Potential & Used

- Class the following resources by
  - Technical Potential

- 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





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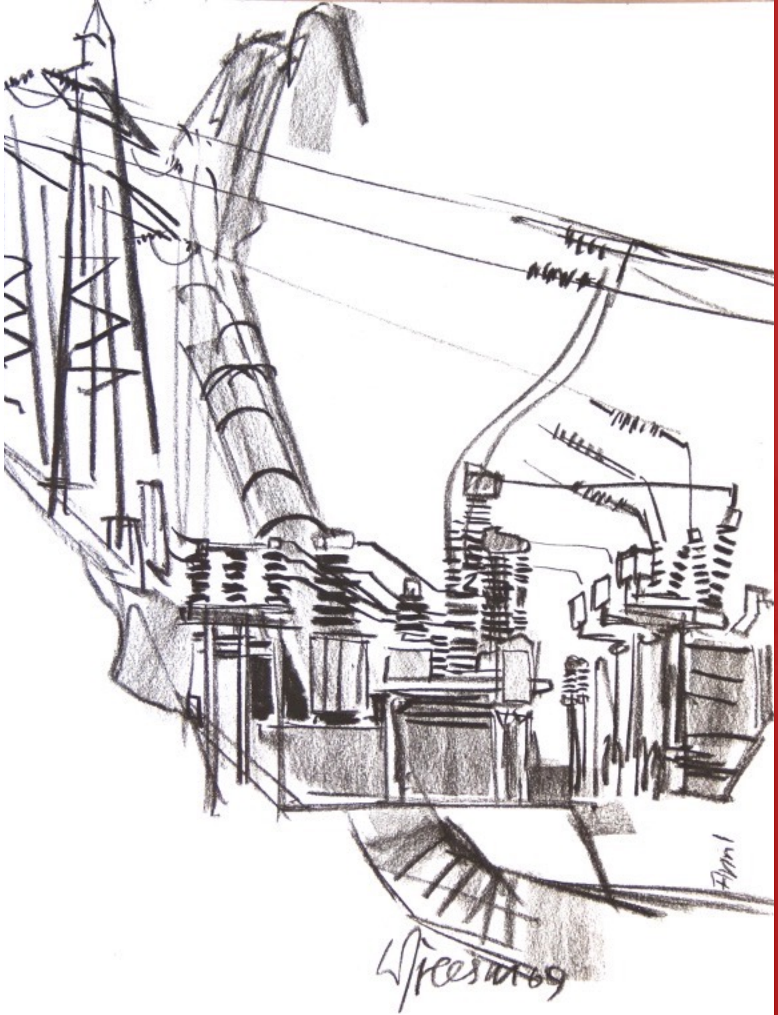


AGENDA

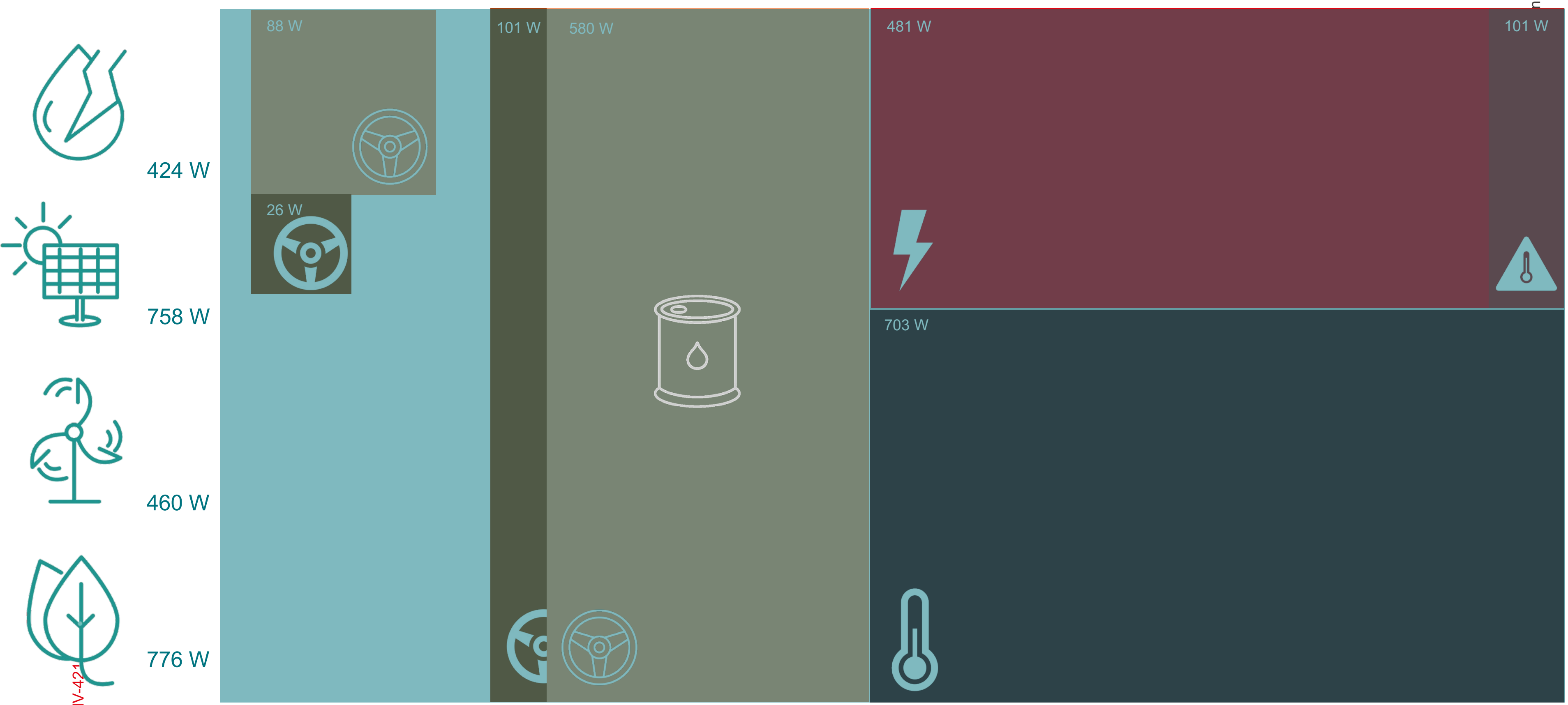
Introduction to Energy Systems

Energy Balance Fundamentals

Analysis and Evaluation of Energy Systems

Swiss Technical Potentials*

Annual Mean Power



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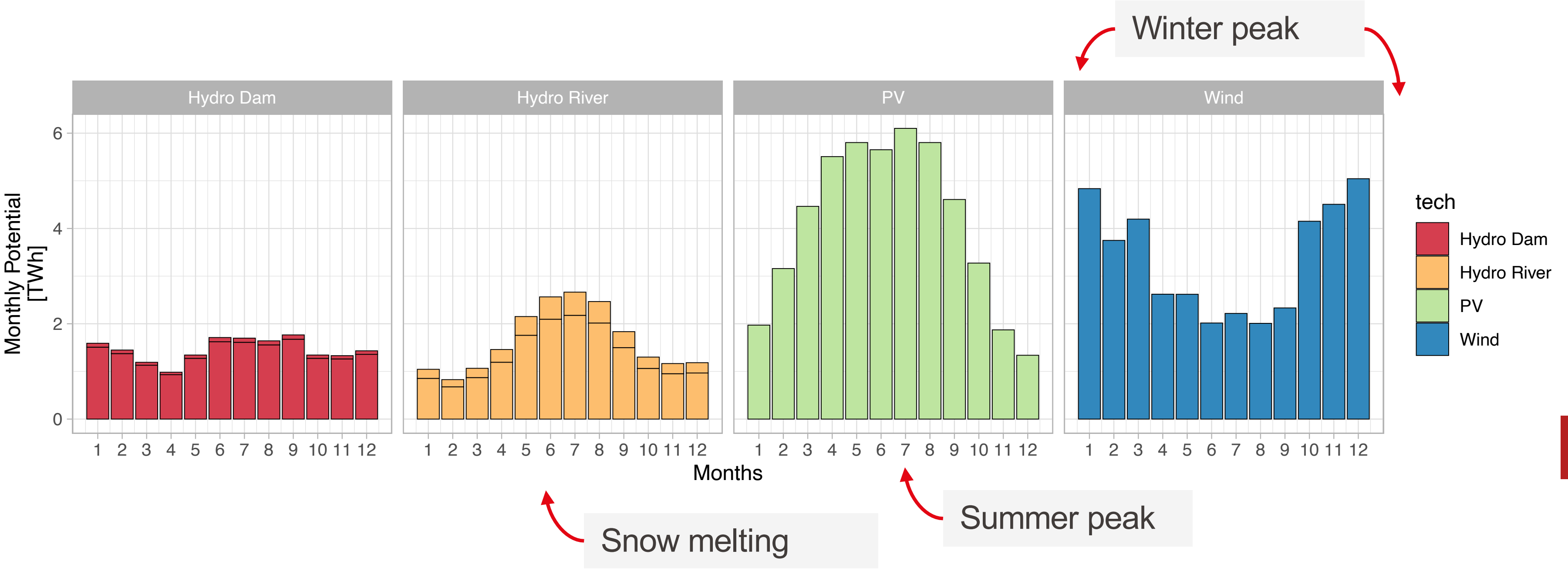
* Non-exhaustive list

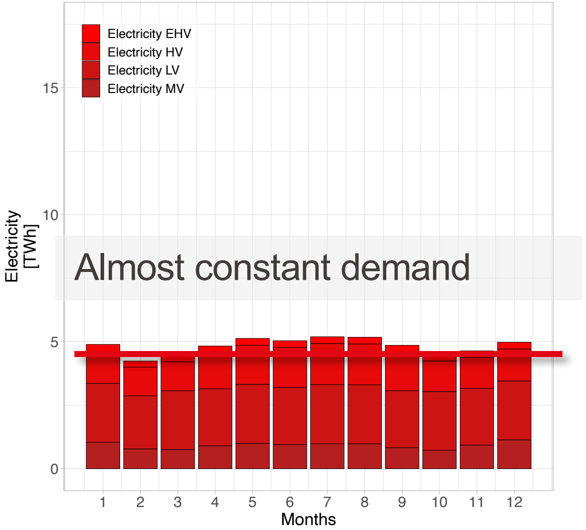
The Systemic Approach
The intermittency Challenge

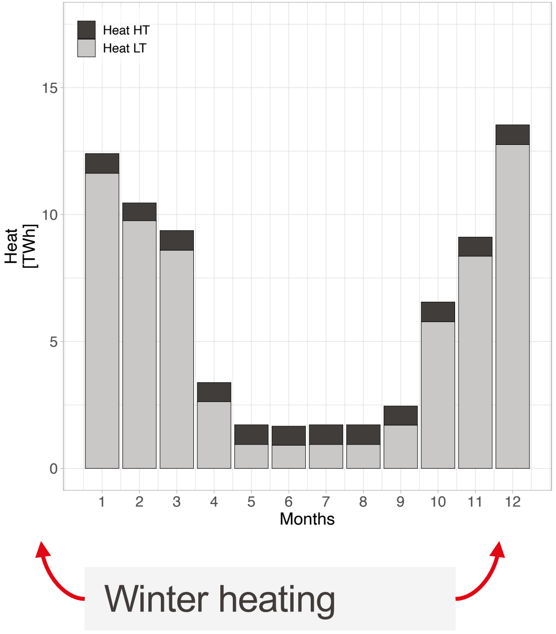
The Systemic approach
Intermittency of Resources

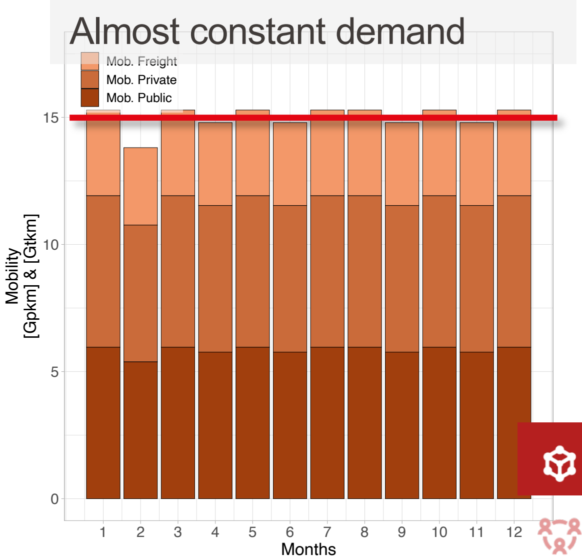


Schnidrig et al. “On the role of energy infrastructure in the energy transition”, Frontiers in Energy 2023

The Systemic approach
Intermittency of demands



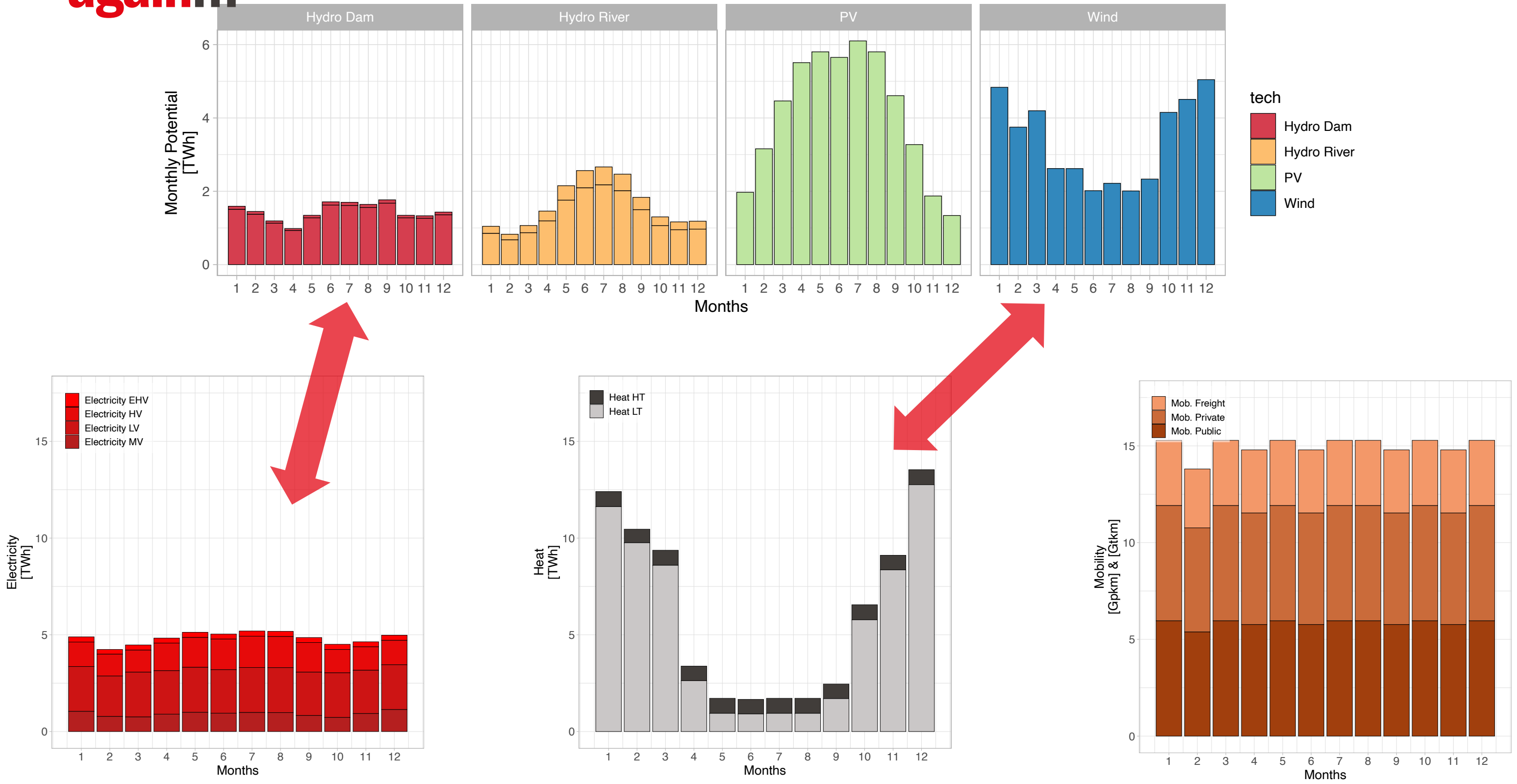




Schnidrig et al. “On the role of energy infrastructure in the energy transition”, Frontiers in Energy 2023

The Systemic approach

A question of equilibrium – again…



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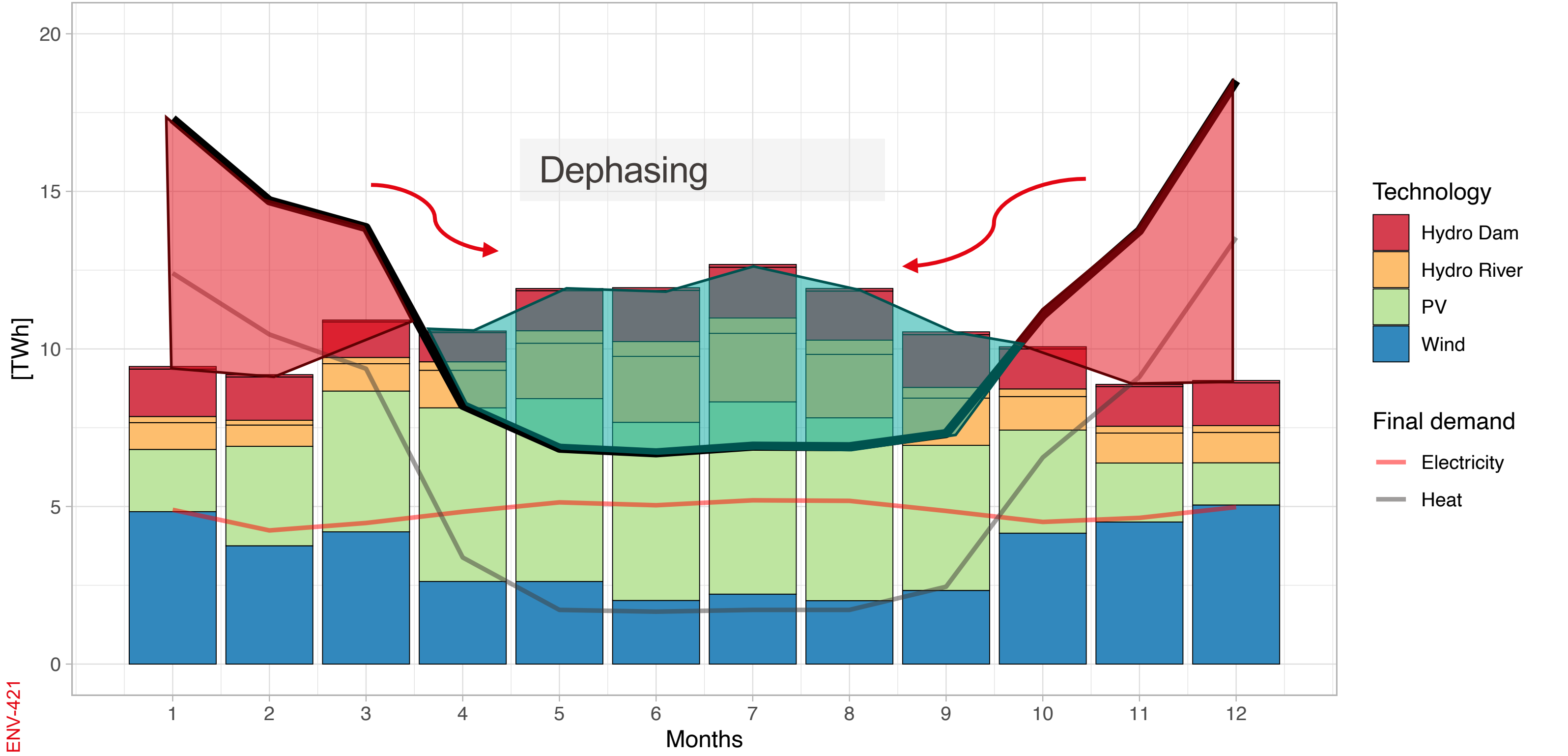
A question of management



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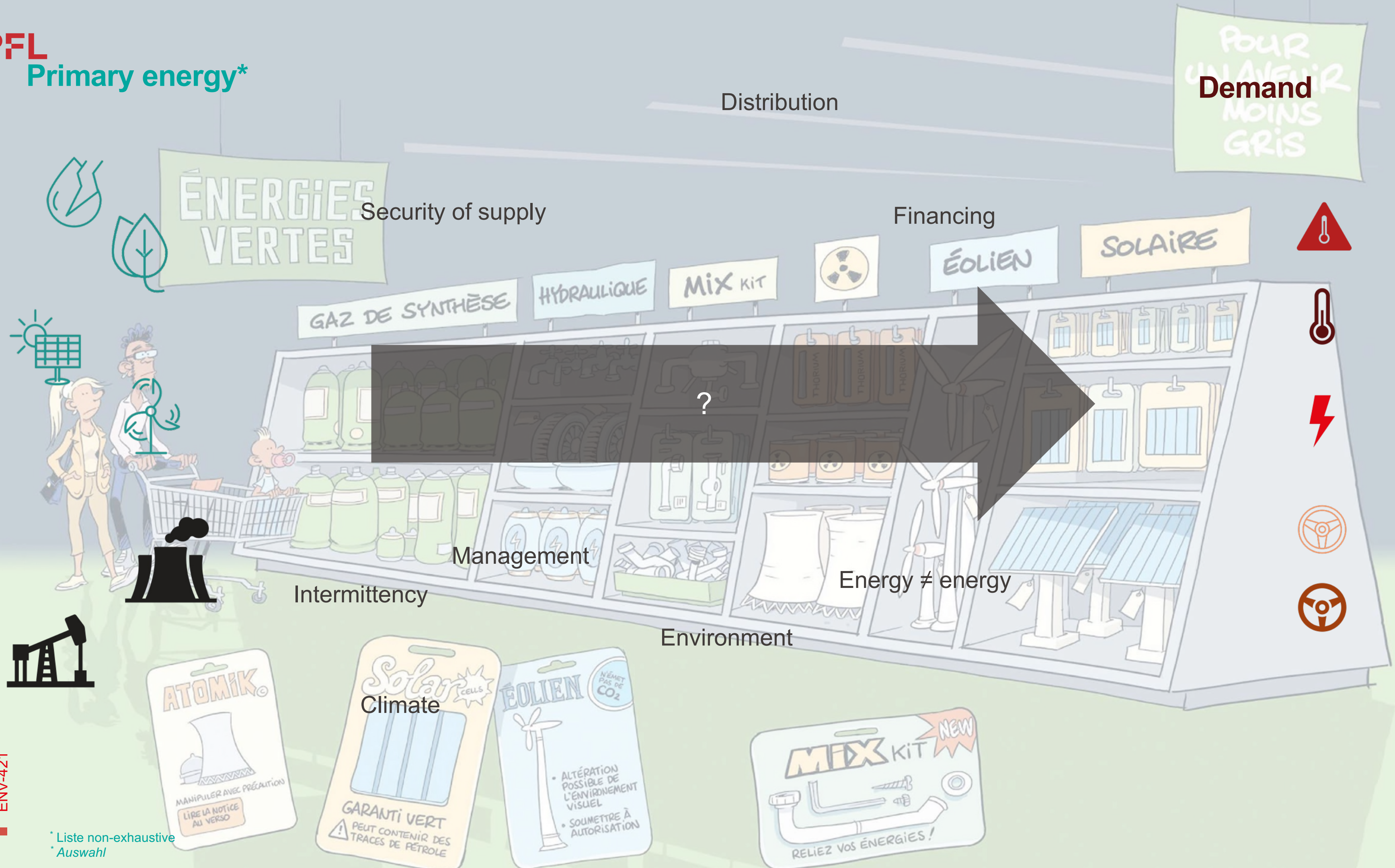
Primary energy*



Demand

Distribution

Security of supply

Financing

?

Management

Intermittency

Energy ≠ energy

Environment

Climate

* Liste non-exhaustive
* *Auswahl*

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Energy system modeling - EnergyScope

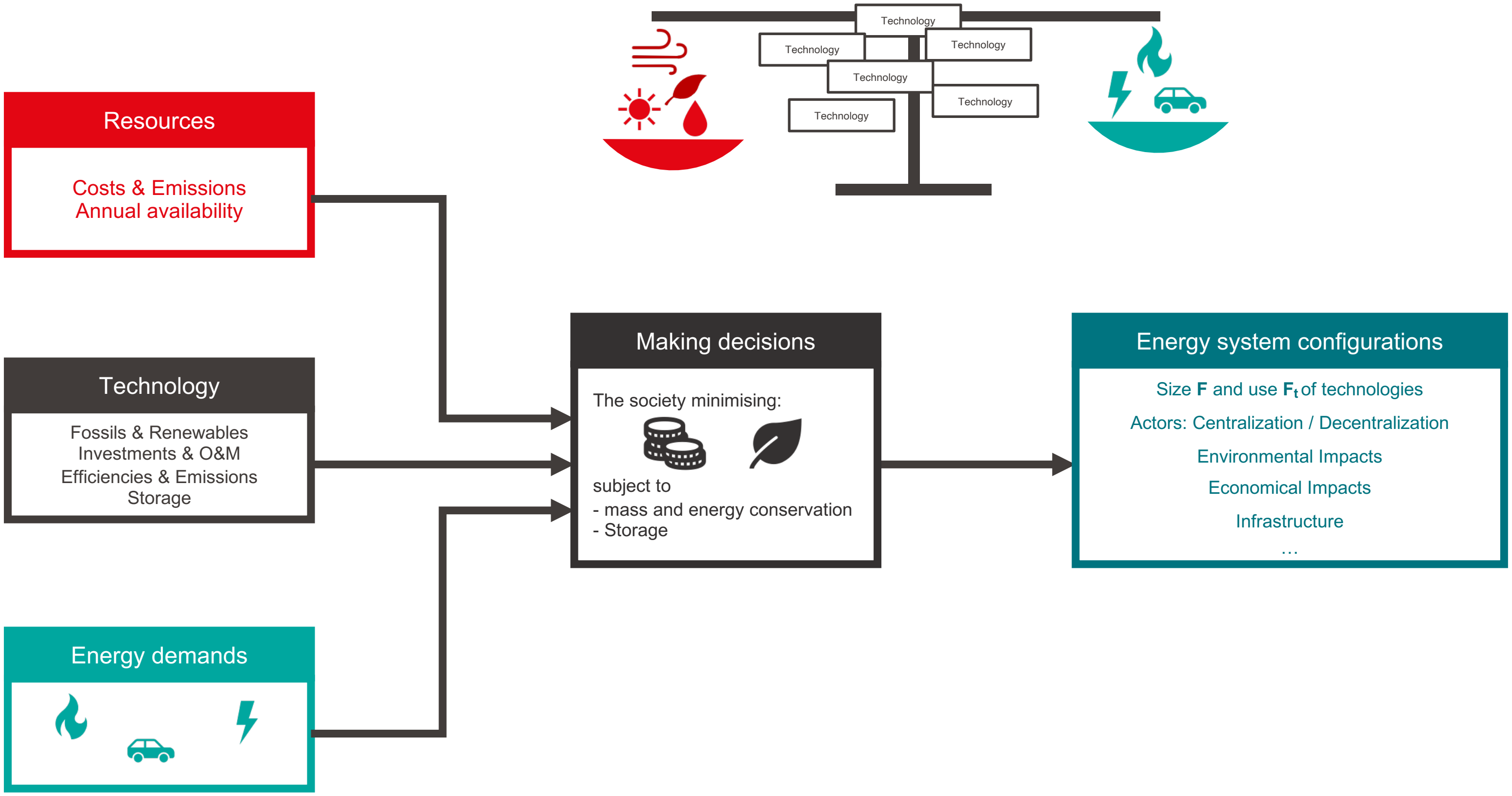

Illustration of the energy system modeling principle

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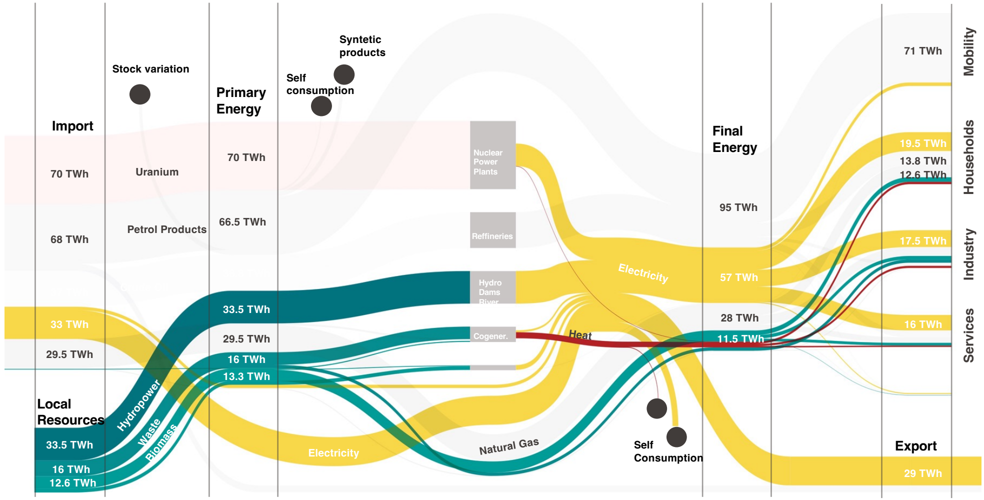
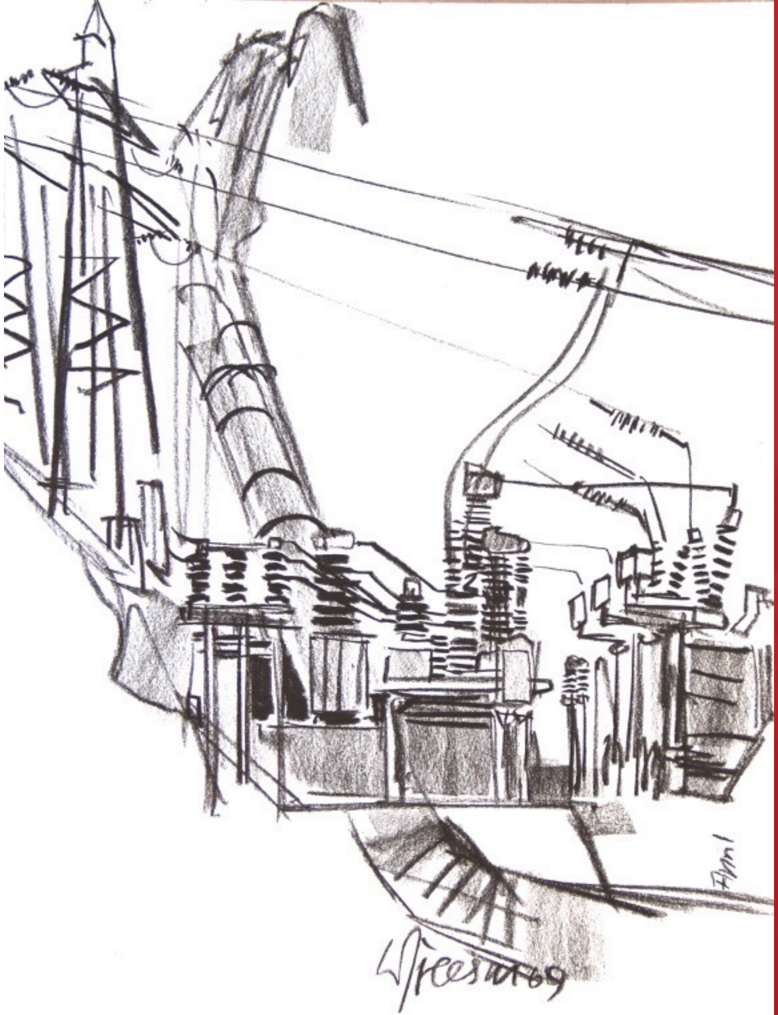
The Swiss Challenge
In the Heart of Europe



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) [79]

- Strategic Geographic Position
  - Bridge of European energy network[57].
  - 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[58-60].
- Pioneering Renewable Energy Integration
  - Historical reliance on hydroelectric power[63-65]
  - play with market fluctuations foundation for expanding renewable energy capacity[63,66,87].
- Decentralized Energy Potential
  - Potential for decentralized renewable energy sources, such as photovoltaics, small hydropower, and wind[64,66,67].
  - Existing centralized renewable energy as opportunity for energy management and distribution [69,70-73].
- Economic and Environmental Synergy
  - Environmental imperatives and economic goals, aiming for sustainability, efficiency, and reliability[61,78].
  - Imperatives on sustainability for unique landscape and tourism reasons.[68,70-73, 84-86]



AGENDA

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 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

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

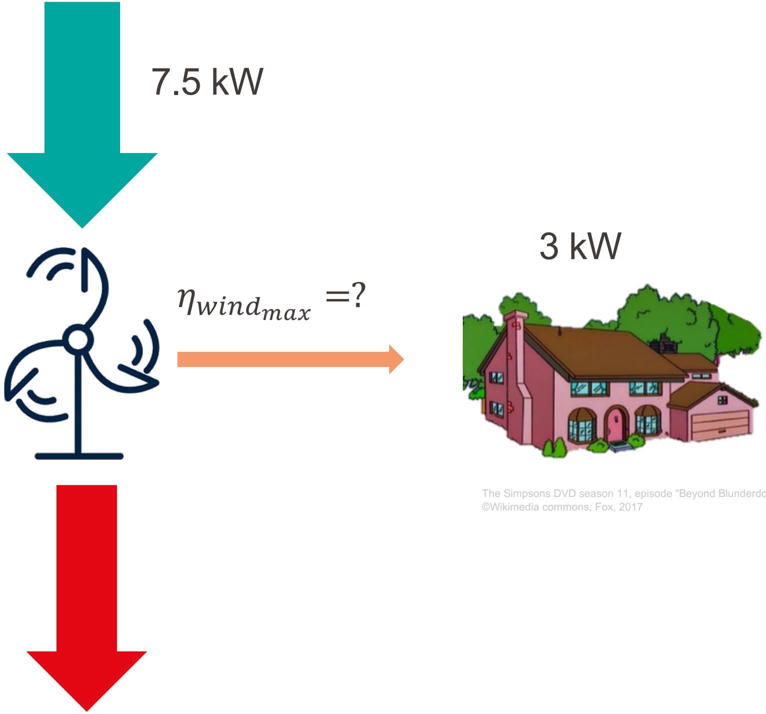
- Combination of efficiencies

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

The systemic perspective
Conversion – the Simpsons live intermittently

Case 1: Full Wind

$\eta_{full-wind} = ?$



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The systemic perspective

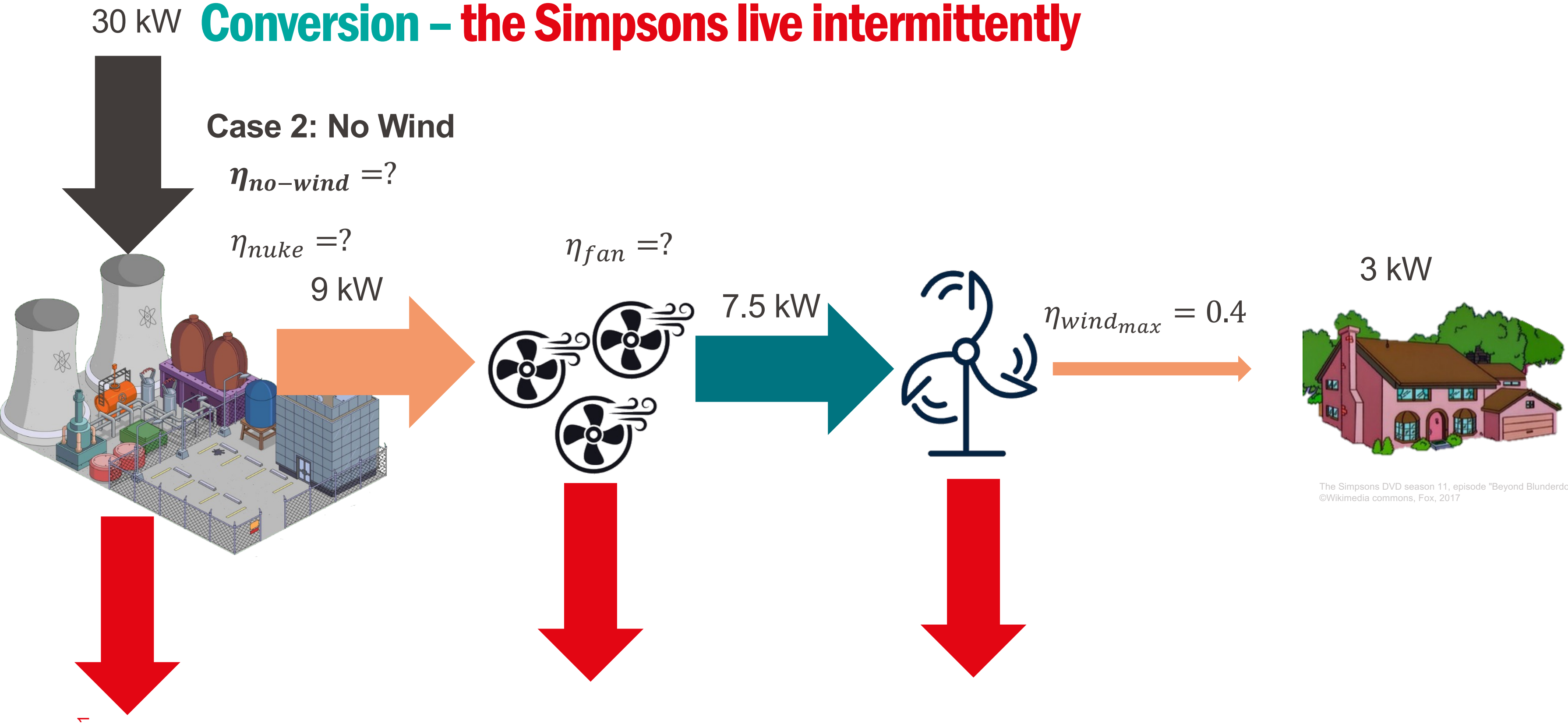
Conversion – the Simpsons live intermittently

Case 2: No Wind

$\eta_{no-wind} = ?$

$\eta_{nuke} = ?$

$\eta_{fan} = ?$



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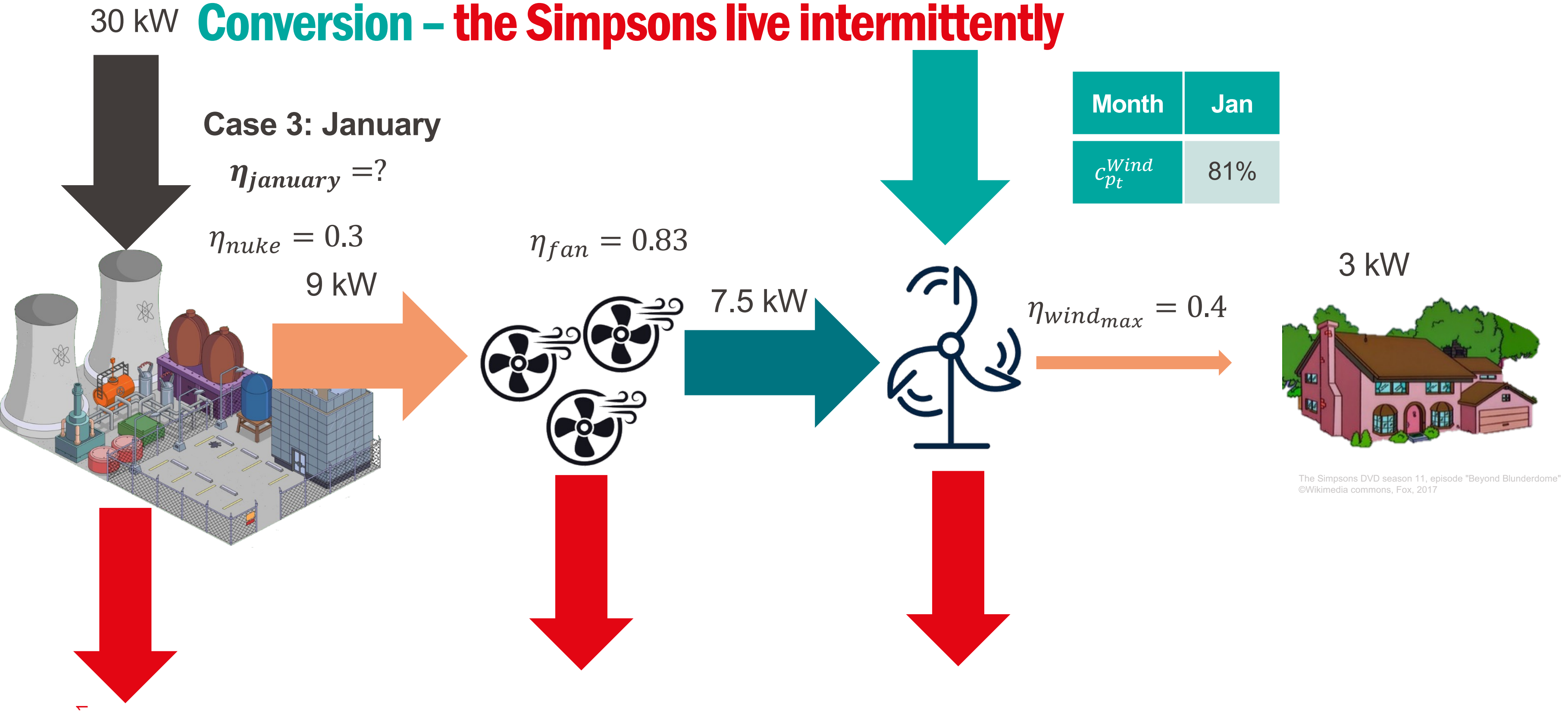
The systemic perspective

Conversion – the Simpsons live intermittently

Case 3: January

$\eta_{january} = ?$

Month	Jan
c_{pt}^{Wind}	81%



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Jonas Schnidrig

The systemic perspective

Conversion – the Simpsons live intermittently

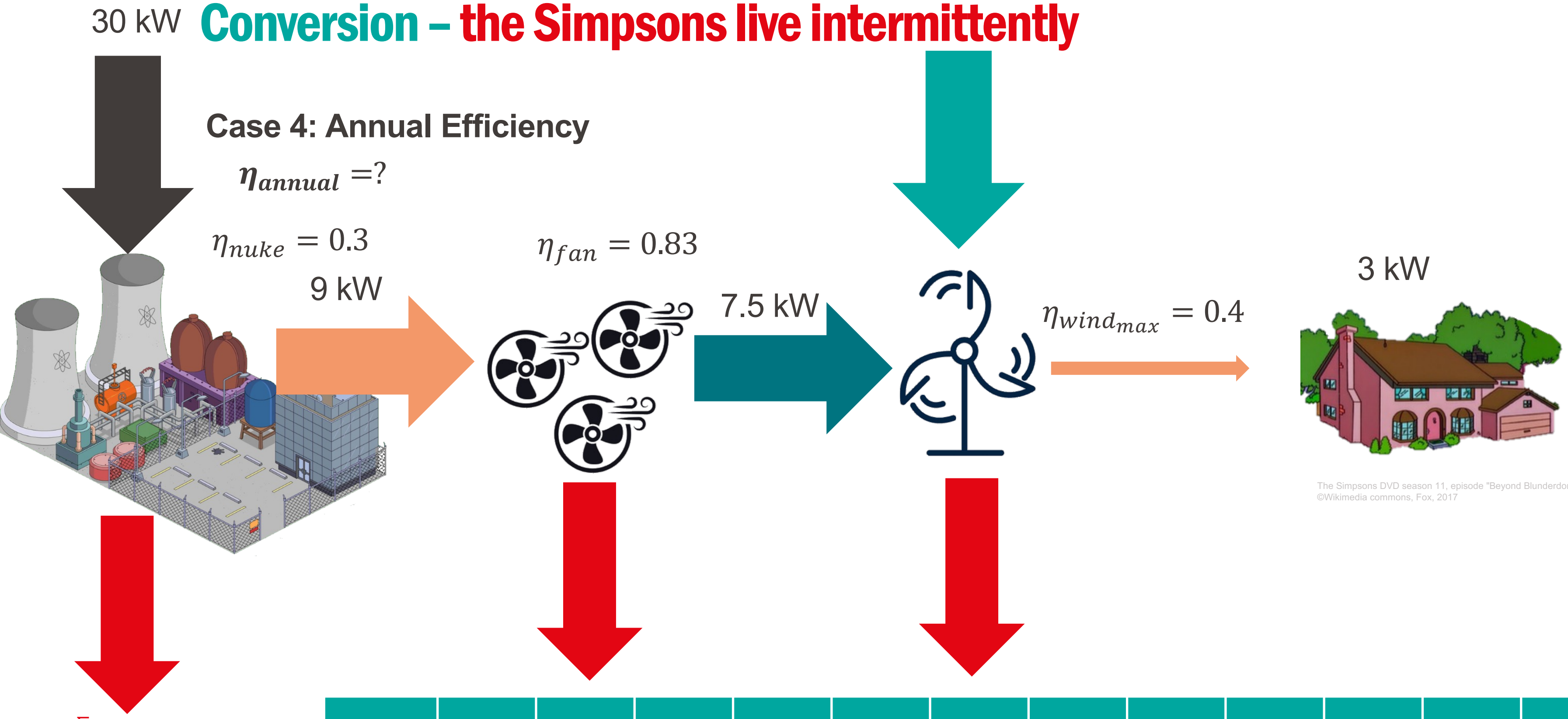
Case 4: Annual Efficiency

$\eta_{annual} = ?$

$\eta_{nuke} = 0.3$

$\eta_{fan} = 0.83$

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



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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%