



MASTER IN ENTREPRENEURSHIP  
INNOVATION MANAGEMENT  
IN COLLABORATION WITH **MIT SLOAN**

IN COLLABORATION WITH

**MIT** MANAGEMENT  
SLOAN SCHOOL



UNIVERSITÀ DEGLI STUDI DI NAPOLI  
**PARTHENOPE**

MASTER MEIM 2021-2022

# Energy planning

Prof. Laura Vanoli

Prof. of Energy Management, University of Naples Parthenope

# Outline of the course

## I. Energy overview

- Energy conversion
- Energy overview
- a) Primary energy sources
- b) Total final consumption
- c) Energy intensity
- Energy problem
- a) Consumption disparity
- b) Energy poverty
- c) Fossil fuels and GHG emissions

## II. Renewable Energy Sources as a mitigation action to climate change

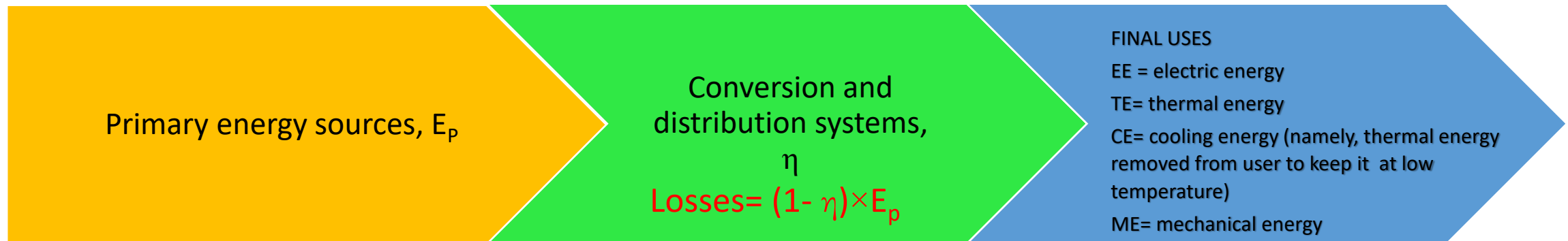
- Classification of the energy sources
- Technologies, efficiency and impacts
- Global efforts
- How to integrate RES in energy systems???

## III. Energy planning

- Introduction
- Smart city and smart community
- Smart Energy Systems
- Electric surplus
- EnergyPLAN software

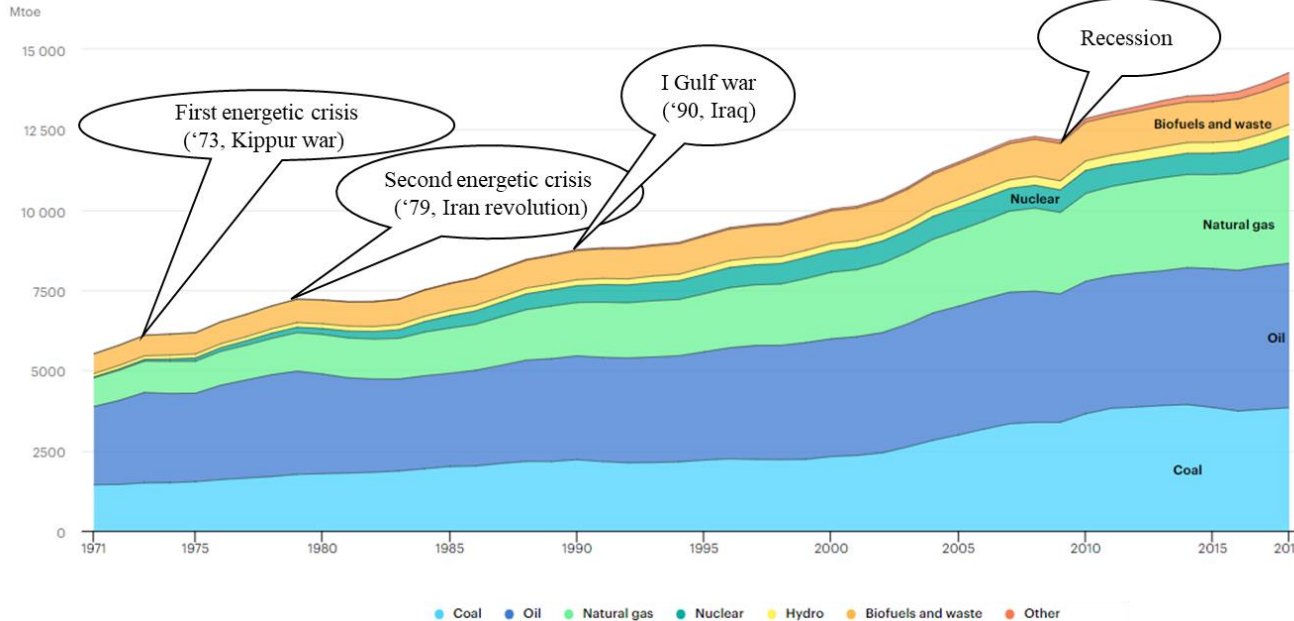
## IV. EnergyPLAN software training

# Energy conversion chain



# Energy overview: Primary energy world consumption

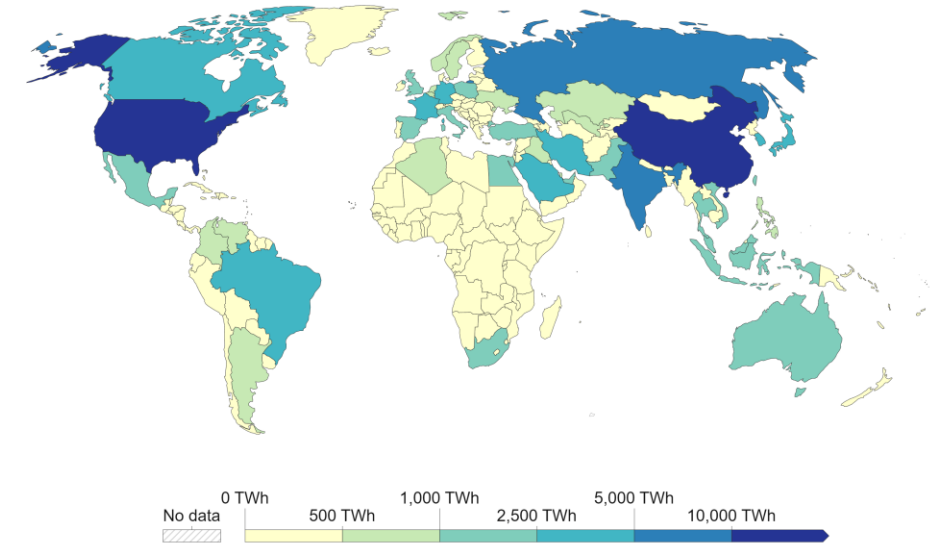
World total energy supply by source, 1971-2018



Primary energy consumption, 2021

Primary energy<sup>1</sup> consumption is measured in terawatt-hours (TWh).

Our World in Data



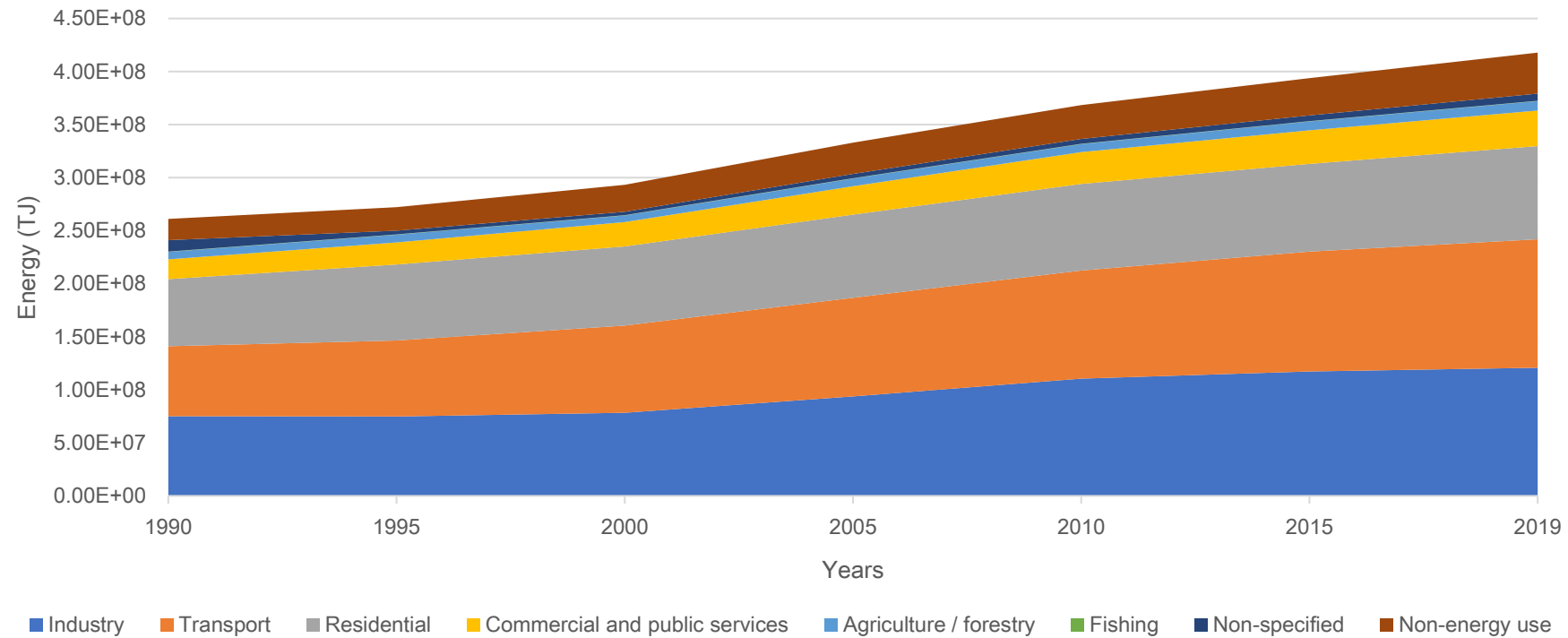
Source: BP Statistical Review of World Energy; and EIA  
OurWorldInData.org/energy • CC BY  
Note: Data includes only commercially-traded fuels (coal, oil, gas), nuclear and modern renewables. It does not include traditional biomass.

1. **Primary energy:** Primary energy is the energy as it is available as resources – such as the fuels that are burnt in power plants – before it has been transformed. This relates to the coal before it has been burned, the uranium, or the barrels of oil. Primary energy includes energy that is needed by the end user, plus inefficiencies and energy that is lost when raw resources are transformed into a useable form. You can read more on the different ways of measuring energy [in our article](#).

Average per capita consumption  $\approx$  1,8 tep

# Energy overview: Total final world consumption

Total final consumption (TFC) by sector, World 1990-2019



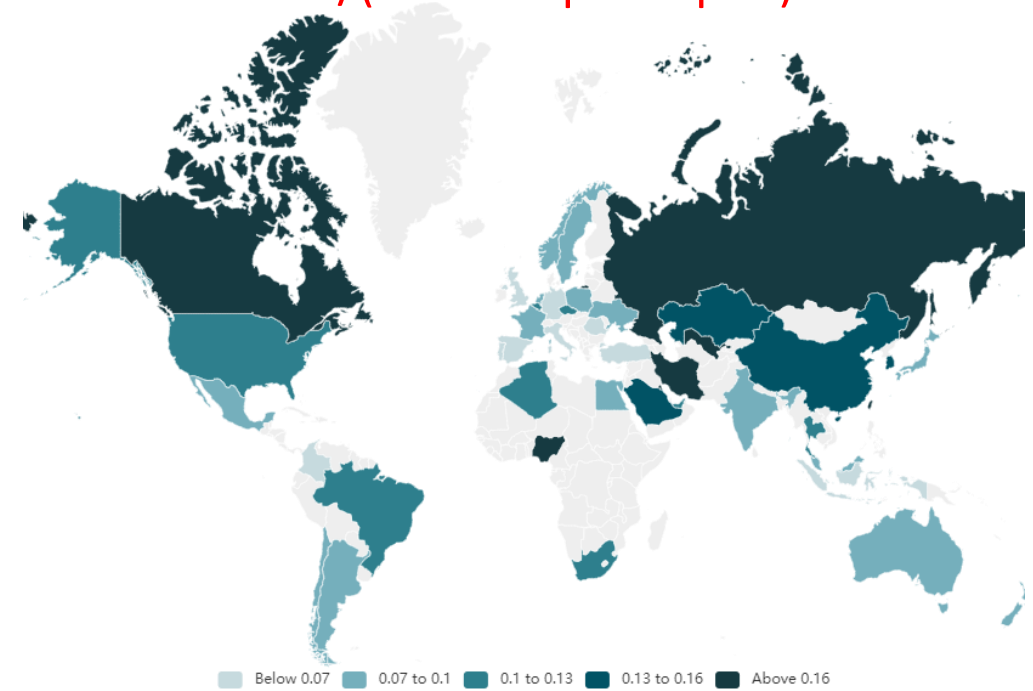
# Energy intensity: world situation

## What is the outlook for the future?

- ✓ The energy needs of a country are linked to several factors:
  - demographic consistency → **inhabitants number, N**
  - level of socio-economic development → **GDP per capita**
  - prevalent economic and productive activities
  - level of technological development and socio-economic progress → **ability of a rational and efficient use of resources**
  - climatic factors

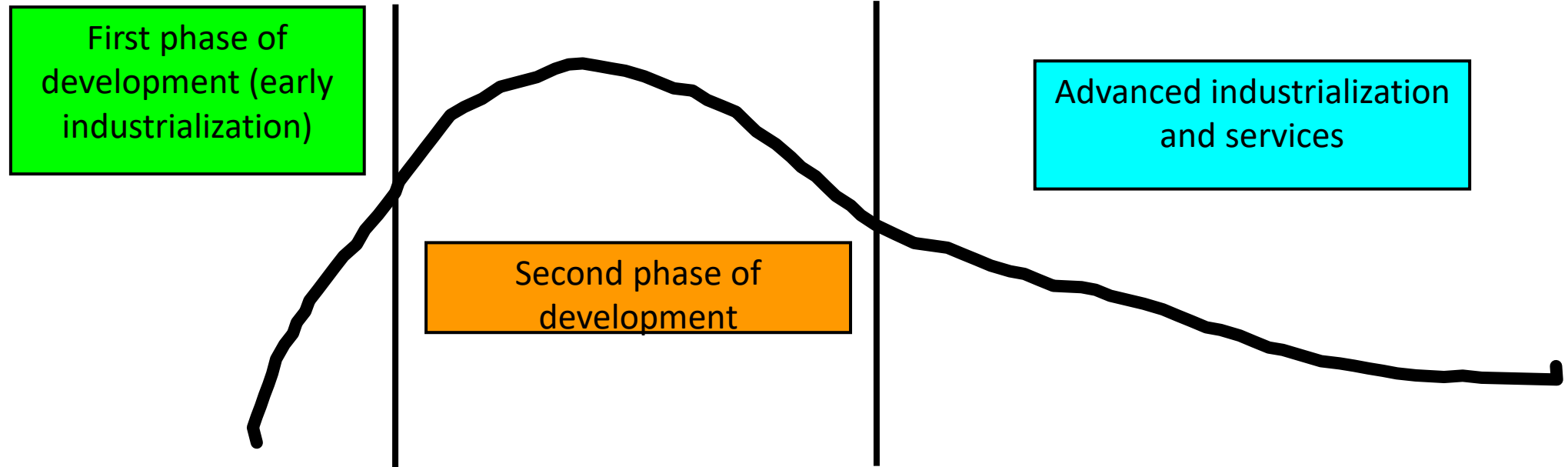
## Energy intensity

$$I = E / (N \times \text{GDP per capita})$$



# Energy intensity: evaluation

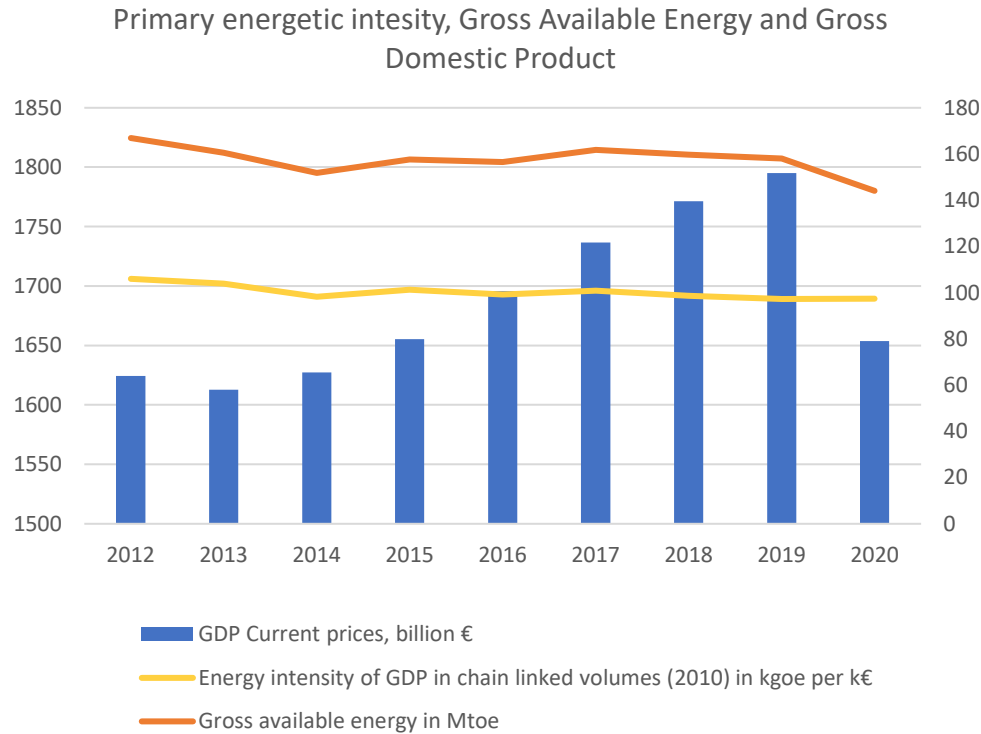
## Temporal evolution of energetic intensity



- ✓ Causes of reduction of energetic intensity:
  - *improved techniques for conversion (ex .: Italy);*
  - *transition from industrial to the service sector with higher added value (ex .: Switzerland);*
  - *both cases (ex .: Japan).*

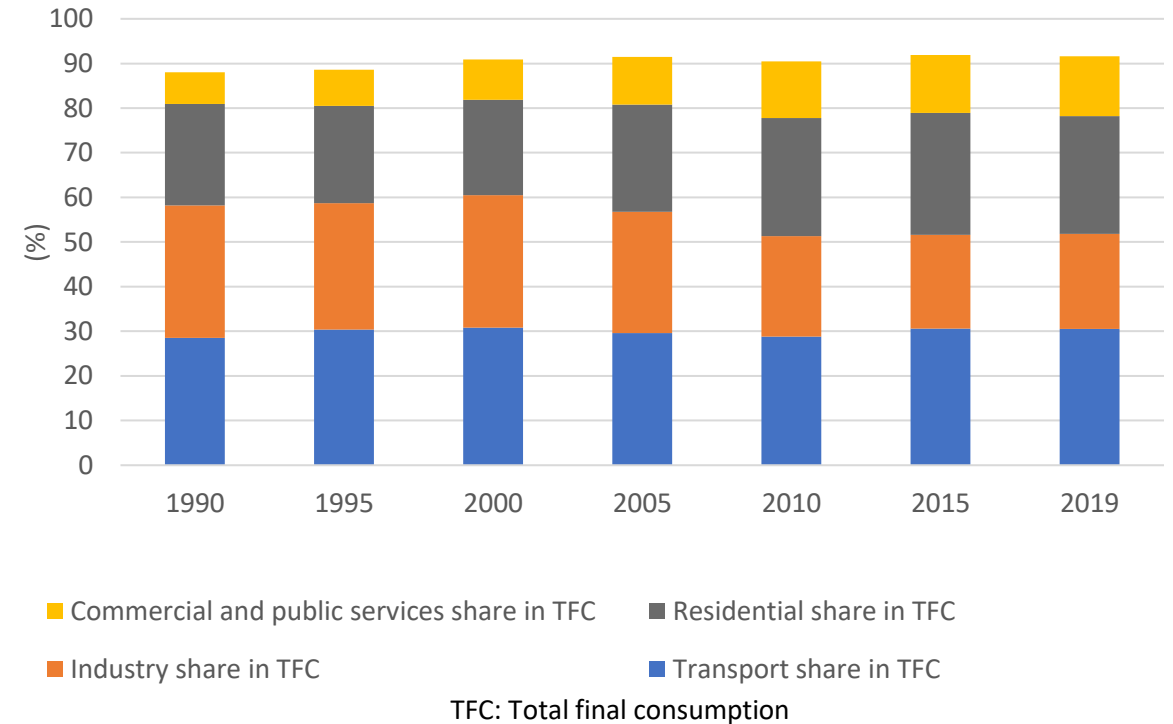
# Environmental-energetic framework: national situation

**Gross consumption of primary energy in Italy  
(in Mtoe, source: Eurostat elaboration on the basis of MSE data)**



Gross Available Energy: total energy delivered/consumed in a Country

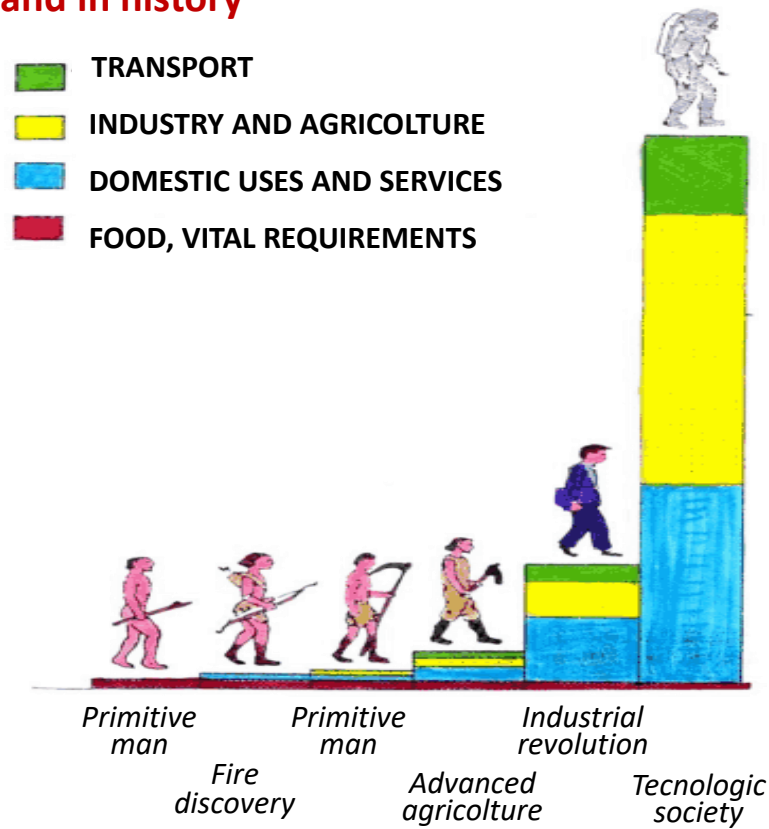
**Final energy consumption in Italy in the three main sectors  
(source: ISPRA elaboration on the basis of MSE, ENEA data)**





# Environmental-energetic framework: world situation

## Primary energy demand in history



Average per capita  
consumption  $\approx$  50.000 kcal/day  
(20 times higher than  
food requirements)

In USA the consumption  
is 4 times higher than  
the mean value,  
in EU 2 times

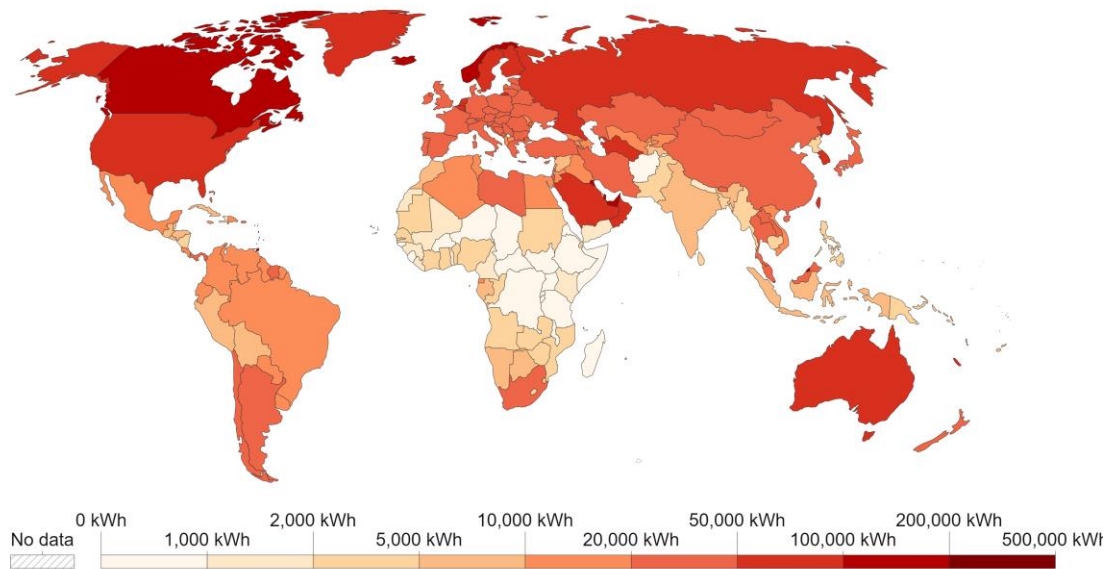
# Environmental-energetic framework: world situation

## Lack of access to energy

### Energy use per person, 2021

Energy use not only includes electricity, but also other areas of consumption including transport, heating and cooking.

Our World  
in Data



Source: Our World in Data based on BP & Shift Data Portal

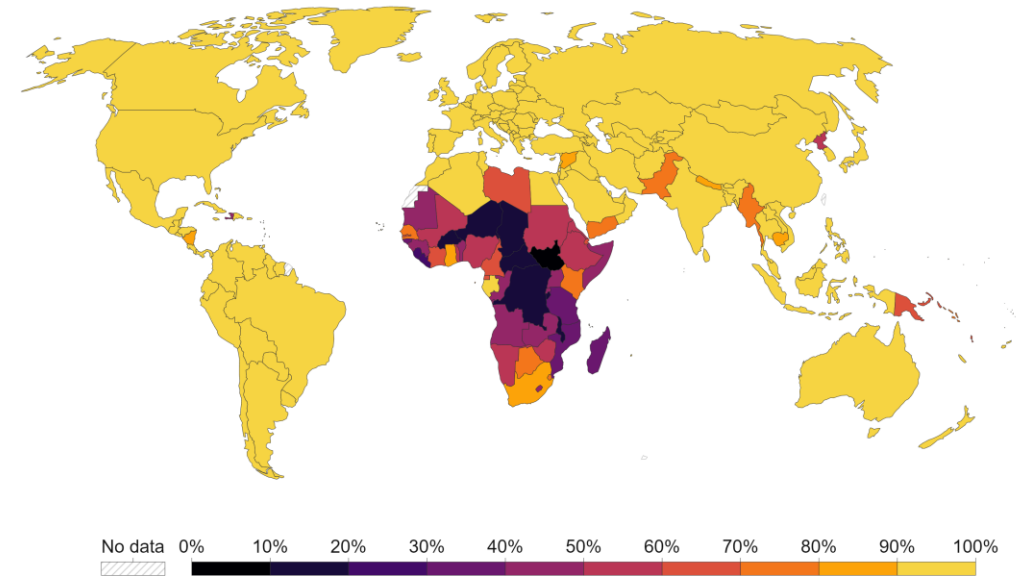
OurWorldInData.org/energy • CC BY

Note: Energy refers to primary energy – the energy input before the transformation to forms of energy for end-use (such as electricity or petrol for transport).

### Electricity access, 2020

Share of the population with access to electricity. The definition used in international statistics adopts a very low cutoff for what it means to 'have access to electricity'. It is defined as having an electricity source that can provide very basic lighting, and charge a phone or power a radio for 4 hours per day.

Our World  
in Data



Source: World Bank

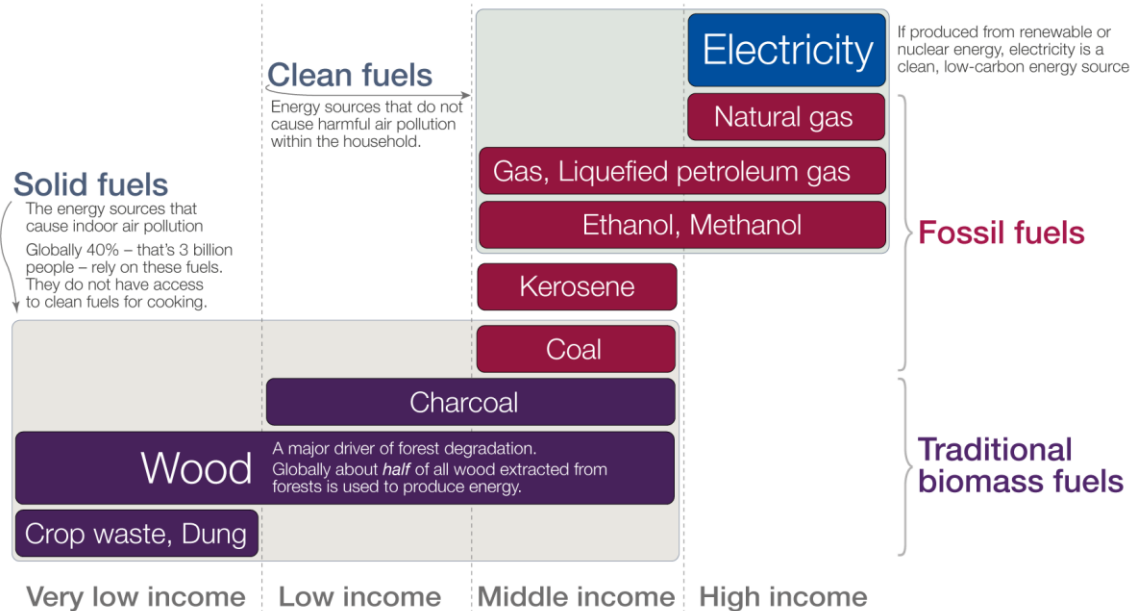
OurWorldInData.org/energy • CC BY

# Environmental-energetic framework: world situation

## The 'Energy Ladder'

The dominant energy source for cooking and heating, by level of income

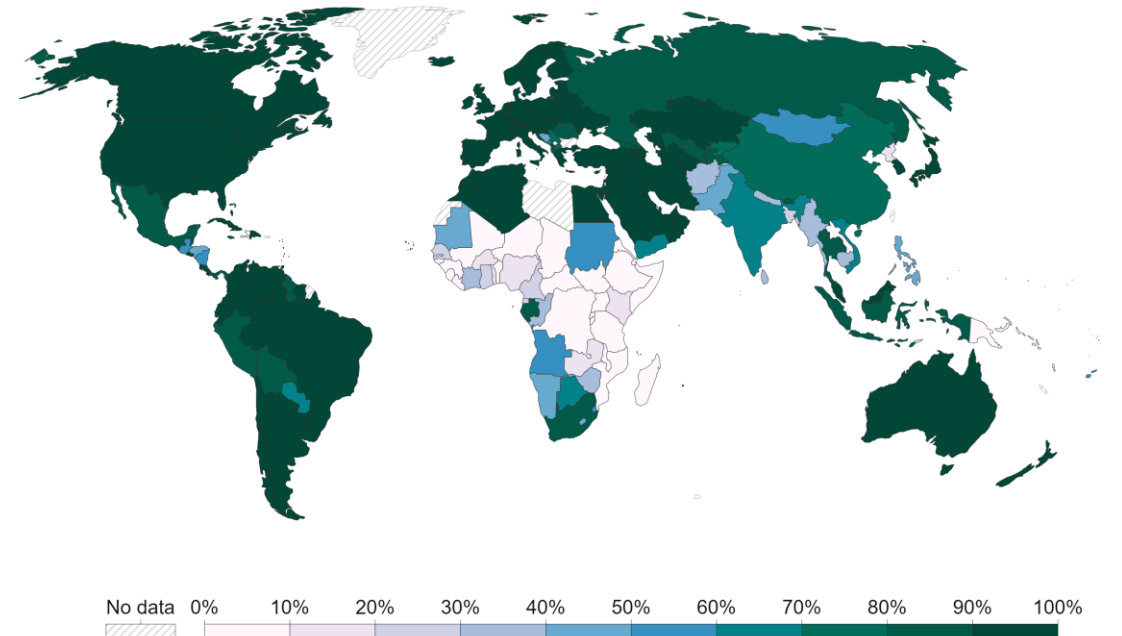
Our World  
in Data



## Share of the population with access to clean fuels for cooking, 2020

Our World  
in Data

Access to clean fuels or technologies such as clean cookstoves reduce exposure to indoor air pollutants, a leading cause of death in low-income households.



Based on: WHO – Fuel for life: household energy and health.  
OurWorldinData.org – Research and data to make progress against the world's largest problems.

Licensed under CC-BY by the author Max Roser  
Version from 2022

Source: WHO, Global Health Observatory (2022)

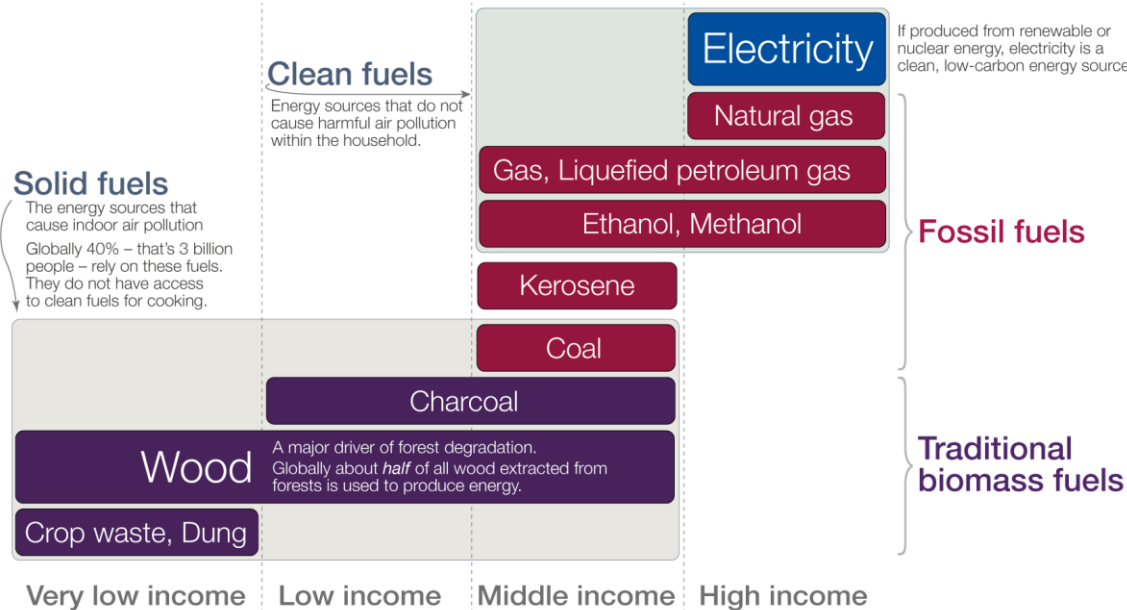
OurWorldInData.org/energy • CC BY

# Environmental-energetic framework: world situation

## The 'Energy Ladder'

The dominant energy source for cooking and heating, by level of income

Our World in Data



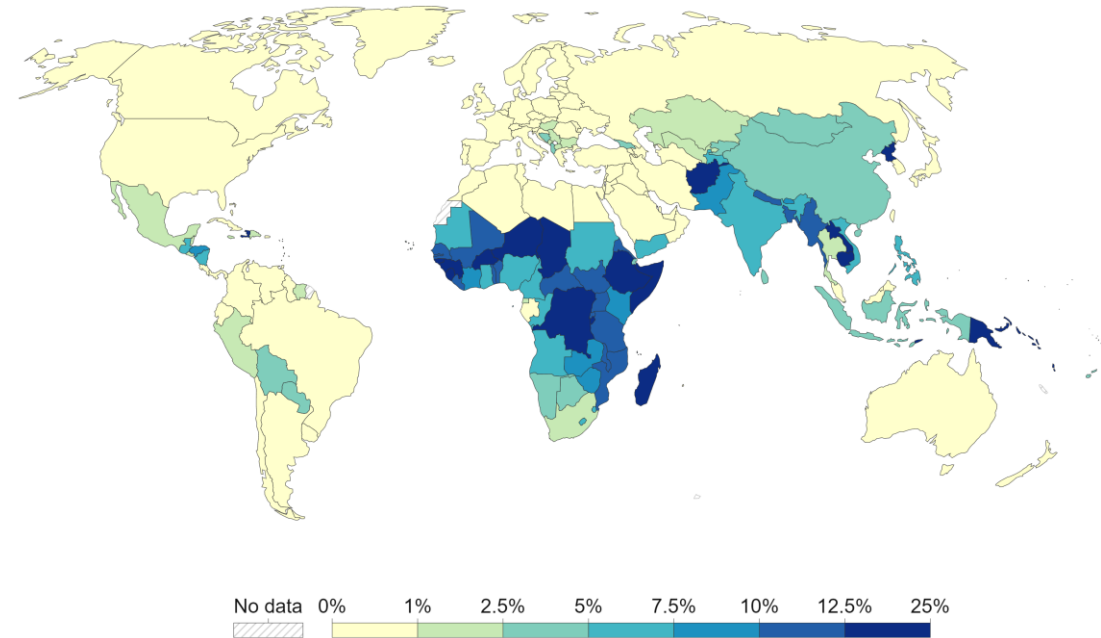
Based on: WHO – Fuel for life: household energy and health.  
OurWorldInData.org – Research and data to make progress against the world's largest problems.

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Version from 2022

## Share of deaths from indoor air pollution, 2019

Share of deaths, from any cause, which are attributed to indoor air pollution – from burning solid fuels – as a risk factor.

Our World in Data



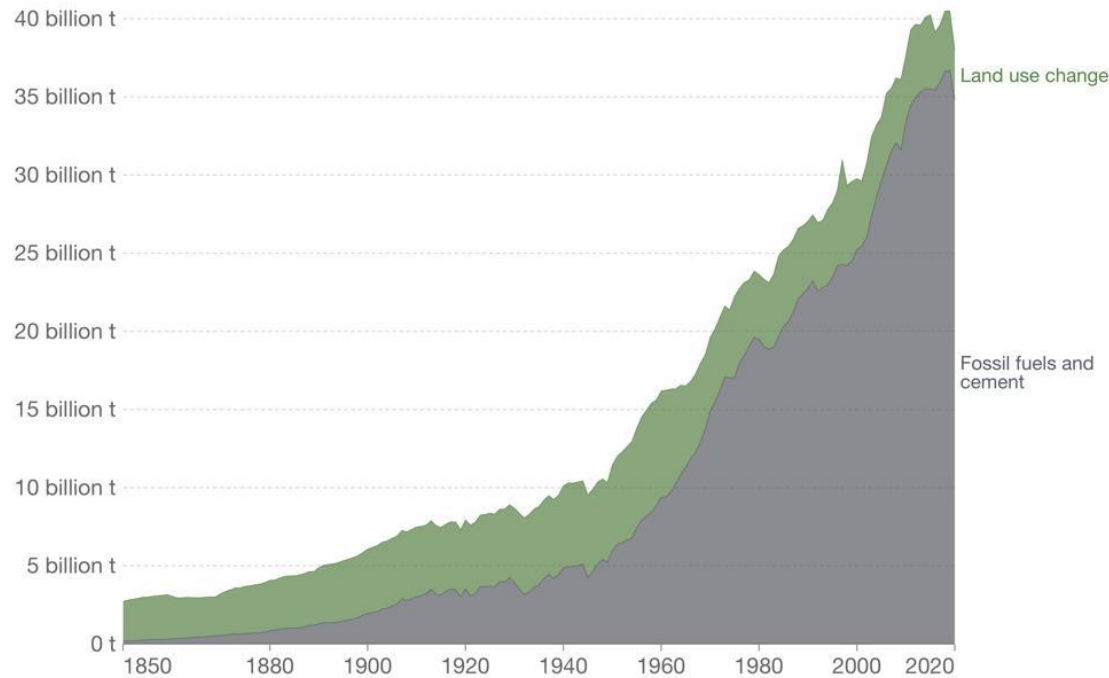
Source: IHME, Global Burden of Disease (2019)

OurWorldInData.org/indoor-air-pollution • CC BY

# Environmental-energetic framework: world situation

## Greenhouse gas emissions by sector (Source: ourworldindata)

Global CO<sub>2</sub> emissions from fossil fuels and land use change

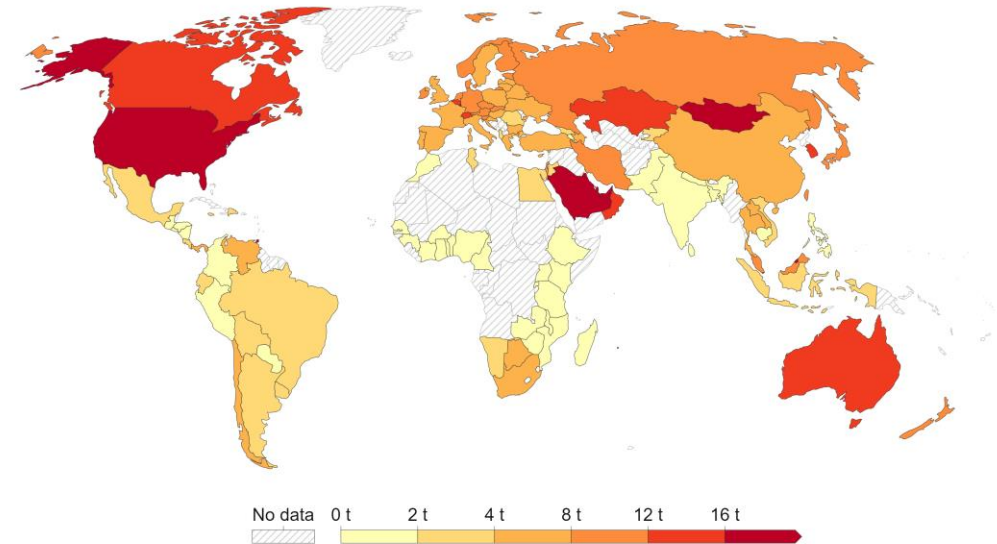


Source: Global Carbon Project (2021)

OurWorldInData.org/co2-and-other-greenhouse-gas-emissions • CC BY

Consumption-based CO<sub>2</sub> emissions per capita vs GDP per capita, 2019

– Consumption-based emissions are domestic emissions adjusted for trade. If a country imports goods the CO<sub>2</sub> emissions needed to produce such goods are added to its domestic emissions; if it exports goods then this is subtracted.  
– GDP per capita is adjusted for price differences between countries (PPP) and over time (inflation).



Source: Our World in Data based on the Global Carbon Project, Data compiled from multiple sources by World Bank  
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions • CC BY



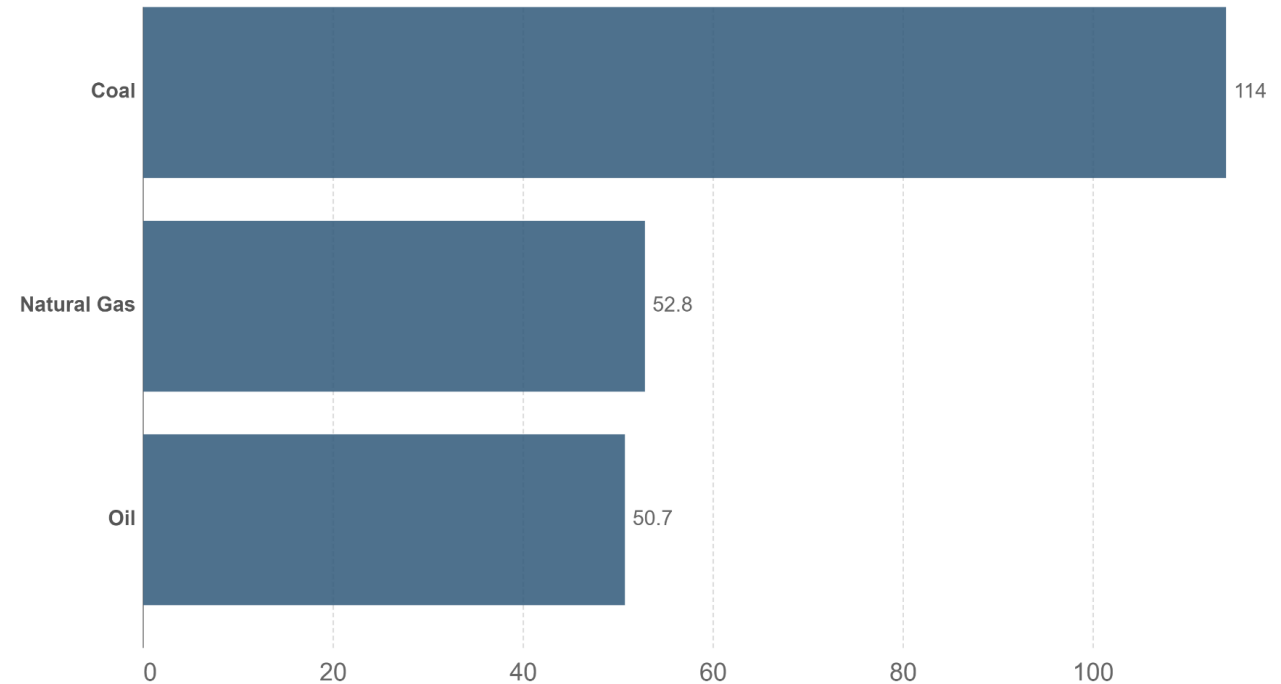
# Environmental-energetic framework: problems and future prespective

## Fossil resources: problems to be faced

- ✓ Current problems:
  - geo-political and economic aspects, related to:
    - non-uniform distribution of resources
    - health impact due to the use of very polluting fuels in cases of lower access to cleaner energy
    - environmental impact (in particular: the greenhouse effect and global warming)
    - financial speculation
- ✓ In the medium and long term:
  - exhaustion of resources

## Years of fossil fuel reserves left

Years of global coal, oil and natural gas left, reported as the reserves-to-product (R/P) ratio which measures the number of years of production left based on known reserves and annual production levels in 2015. Note that these values can change with time based on the discovery of new reserves, and changes in annual production

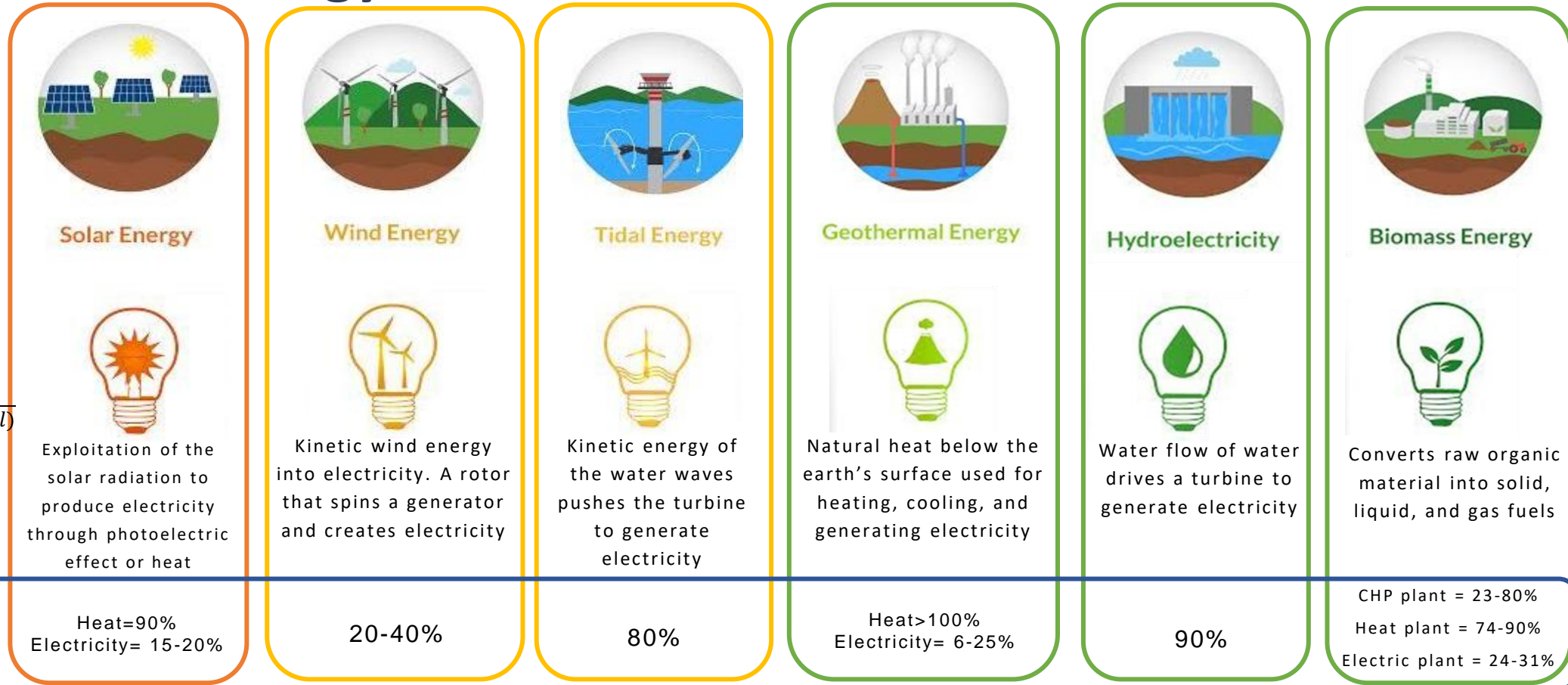


Source: BP Statistical Review of World Energy 2016

OurWorldInData.org/how-long-before-we-run-out-of-fossil-fuels/ • CC BY

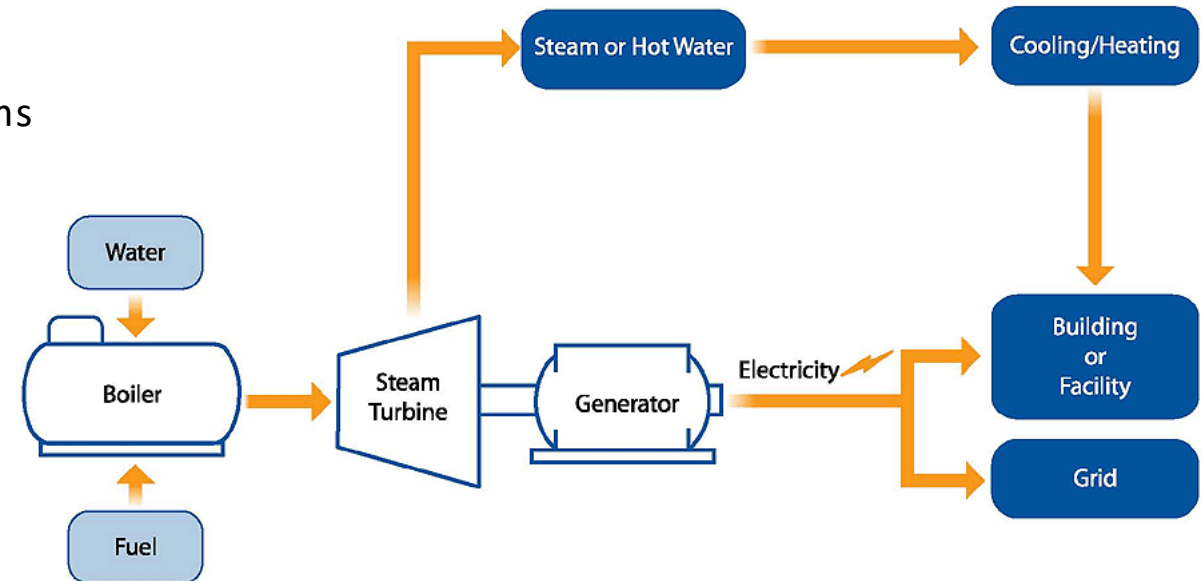
# Classification of energy source: RES

Source: <https://www.energy.gov/fecm/science-innovation/>



# Classification of energy source: non RES

- Fossil fuel-based power plants
- Carbon emissions is the main concern in these systems
- Conversion efficiency
  - Coal based = 33 %
  - Oil based = 28-46 %
  - Natural gas based = 42-60%



Coal



Oil



Natural gas



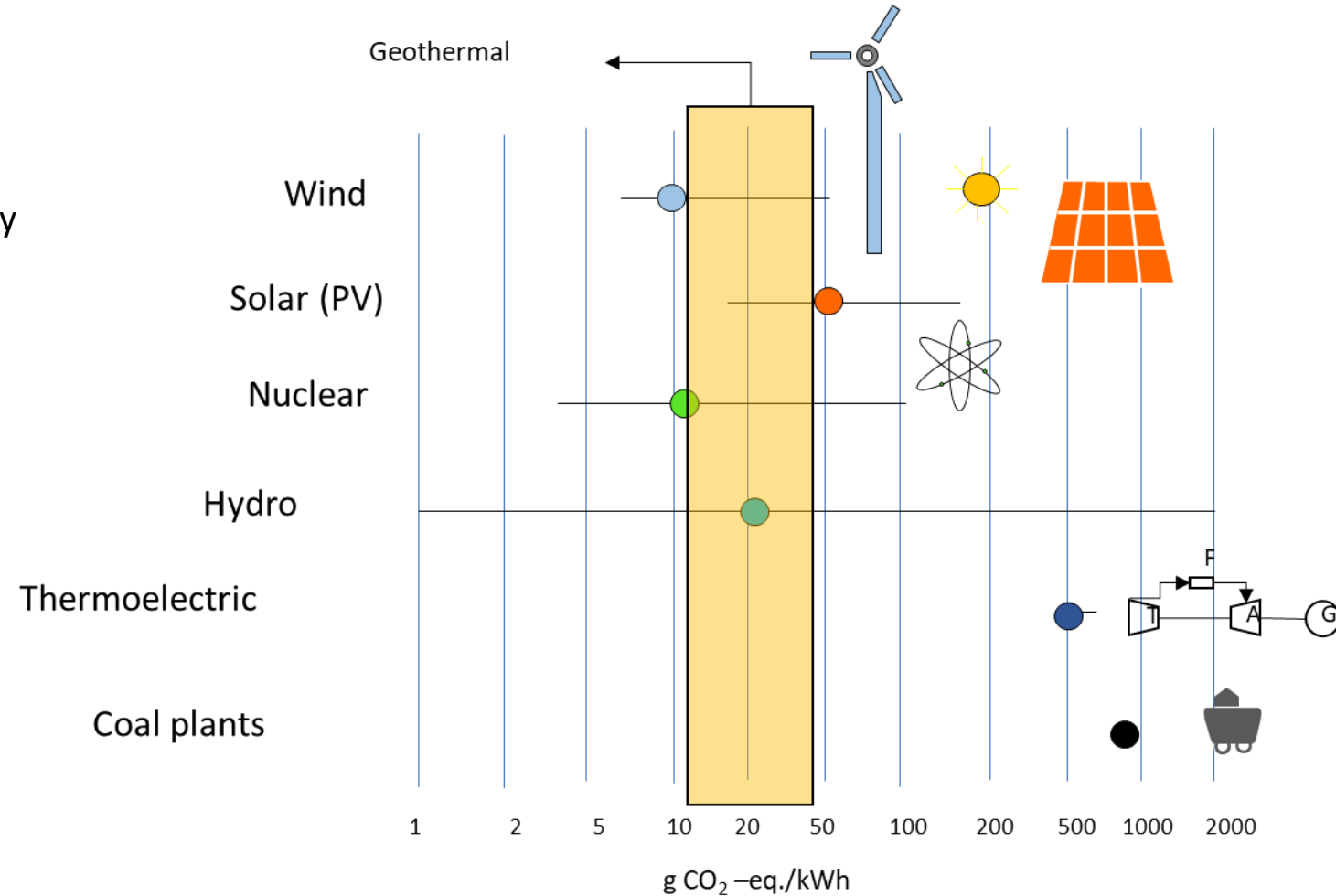
Fuel =

Source: [https://archive.ipcc.ch/publications\\_and\\_data/ar4/wg3/en/ch4s4-4-3-1.html](https://archive.ipcc.ch/publications_and_data/ar4/wg3/en/ch4s4-4-3-1.html)



# GHG from RES

Minimum and maximum carbon intensity  
by technology

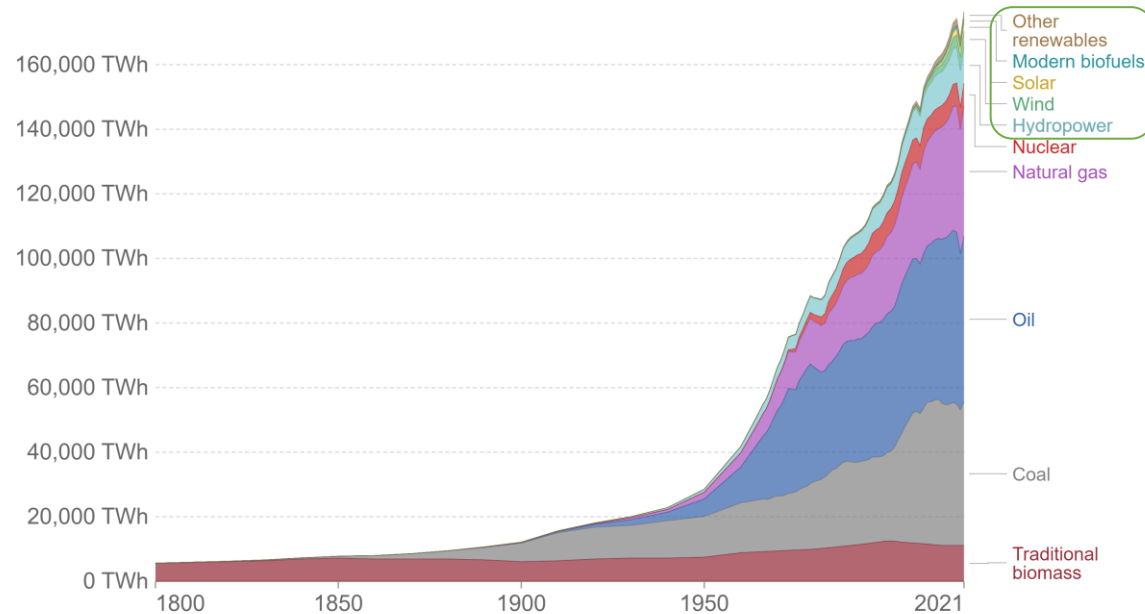


# Renewable energy sources use

## Global primary energy consumption by source

Primary energy is calculated based on the 'substitution method' which takes account of the inefficiencies in fossil fuel production by converting non-fossil energy into the energy inputs required if they had the same conversion losses as fossil fuels.

Our World in Data



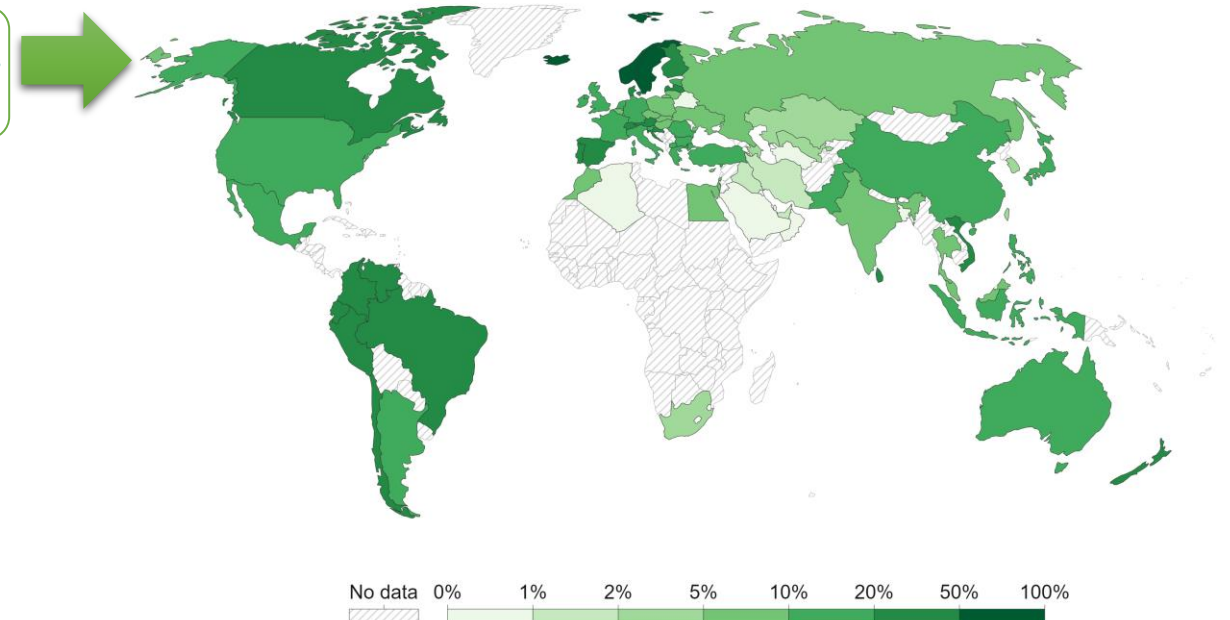
Source: Our World in Data based on Vaclav Smil (2017) and BP Statistical Review of World Energy

OurWorldInData.org/energy • CC BY

## Share of primary energy from renewable sources, 2021

Renewable energy sources include hydropower, solar, wind, geothermal, bioenergy, wave, and tidal. They don't include traditional biofuels, which can be a key energy source, especially in lower-income settings.

Our World in Data



Source: Our World in Data based on BP Statistical Review of World Energy (2022)

OurWorldInData.org/energy • CC BY

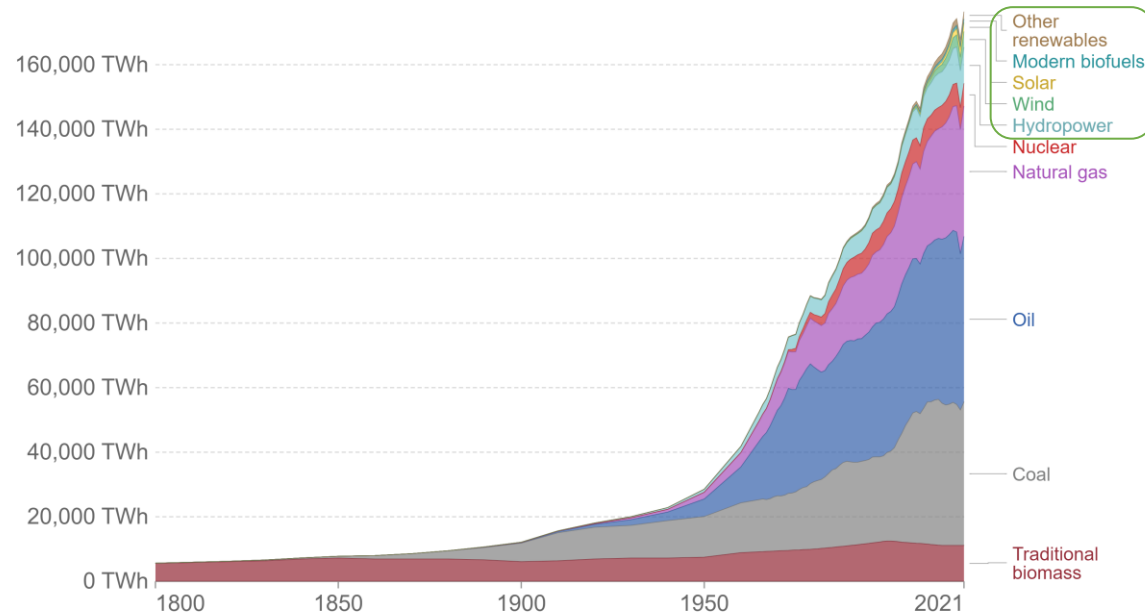
Note: Primary energy is calculated using the 'substitution method' which takes account of the inefficiencies energy production from fossil fuels.

# Renewable energy sources use

## Global primary energy consumption by source

Primary energy is calculated based on the 'substitution method' which takes account of the inefficiencies in fossil fuel production by converting non-fossil energy into the energy inputs required if they had the same conversion losses as fossil fuels.

Our World in Data

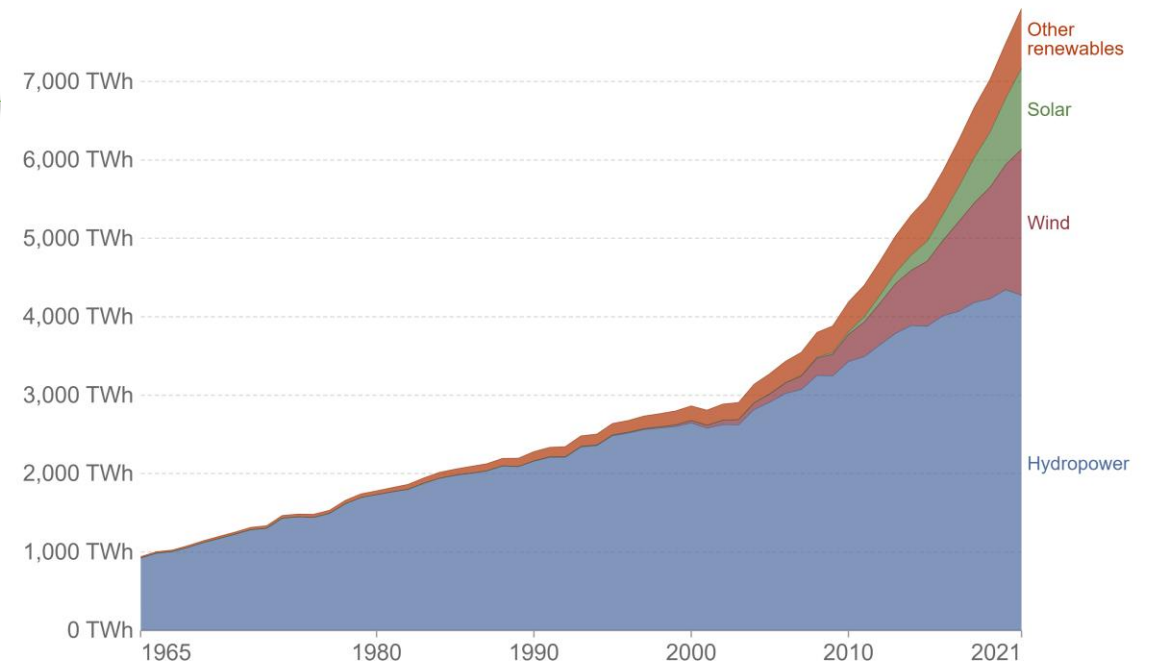


Source: Our World in Data based on Vaclav Smil (2017) and BP Statistical Review of World Energy

OurWorldInData.org/energy • CC BY

## Renewable energy generation, World

Our World in Data



Source: BP Statistical Review of Global Energy

OurWorldInData.org/renewable-energy • CC BY

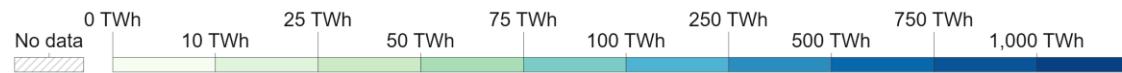
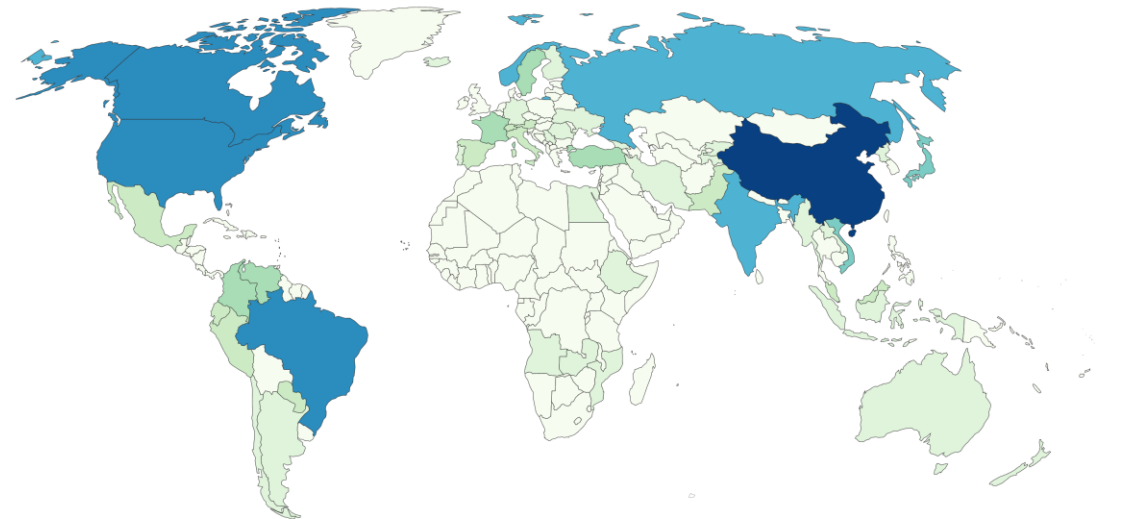
Note: 'Other renewables' refers to renewable sources including geothermal, biomass, waste, wave and tidal. Traditional biomass is not included.

# Renewable energy sources

## Hydropower generation, 2021

Annual hydropower generation is measured in terawatt-hours (TWh).

Our World  
in Data



Source: Our World in Data based on BP Statistical Review of World Energy & Ember

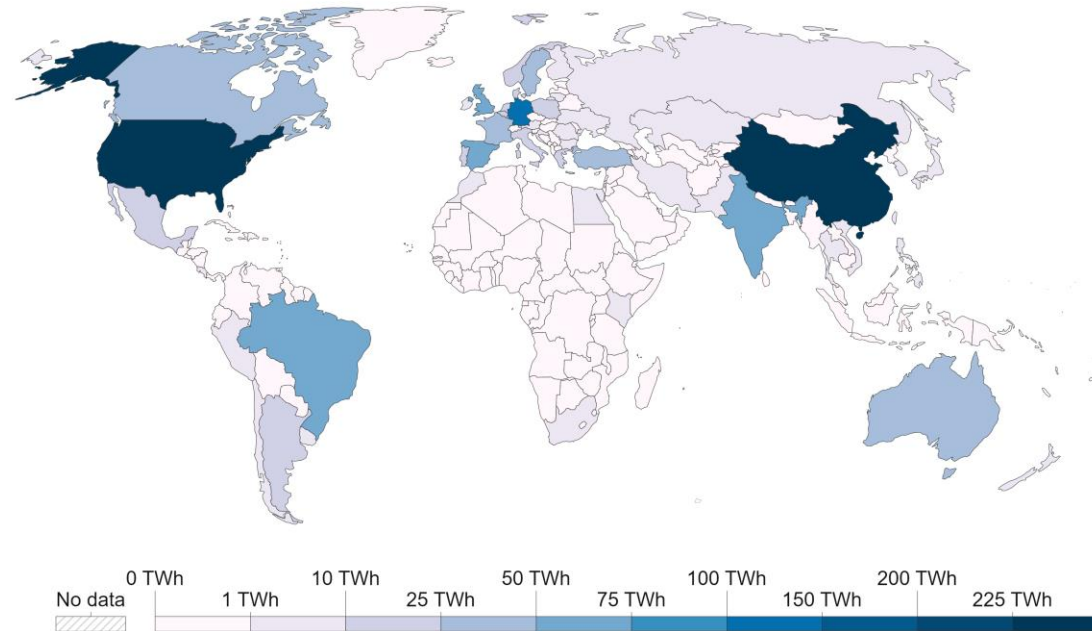
OurWorldInData.org/renewable-energy • CC BY

# Renewable energy sources

## Wind power generation, 2021

Annual electricity generation from wind is measured in terawatt-hours (TWh) per year. This includes both onshore and offshore wind sources.

Our World  
in Data



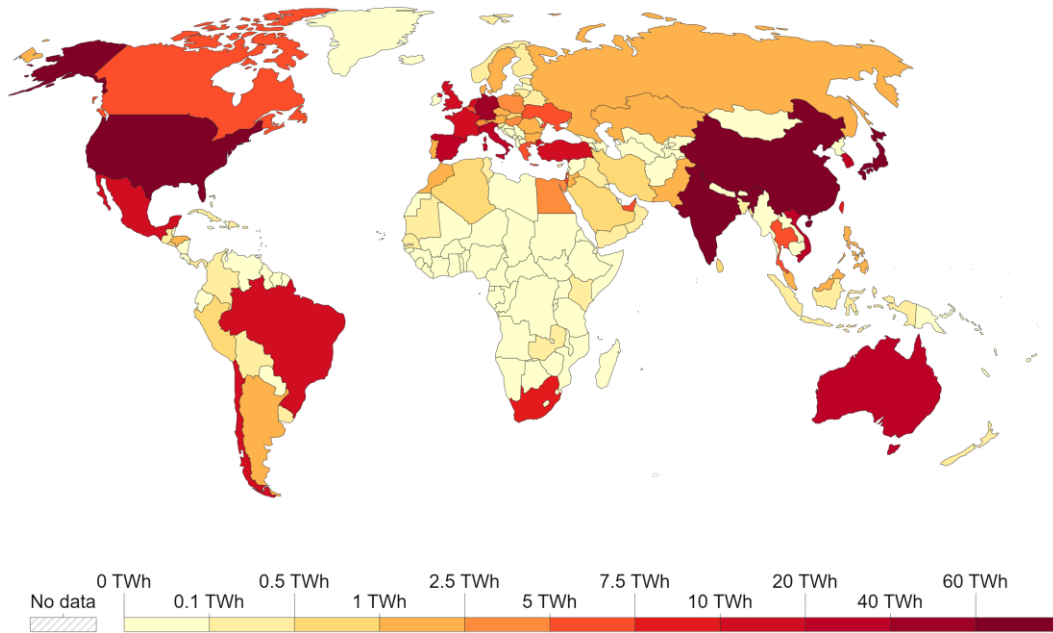
Source: Our World in Data based on BP Statistical Review of World Energy (2022); Our World in Data based on Ember's Global Electricity Review (2022); Our World in Data based on Ember's European Electricity Review (2022)  
OurWorldInData.org/renewable-energy • CC BY

# Renewable energy sources

## Solar power generation, 2021

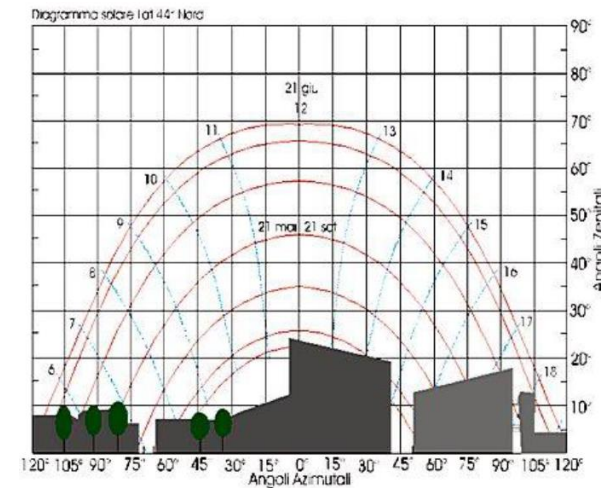
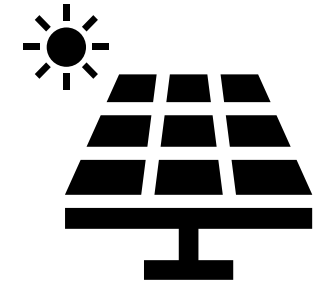
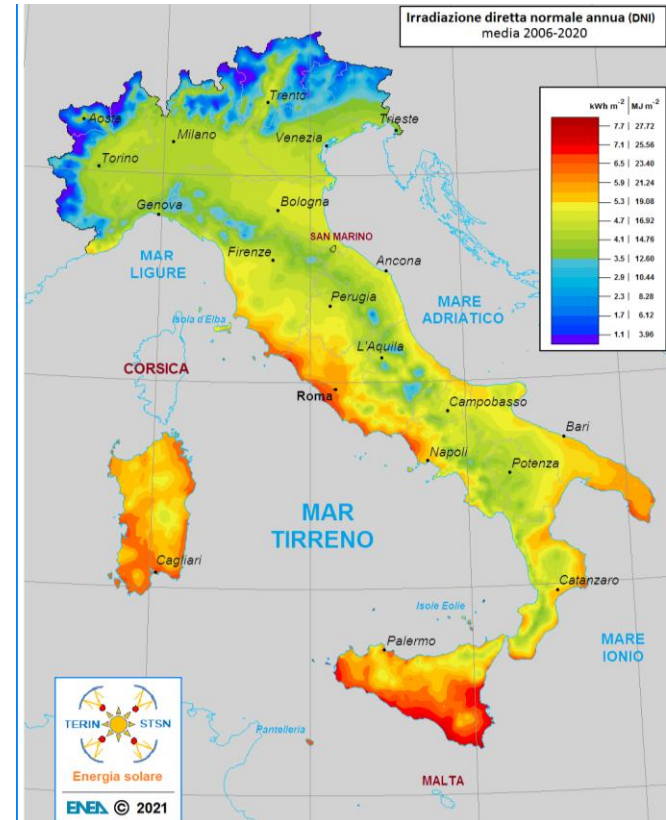
Electricity generation from solar, measured in terawatt-hours (TWh) per year.

Our World  
in Data



Source: Our World in Data based on BP Statistical Review of World Energy & Ember

OurWorldInData.org/renewable-energy • CC BY



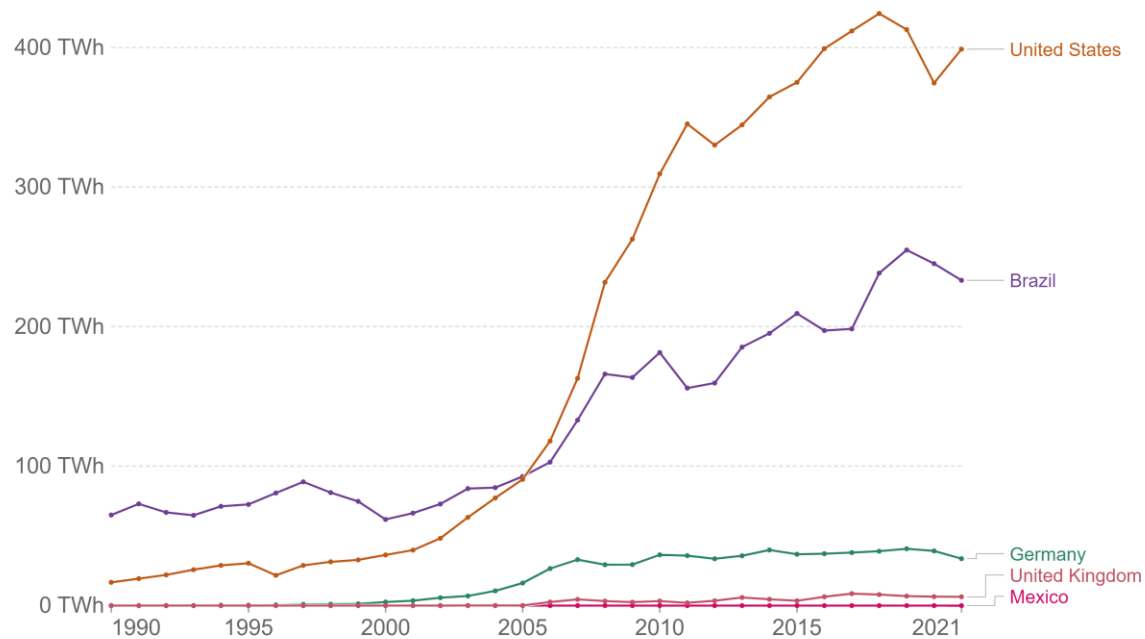


# Renewable energy sources

## Biofuel energy production

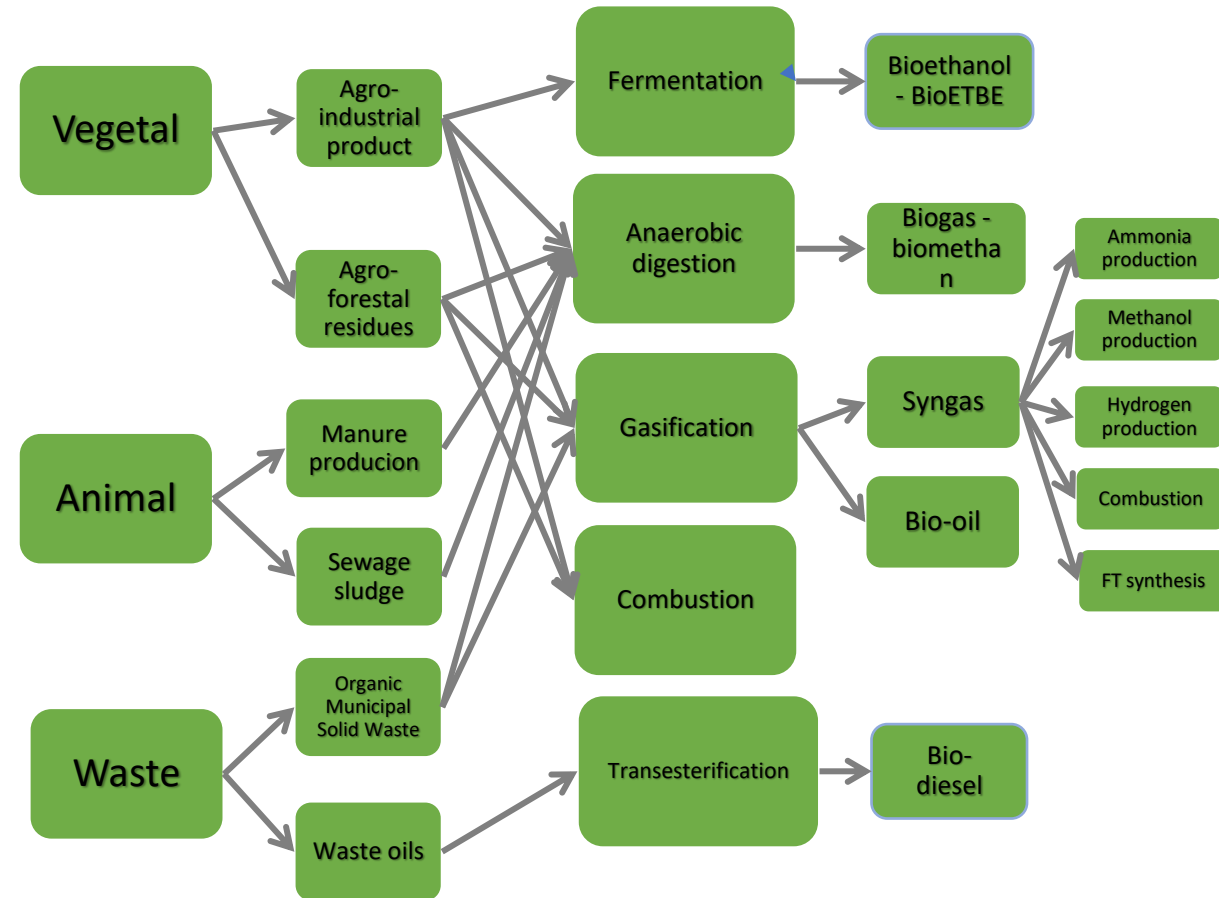
Total biofuel production is measured in terawatt-hours (TWh) per year. Biofuel production includes both bioethanol and biodiesel.

Our World in Data



Source: BP Statistical Review of World Energy

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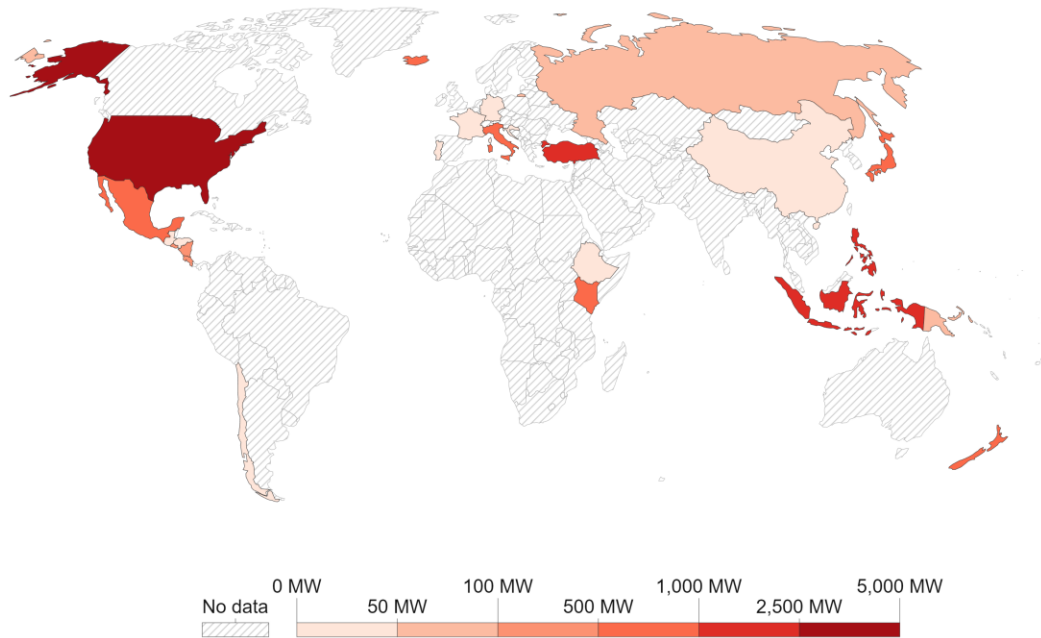


# Renewable energy sources

## Installed geothermal energy capacity, 2020

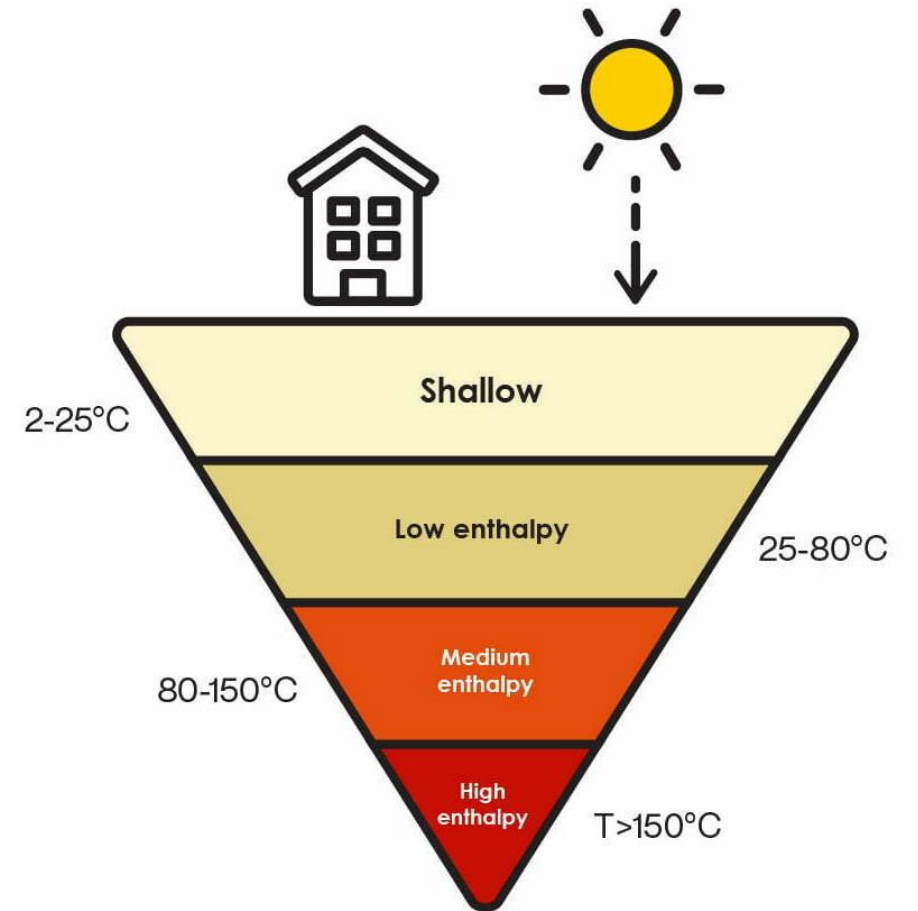
Cumulative installed capacity of geothermal energy, measured in megawatts.

Our World  
in Data



Source: Statistical Review of World Energy - BP (2021)

OurWorldInData.org/renewable-energy • CC BY

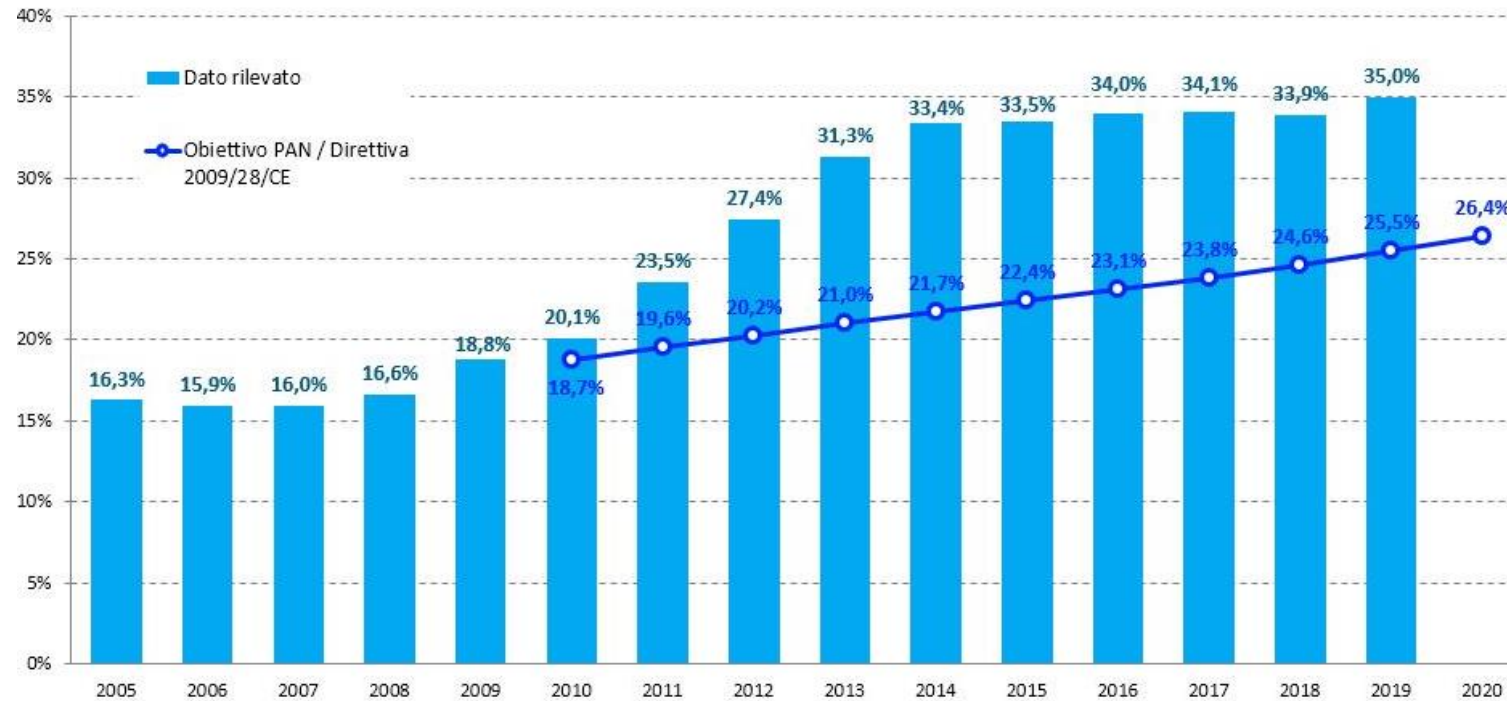




# International and national energy policies: National level

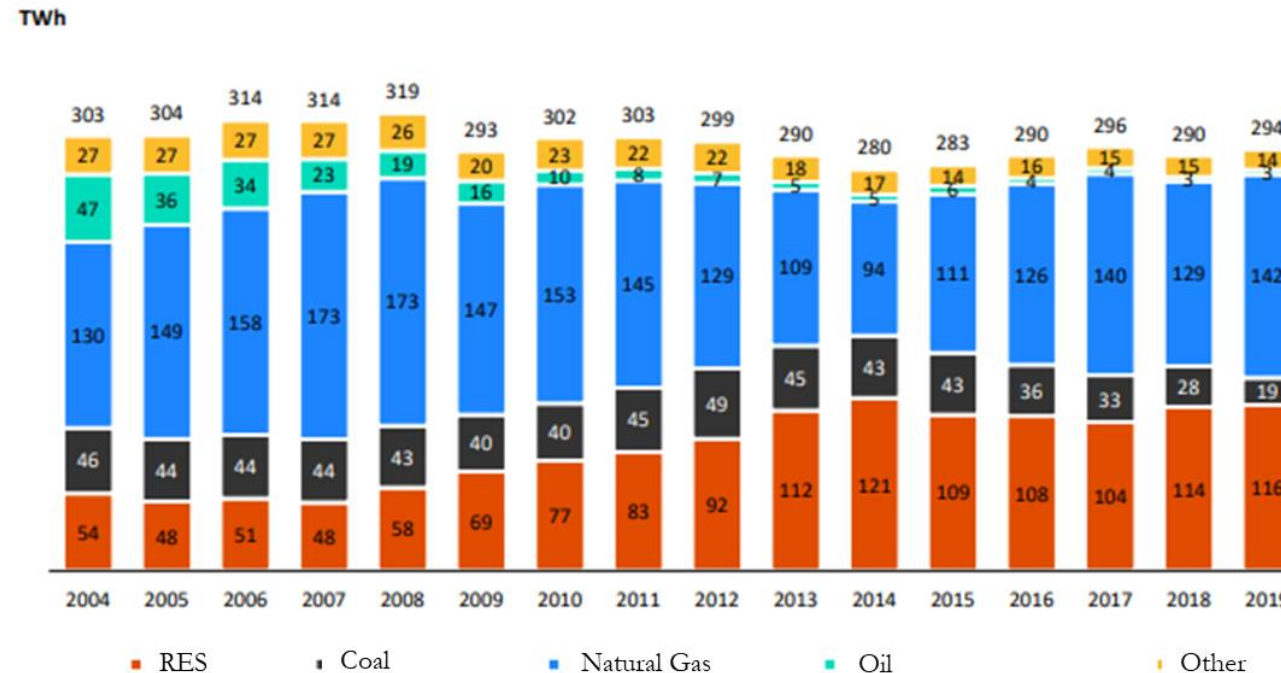
The National Action Plan for Renewable Energy (June 2015)

Total contribution from RES in the electricity sector in Italy (% of gross final consumption, 2005-2020 – GSE data)



# International and national energy policies: National level

Electricity from renewable in Italy (2004-2019) (Source: ENEA elaboration of Terna and ENEA data)



Fonte: elaborazioni GSE su dati Terna e GSE



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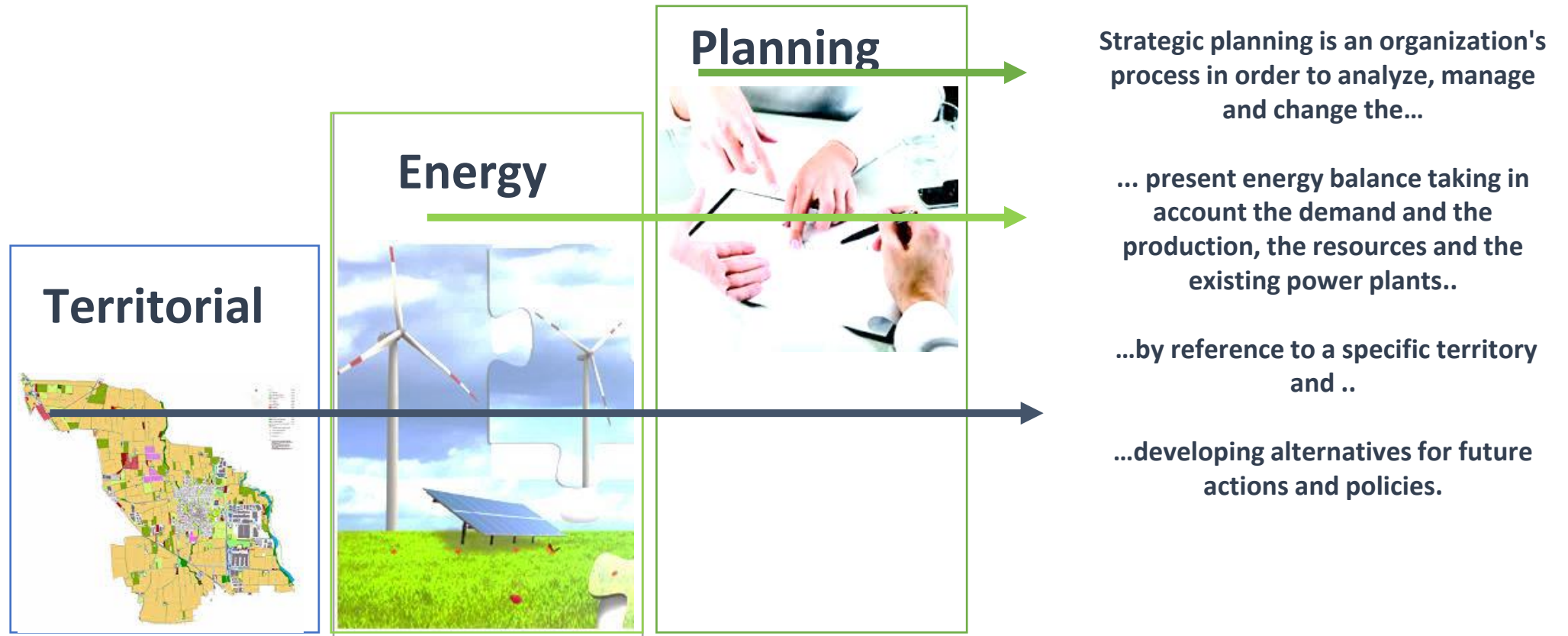
# How can society maximize the use of RES???

## Energy planning: definition

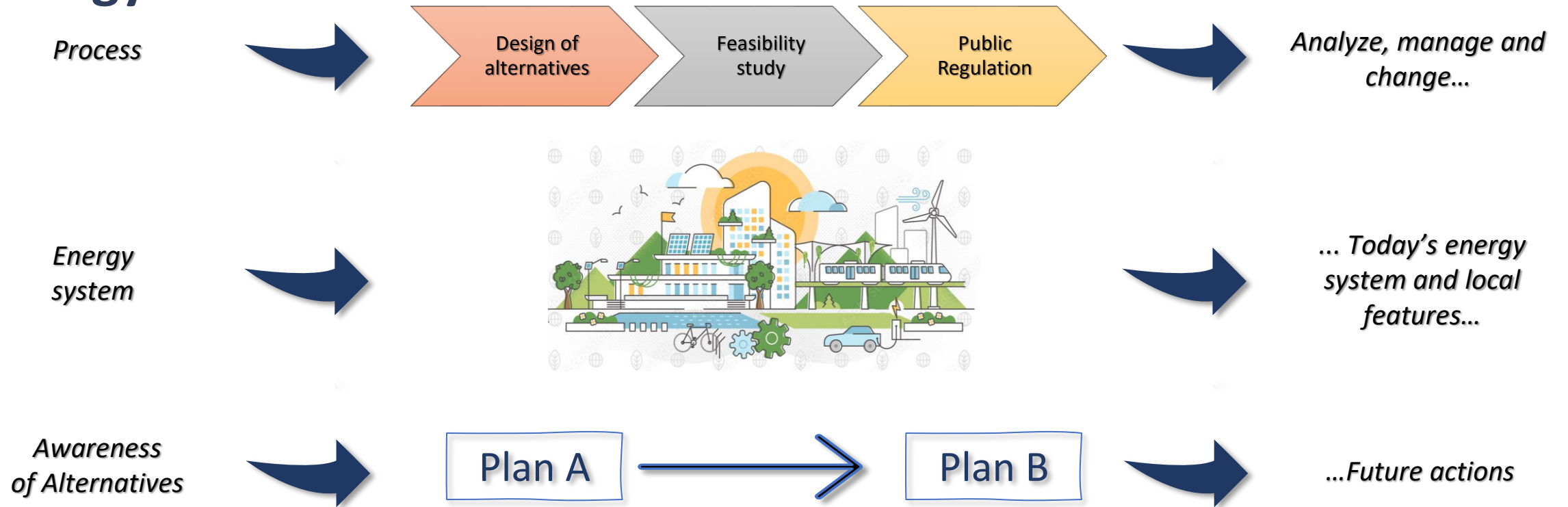
Territorial energy planning is a process for coordinating different energy flows and is an instrument based on the rational utilization of conventional and / or renewable energy (locally bound) that must be harmonized with territorial development.

Through the concept of energy planning, the territory no longer varies marginally but becomes the dominant one.

# Energy planning: definition



# Energy planning for mitigating the environmental impacts of the energy sector



# Why energy planning?

## Environment

- ✓ Fight Climate Change;
- ✓ Improve Air Quality;
- ✓ Protect the Environment and the Soil.

## Policy

- ✓ Europe asks to fulfill its obligations under the Climate-Energy Package;
- ✓ Create new partnerships (Universities, Energy Agencies, Other Agencies ...) for the Local Authority;
- ✓ Choice the Possible Future Energy Supply Scenario.

## Economy

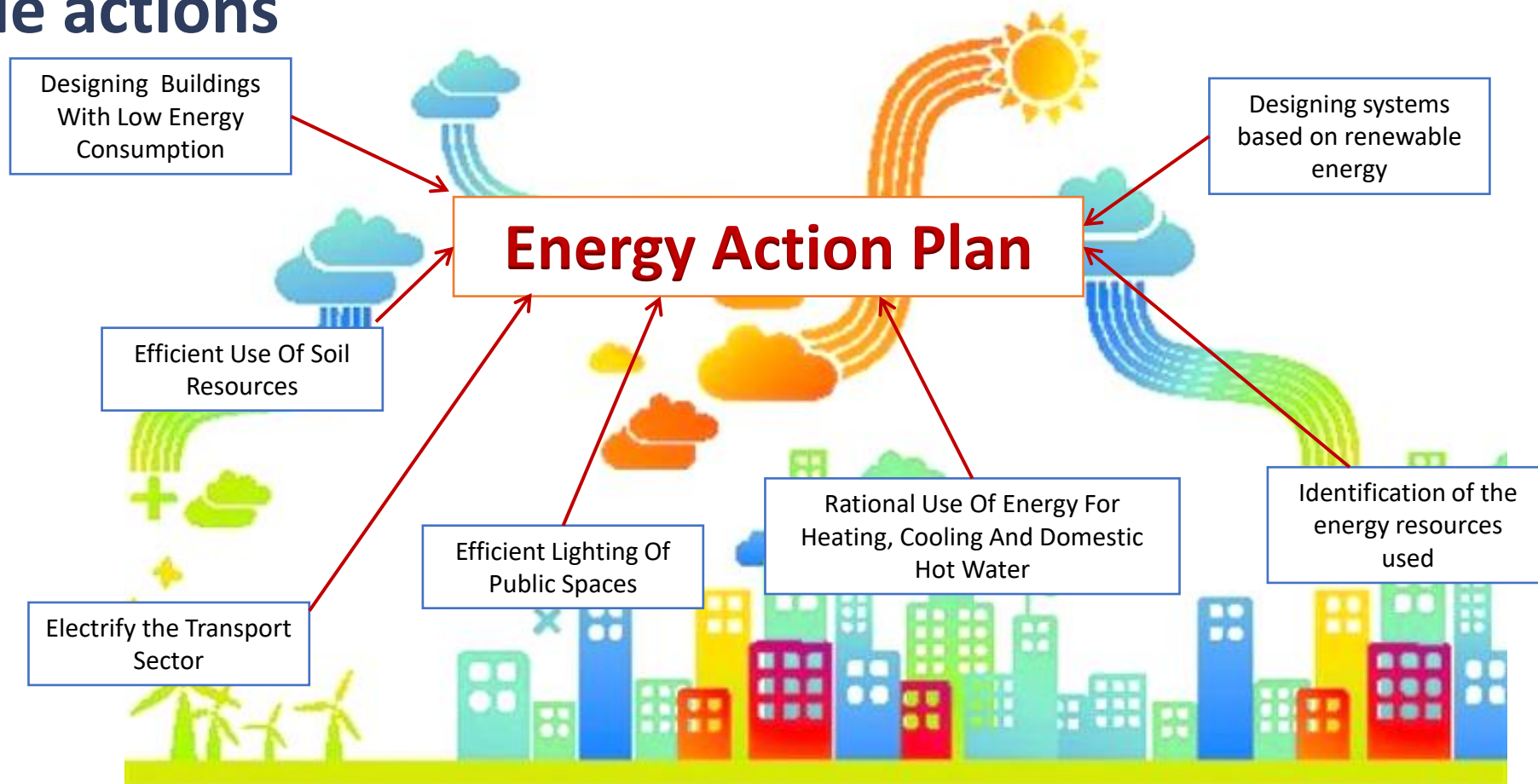
- ✓ Cost Savings due to the energy efficiency measures and to the use of renewable energy sources;
- ✓ Local/National Energy security;
- ✓ Green Economy and Sustainable Development;
- ✓ Sustainable Tourism Development.

# Energy planning process





## Possible actions



# Energy planning goals

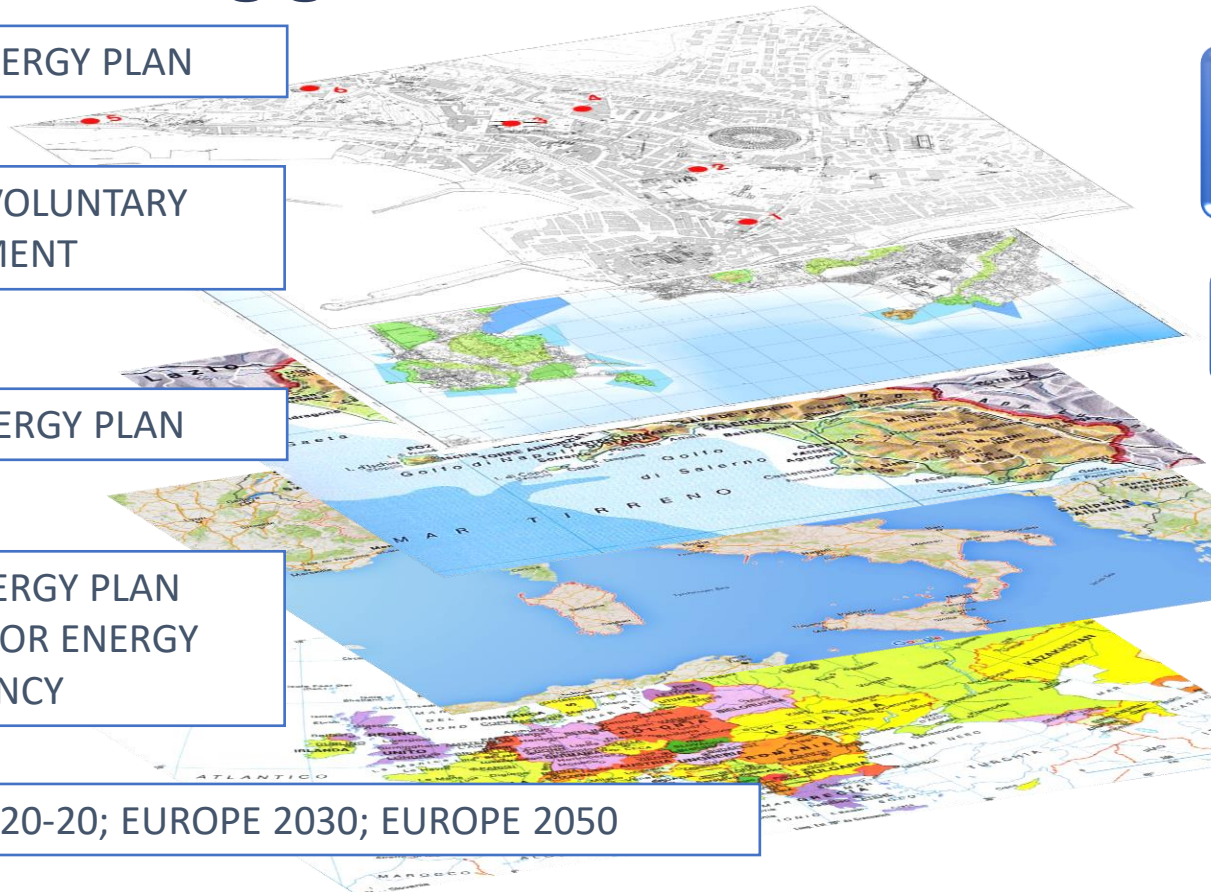
MUNICIPAL ENERGY PLAN

TERRITORIAL VOLUNTARY AGREEMENT

REGIONAL ENERGY PLAN

NATIONAL ENERGY PLAN  
ACTION PLAN FOR ENERGY EFFICIENCY

EUROPE 20-20-20; EUROPE 2030; EUROPE 2050



Specific aim related to energy needs and energy sources in the area



Territorial agreements in order to establish energy exchanges between the municipality, on the basis of resources and demand



Regional Energy Strategy Development

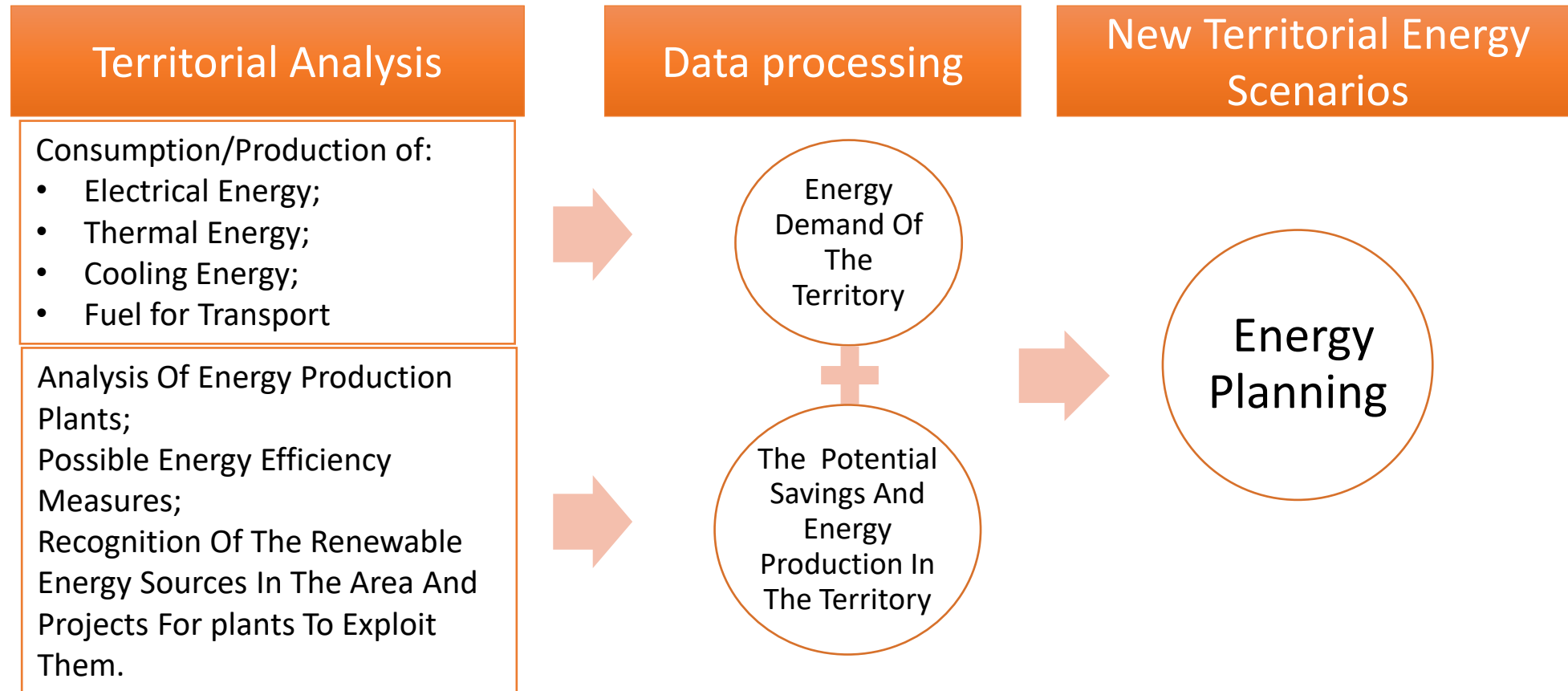


National Energy Guidelines for the development on the basis of the European Community Directives



European Vision: achieve a low-carbon economy in Europe, in line with the energy security, environmental and economic goals.

# Scenarios planning





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# Some examples of mitigation targets against climate change...

# International and national energy policies: global agreements

## COP21 -2015

Governments agreed:

- a long-term goal of keeping the increase in global average temperature to well below 2°C above pre-industrial levels;
- to aim to limit the increase to 1.5°C, since this would significantly reduce risks and the impacts of climate change;
- on the need for global emissions to peak as soon as possible, recognising that this will take longer for developing countries;
- to undertake rapid reductions thereafter in accordance with the best available science.



# International and national energy policies: EU agreements

## Europe Energy Target 2030

The 2030 climate and energy framework sets three key targets for the year 2030:

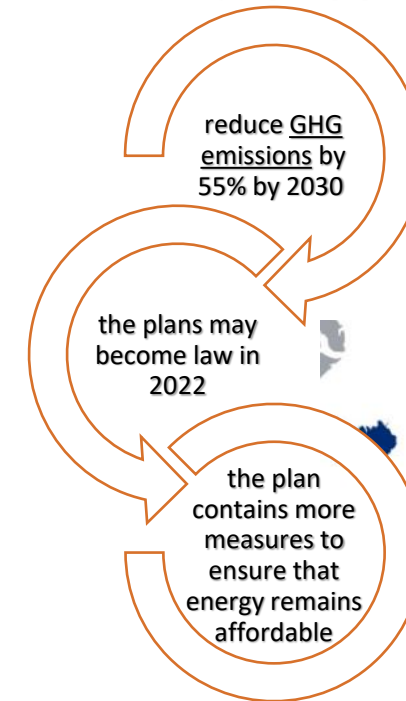
- At least 40% cuts in greenhouse gas emissions (from 1990 levels)
- At least 27% share for renewable energy
- At least 27% improvement in energy efficiency

## Europe Energy Target 2050

The European Commission low-carbon economy roadmap suggests that:

- By 2050, the EU should cut greenhouse gas emissions to 80% below 1990 levels
- Milestones to achieve this are 40% emissions cuts by 2030 and 60% by 2040
- All sectors need to contribute
- The low-carbon transition is feasible & affordable.

## Fit for 55







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# Some examples of energy plans...

# National energy plans

## Energy plans

### National goals for 2030



Share of RES of TFC 30%



Share of RES of transport  
TFC 22%



Reduction of the primary  
energy with respect to the  
PRIMES 2007 scenario -43%

Decarbonization

Self-consumption

Security

Energy efficiency

Integration with the EU

## Regional



### Regional Environmental Energy Plan

#### Study Plan

- Cognitive framework of the territory
- Scoreboard of possible interventions
- Framework of scenarios

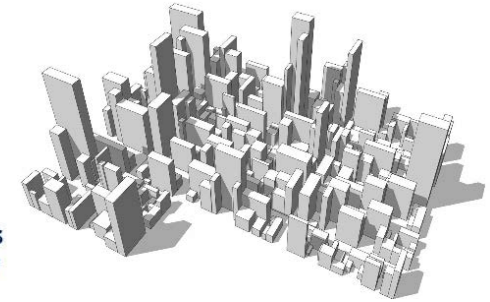
#### Operational Plan

- Definition of objectives
- Interconnection with other sectors and plans
- Financial resources
- Realization times
- Stakeholders and participants

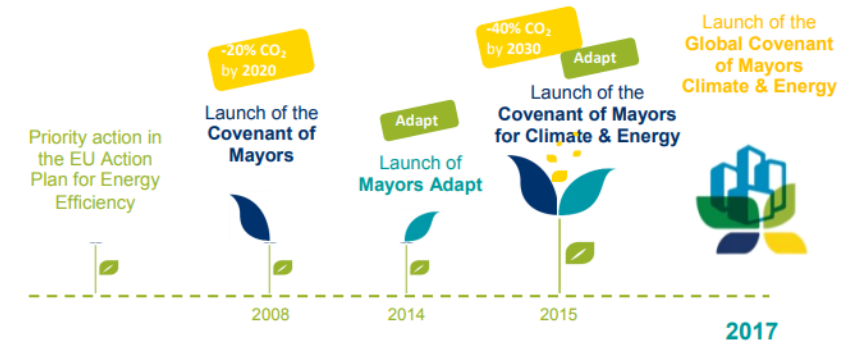
## Municipal



Covenant of Mayors  
for Climate & Energy



### The evolution of the Covenant of Mayors





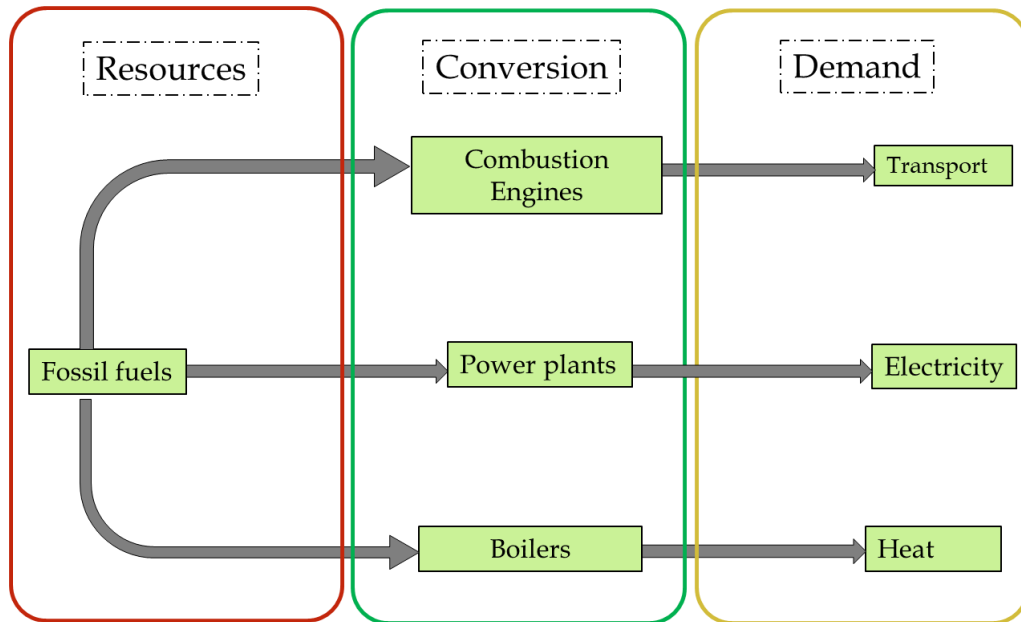
# International and national energy policies: EU and National level

## Objectives 2030

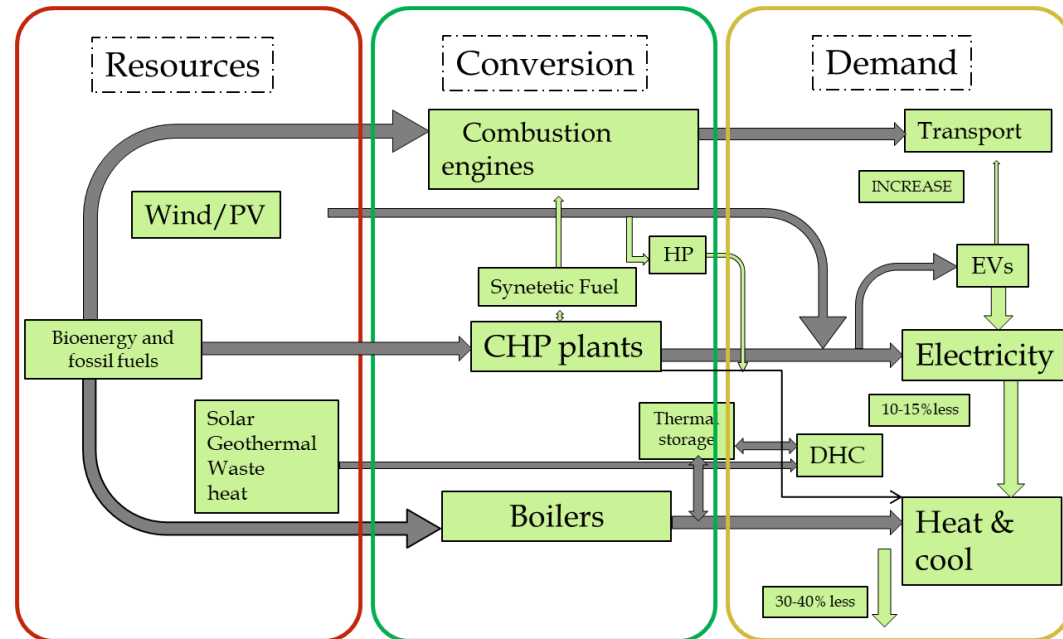
	UE	ITALY
		INECP
	<b>Renewables</b>	
Share of RES of TFC	32%	30%
Share of RES of transport TFC	14%	22%
Share of RES of heating and cooling TFC	+1.3% each year	+1.3% each year
	<b>Energy efficiency</b>	
Reduction of the primary energy with respect to the PRIMES 2007 scenario	-32.5%	-43%
Reduction of the primary energy with respect to the PRIMES 2007 scenario	-0.8%	-0.8%
	<b>GHG emissions</b>	
GHG reduction vs 2005 for all the ETS plants	-43%	
GHG reduction vs 2005 for non ETS plants	-30%	-33%
GHG reduction vs 1990 levels	-40%	

# Energy systems' configuration

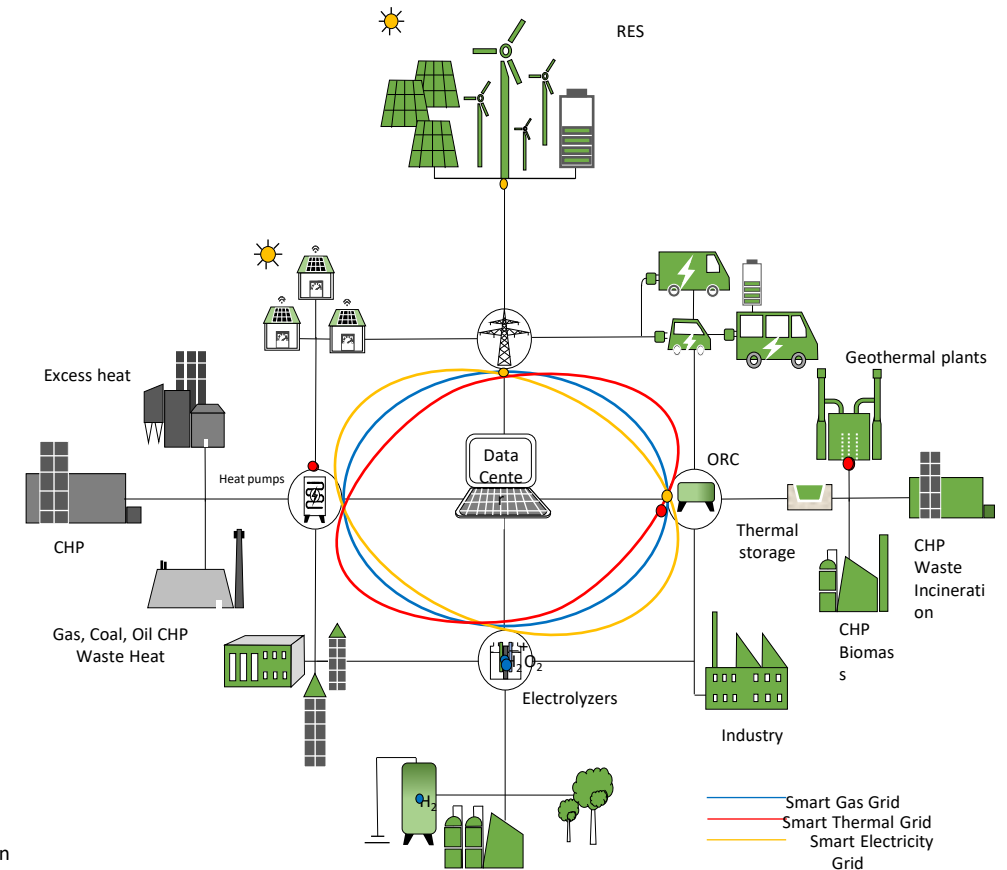
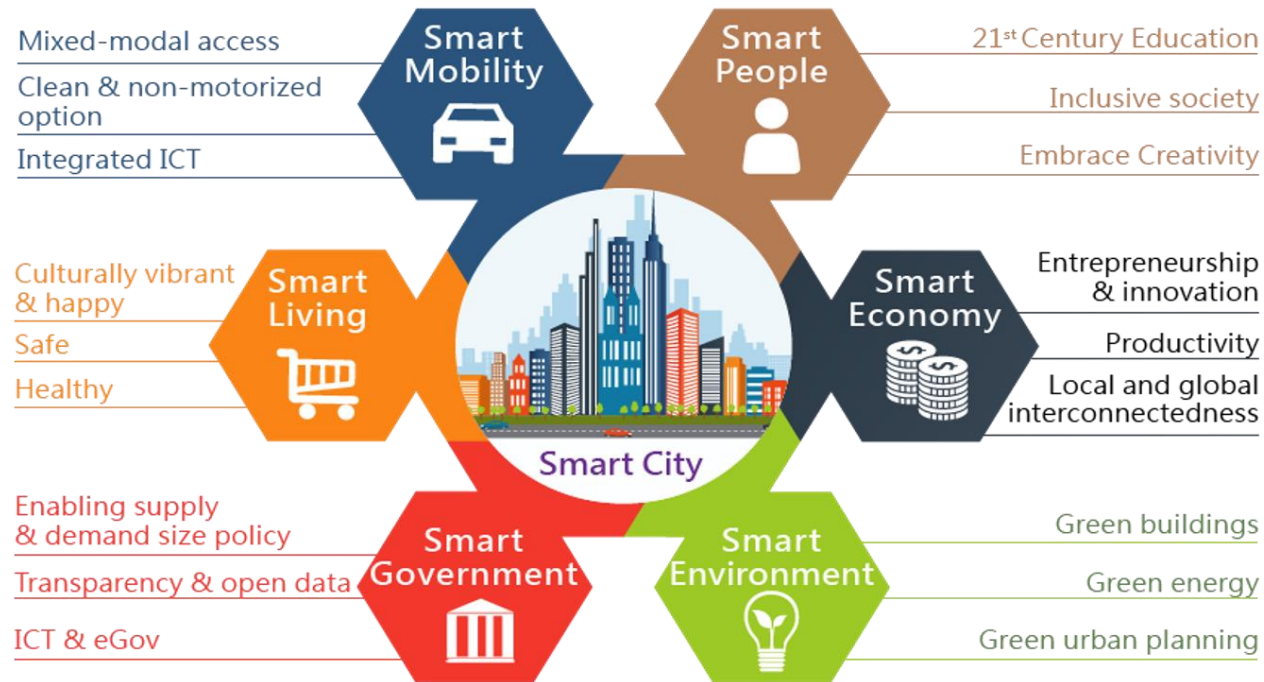
## Energy system today



## Future smart energy system



# Smart CITIES and COMMUNITIES



Source: M. Oberascher, W. Rauch, and R. Sitzenfrei, "Towards a smart water city: A comprehensive review of applications, data requirements, and communication technologies for integrated management," *Sustain. Cities Soc.*, vol. 76, no. October 2021, p. 103442, 2022.

Source: R. Obringer and R. Nateghi, "What makes a city 'smart' in the Anthropocene? A critical review of smart cities under climate change," *Sustain. Cities Soc.*, vol. 75, no. July, p. 103278, 2021.

## Smart energy systems: definition

- It include the entire energy system in its approach to identifying suitable energy infrastructure designs and operation strategies
- It consists of “new technologies and infrastructures which create new forms of flexibility, primarily in the ‘conversion’ stage of the energy system
- It combines the electricity, thermal, and transport sectors so that the flexibility across these different areas can compensate for the lack of flexibility from renewable resources such as wind and solar

Lund H, et al., *Smart energy and smart energy systems*, *Energy* (2017),  
<http://dx.doi.org/10.1016/j.energy.2017.05.123>



# Smart energy systems: definition



[www.energyplan.eu/smartenergy](http://www.energyplan.eu/smartenergy)

## Smart energy systems

- A sole focus on renewable **electricity (smart grid)** production leads to electricity storage and flexible demand solutions!
- Looking at renewable electricity as a part of the smart energy systems including heating, industry, gas and transportation opens for cheaper and better solutions...



**Power-to-Gas**  
**Power-to-Transport**  
**Power-to-Heat**

# Smart grids

**Smart Energy System** is built around three grid infrastructures:

- **Smart Electricity Grids** to connect flexible electricity demands such as heat pumps and electric vehicles to the intermittent renewable resources such as wind and solar power.
- **Smart Thermal Grids (District Heating and Cooling)** to connect the electricity and heating sectors. This enables the use of thermal storage for creating additional flexibility and the recycling of heat losses in the energy system.
- **Smart Gas Grids** to connect the electricity, heating, and transport sectors. This enables the use of gas storage for creating additional flexibility. If the gas is refined to a liquid fuel, then liquid fuel storages can also be used.

In **Smart Energy System** smart electricity, thermal and gas grids are combined with storage technologies and coordinated to identify synergies between them in order to achieve an optimal solution for each individual sector as well as for the overall energy system

## Synergies

- Energy savings in buildings make low-temperature district heating possible to use which utilize low-temperature sources from industrial surplus heat and CHP
- Excess heat from industry and electricity production can be used for heating
- Electricity for heating purposes allow to use heat storage and provides a more flexible CHP production
- Heat pumps for heating can provide cooling for DHC networks
- Electricity for heating may be used for balancing power and electric grid
- Electricity for vehicles can be used to replace fuel and provide for electricity balancing



## Surplus Electricity Production

**Surplus Electricity Production (SEP)** *is defined as situations in which the electricity production exceeds the demand in a given area.*

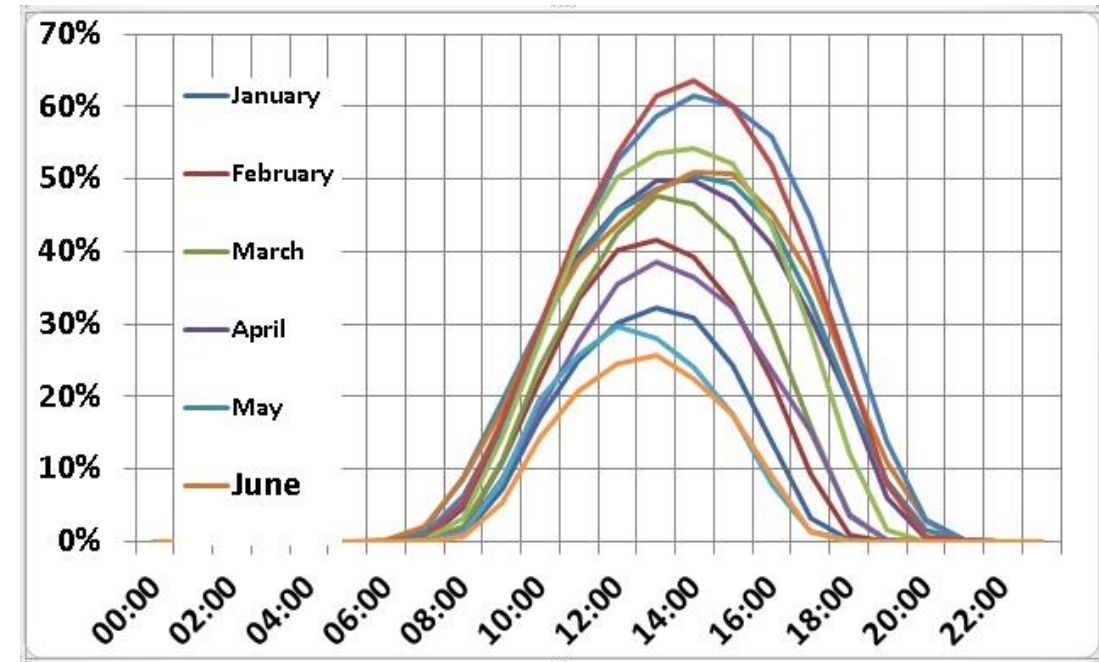
*The SEP can be defined as:*

- **Exportable Surplus Electricity Production (ESEP):** *when it can be exported;*
- **Critical surplus Electricity Production (CSEP):** *when cannot be exportable.*

*In some cases, the surplus production exceed the technical possibilities of being exported, for instance if the surplus production becomes higher than the capacity of existing transmission lines.*

## Why does it happen???

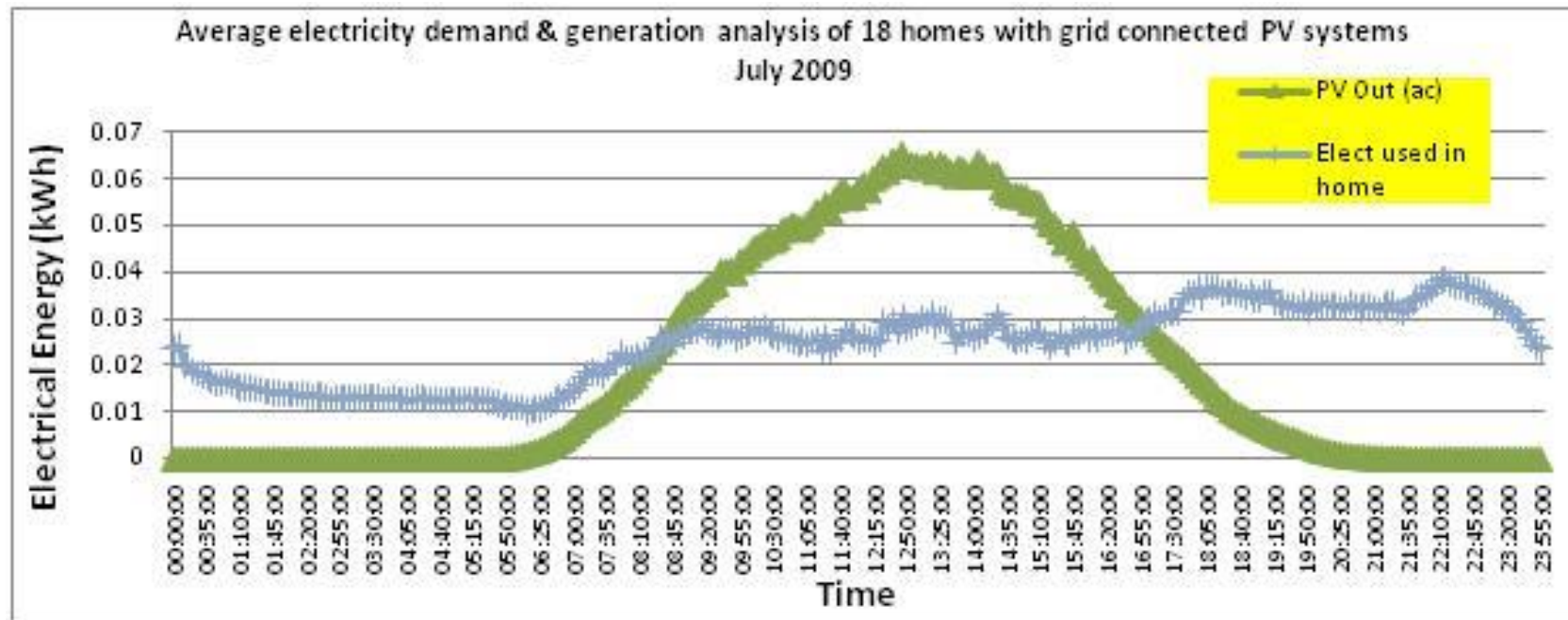
- In stock-based electricity production systems, conversion technologies (e.g., nuclear, coal, oil and gas generators) produce steady output flows. In these situations, inflexibility of supply can be managed. However, flow-based energy sources such as run-of-river hydropower, solar power, and wind energy, do not allow for supply-side control without additional investments and storage losses.
- Solar and wind plants deliver energy stochastically as a function of weather conditions.
- Once the infrastructure for these technologies has been installed (e.g., a photovoltaic panel, a wind turbine or a solar thermal concentrator) it can produce anything from 0% to 100% of nameplate capacity, relatively independent of demand..



# Why does it happen???

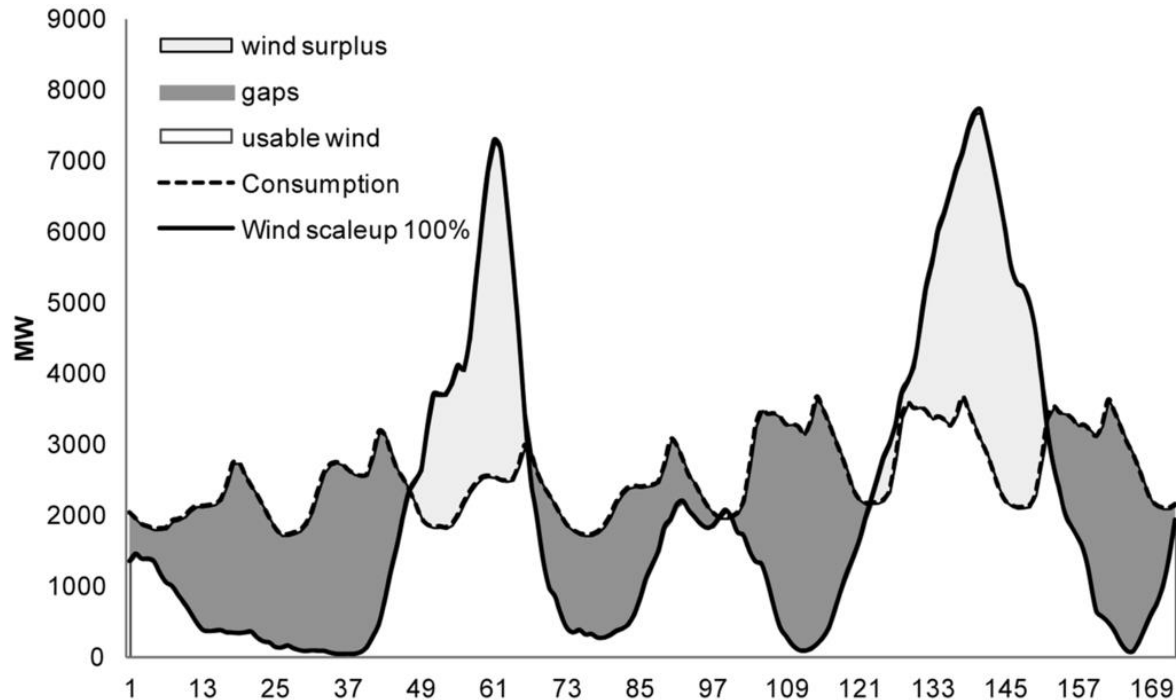
Exportable o Critical?

It depends on capacity of existing transmission lines



Source: Technical and policy challenges of wide-scale integration of PV systems into UK homes *Joyal Abedin, Loughborough University*

# Why does it happen???



A similar problem arises with the wind plants.

Wind power production (scaled to 100% annual electricity consumption) plotted against actual gross consumption for electricity in Denmark West

Exportable o

Critical?

It depends on capacity of existing transmission lines



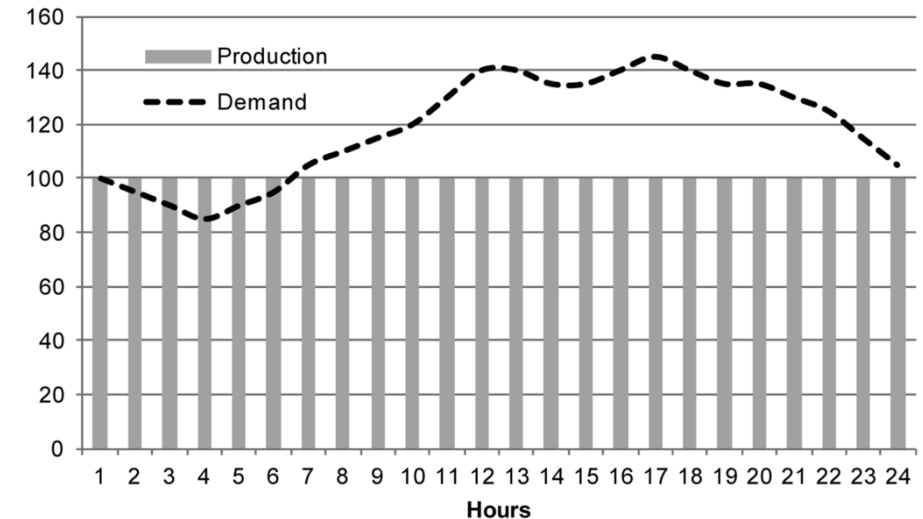
## How to avoid the issue of SEP?

- 1) **New Electric Energy System:** RES electricity plants combined with Stable Output Technologies and Flexible Technologies;
- 2) **Increasing the electricity grid capacity;**
- 3) **New Energy System:** SEP used to heat production;
- 4) **Integration of electric storage;**
- 5) **Integration of electric transportation.**

# How to avoid the issue of SEP?

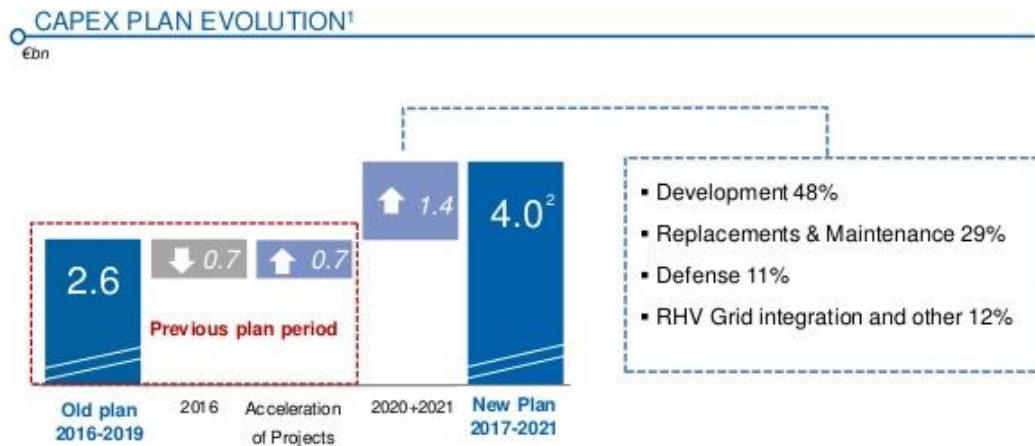
**1) New Electric Energy System:** RES electricity plants combined with Stable Output Technologies and Flexible Technologies;

Stable Output Technologies	Flexible Output Technologies
<ul style="list-style-type: none"> <li>-Their outputs vary little and are predictable for extended periods of time;</li> <li>-These technologies are not flexible enough to follow all the peaks and lows</li> <li>-Run-of-river hydropower delivers steady outputs that are not typically easy to alter</li> </ul>	<ul style="list-style-type: none"> <li>- Most stock-based technologies, like gas- or oil-fired power plants, or stored hydropower, can be modulated to follow demand patterns as they emerge;</li> <li>-They bear no demand shortfall risk in their application;</li> </ul>



# How to avoid the issue of SEP?

Terna 2017>2021  
ENABLING ENERGY TRANSITION  
Regulated Capex Plan 2017-2021  
Milan > February 20, 2017



Average annual investing ~+30% vs Old Plan

2) Increasing the electricity grid capacity

The TERNA CAPital Expenditure Plan involves investments in Development of new grids



## How to avoid the issue of SEP?

### 3) **New Energy System:** SEP used to heat production;

- Exploiting existing or additional heat-storage capacity in CHP units by moving production from CHP units from hours with a lot RES power to hours with less RES power;
- Replacing CHP production with biomass boiler production during hours of critical surplus production;
- Using excess electricity to produce Hydrogen;
- Using electric heating by replacing heat production from CHP or biomass boilers.

# How to avoid the issue of SEP?

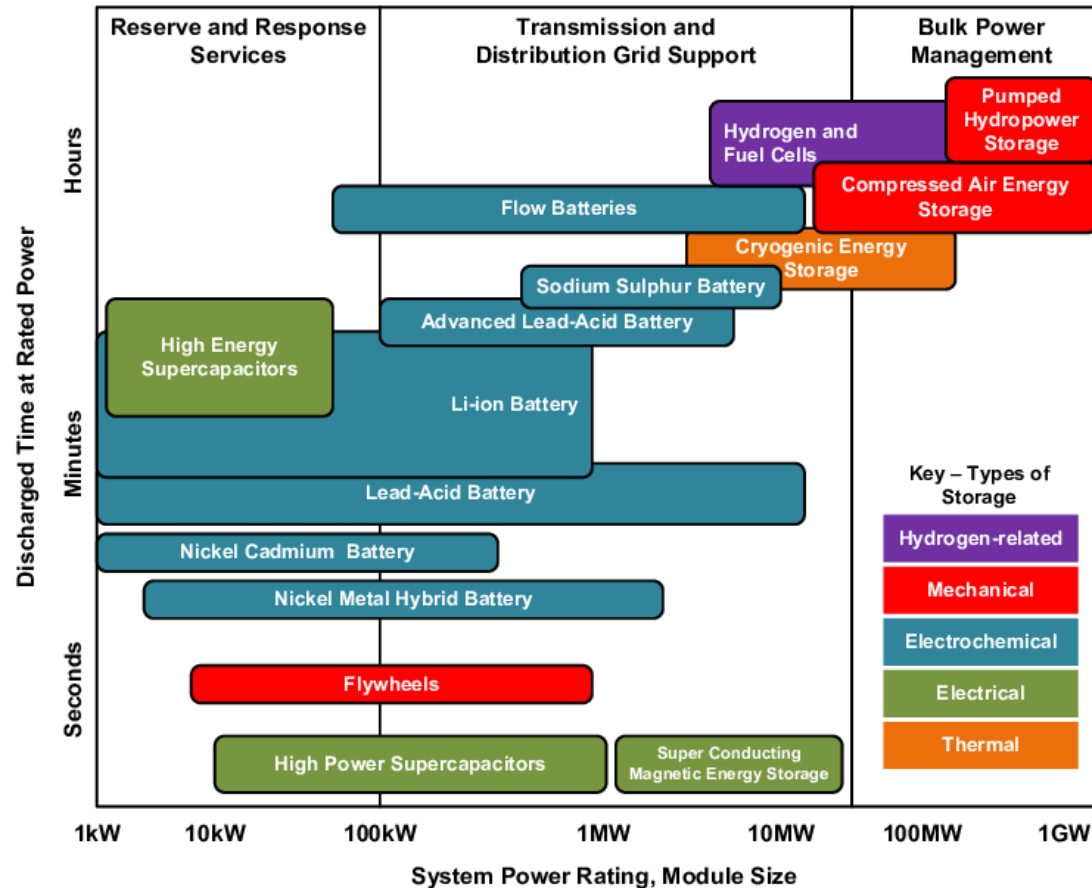
## 4) Integration of electric storage

Six main categories:

- **Solid State Batteries** - a range of electrochemical storage solutions, including advanced chemistry batteries and capacitors
- **Flow Batteries** - batteries where the energy is stored directly in the [electrolyte](#) solution for longer [cycle](#) life, and quick response times
- **Compressed Air Energy Storage** - utilizing compressed air to create a potent energy reserve
- **Thermal** - capturing heat and cold to create energy on demand
- **Pumped Hydro-Power** - creating large-scale reservoirs of energy with water

<http://energystorage.org/energy-storage-1>

# How to avoid the issue of SEP?



TY - BOOK  
 AU - Sprake, David  
 AU - Vagapov, Yuriy  
 AU - Lupin, Sergey  
 AU - Anuchin, Alecksey  
 PY - 2017/09/12  
 SP -  
 T1 - Housing Estate Energy Storage  
 Feasibility for a 2050 Scenario  
 DO - 10.1109/ITECHA.2017.8101925  
 ER -

## How to avoid the issue of SEP?

### 5) Integration of electric transportation.

The technical performance of battery cars and hydrogen fuel cell cars will gradually improve in the coming decades, making it feasible for these types of cars to take over a substantial part of the transport task, particularly for passenger cars and small delivery vans below 2 t.

## How to avoid the issue of SEP?

### 5) Integration of electric transportation.

The barriers to the integration of electric transportation are mainly due:

- to current high technology cost (especially fuel cell vehicles),
- insufficient infrastructure, and high cost of public charging stations (especially fast-charging electricity chargers and hydrogen fuel stations)

# EnergyPLAN

<https://www.energyplan.eu/download/>  
[www.EnergyPLAN.eu](http://www.EnergyPLAN.eu)

- Download EnergyPLAN
- Download documentation
- Links to journal articles
- Links to research reports
- The FIDE guide

## Energy PLAN

Advanced energy  
system analysis  
computer model

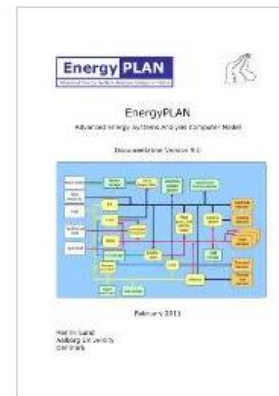
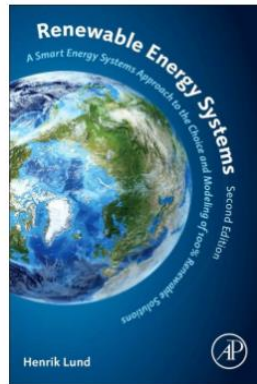
The screenshot shows the EnergyPLAN website interface. At the top, there's a navigation bar with 'Home', 'Download', 'About', 'Contact', and social media icons. Below the header, there are several content sections:
 

- Get Started:** A section inviting users to read the introduction and obtain a guide. It mentions 'existing models, cost data, and case studies'.
- Download:** A prominent orange button labeled 'Download Model' with a sub-link 'Download the latest version and get started right away!'.
- Training Links:** A list of resources including 'Introduction', 'Training Exercises', 'Energyland Exercises', 'Workshops', 'FAQs', 'Documentation', 'The FIDE Guide', and 'Theory'.
- Questions?:** A section for user inquiries, encouraging them to check the FAQs and training material, and to post questions on the forum or contact the team.



A renewable energy scenario for Aalborg Municipality based on low-temperature geothermal heat, wind power and biomass  
Paul Alberg Thorsgaard\*, Brian Vad Mathiesen<sup>1</sup>, Bernd Müller<sup>2</sup>, Henrik Lund<sup>1</sup>

**ABSTRACT**  
Energy transition is essential to meet the challenges of climate change and sustainable development. This article describes a scenario for meeting Aalborg Municipality's energy needs through a combination of geothermal heat, wind power and biomass. The scenario is based on the analysis view that it is possible to meet Aalborg Municipality's energy needs through the use of locally available resources in combination with optimal energy storage. The energy production is optimized for net cost and fuel substitution in the transport sector. With biomass resources being finite, the scenario is optimized to reduce the environmental impact and avoid greenhouse gas emissions as much as possible. The scenario is a sustainable model for the reference situation, but with significant potential for further development and cost reduction. The scenario is based on a number of assumptions and a number of uncertainties are shown. The authors encourage other researchers to investigate the scenario and its potential for other municipalities and regions.



# EnergyPLAN

<https://www.energyplan.eu/download/>

## The EnergyPLAN Model:

- Energy System Analysis Model - Excel~Visual Basic~Delphi Pascal
- Main focus: Compare different regulation systems and the ability to integrate and trade RES (Wind)
- Simplified modelling of energy system.



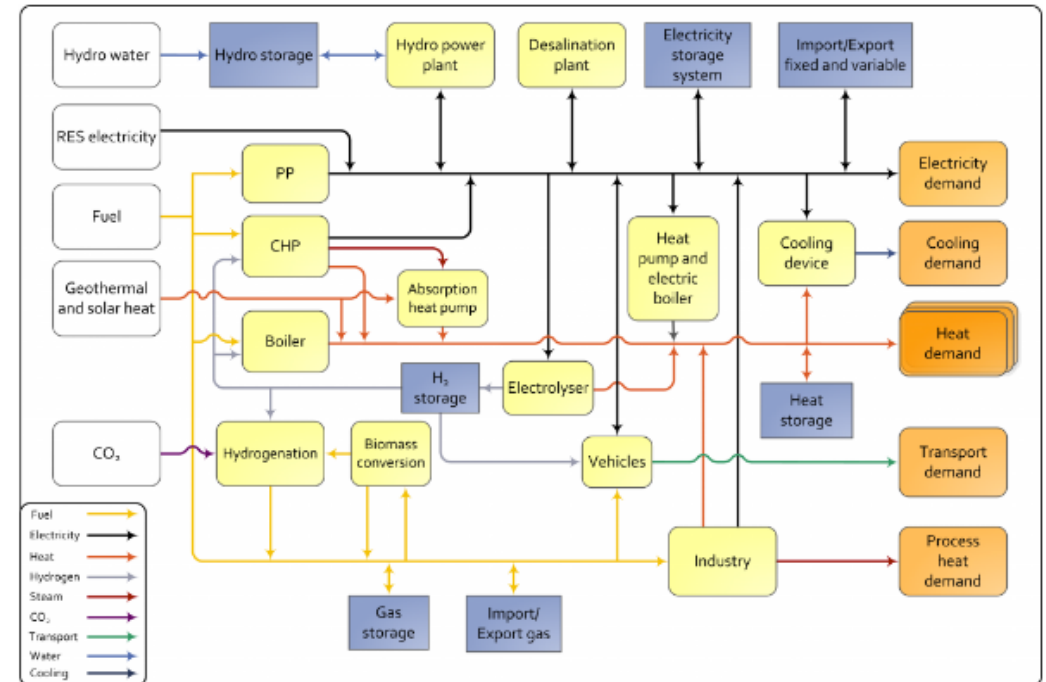
# EnergyPLAN

<https://www.energyplan.eu/download/>

## Main features

The main purpose of the EnergyPLAN model is to analyse the energy, environmental, and economic impact of various energy strategies. The key objective is to model a variety of options so that they can be compared with one another, rather than model one 'optimum' solution based on defined pre-conditions.

- A sole focus on renewable electricity production leads to storage solutions!
- Looking at renewable electricity as a part energy systems including heating, industry and transportation opens for cheaper and better solutions...

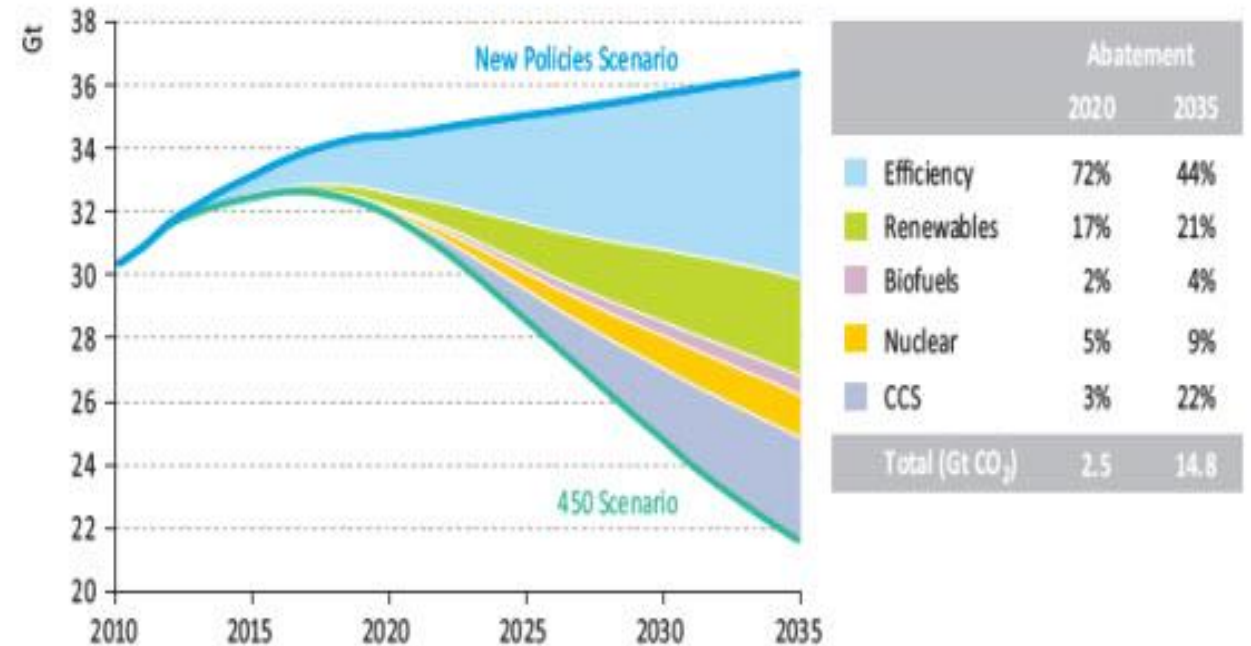


# EnergyPLAN

<https://www.energyplan.eu/download/>

## Main features

Furthermore, the aim of EnergyPLAN is to model the **'finishing point'** of the energy system rather than the starting point. The focus is placed on the future energy system and how that will operate, rather than on today's energy system. The focus is on the future rather than the present.



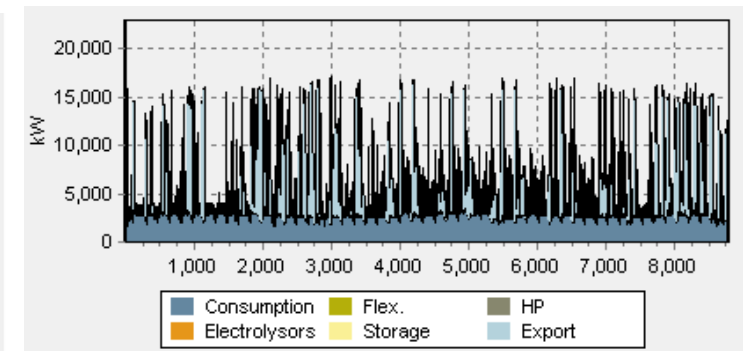
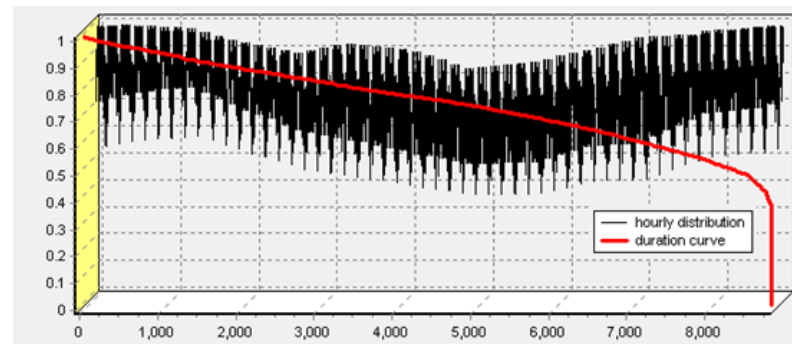
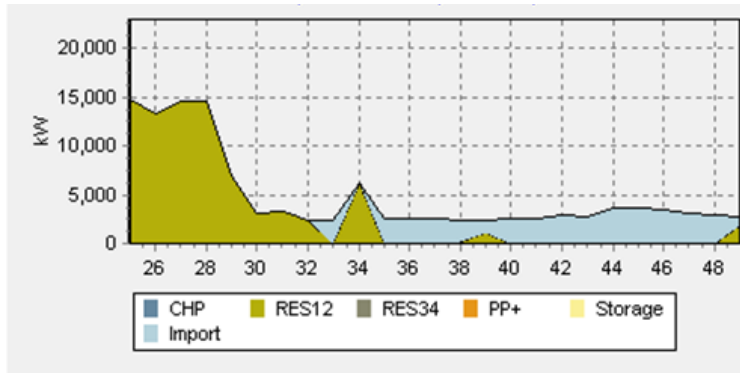
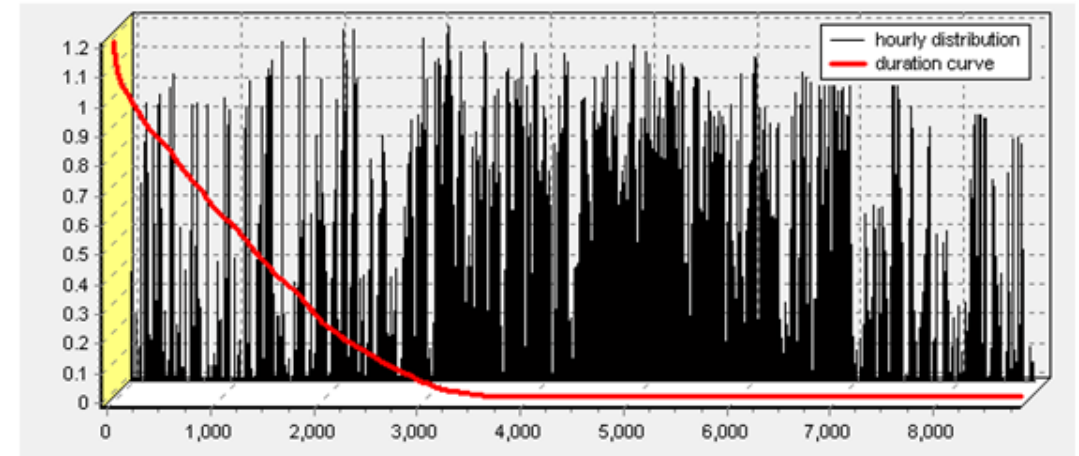
World Energy Outlook 2011 © OECD/International Energy Agency 2011, figure 6.4, page 214

# EnergyPLAN

<https://www.energyplan.eu/download/>

## Main features

EnergyPLAN is an **hour-simulation model** as opposed to a model based on aggregated annual demands and production. Consequently, the model can analyze the influence of fluctuating RES on the system as well as weekly and seasonal differences in electricity and heat demands and water inputs to large hydropower systems.



# EnergyPLAN

<https://www.energyplan.eu/download/>

## Main features



### INPUT

**Demands**  
Electricity  
Cooling  
District Heating  
Individual Heating  
Fuel for Industry  
Fuel for Transport

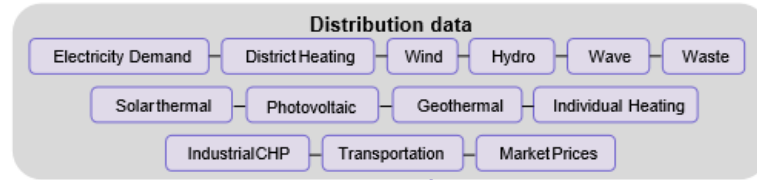
**RES**  
Wind  
Solar Thermal  
Photovoltaic  
Geothermal  
Hydro Power  
Wave

**Capacities & efficiencies**  
Power Plant  
Boilers  
CHP  
Heat Pumps  
Electric Boilers  
Micro CHP

**Storage**  
Heat Storage  
Hydrogen Storage  
Electricity Storage  
CAES

**Transport**  
Petrol/Diesel Vehicles  
Gas Vehicles  
Electric Vehicles  
V2G Electric Vehicles  
Hydrogen Vehicles  
Biofuel Vehicles

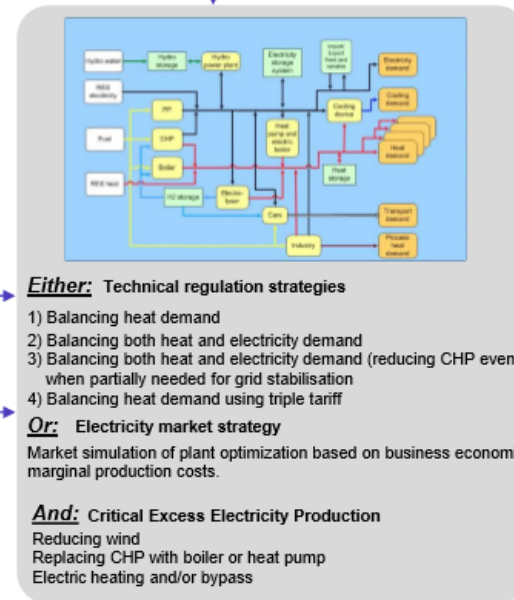
### EnergyPLAN



**Regulation**  
Technical Limitations  
Choice of Strategy  
CEEP Strategies  
Transmission Cap.  
External Electricity  
Market

**Fuel Cost**  
Types of fuel  
CO2 Emission Factor  
CO2 Emission Costs  
Fuel Prices

**Cost**  
Variable Operation  
Fixed Operation  
Investment  
Interest Rate



### OUTPUT

**Results**  
(Annual, Monthly and Hourly Values)

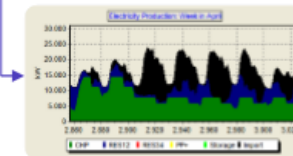
Electricity Production  
Electricity Import/Export  
electricity Excess Production

Import Expenditures  
Export Revenues

Fuel Consumption

CO2 Emissions

Share of RES



# EnergyPLAN

<https://www.energyplan.eu/download/>

## Main features

Different kinds of studies:

- Technical system studies in closed and open systems (Results are energy balances, CO<sub>2</sub>-emissions and Excess electricity productions)
- Market exchange studies (Results are optimal exchange strategies and costs)
- Feasibility Studies (Results are socio economic costs including CO<sub>2</sub> trade costs)

# EnergyPLAN

<https://www.energyplan.eu/download/>

## Main features

Step by step:

1. Defining energy demands (electricity, individual and district heating, industry, transportation)
2. Defining a reference energy production system
3. Defining alternatives
4. Results



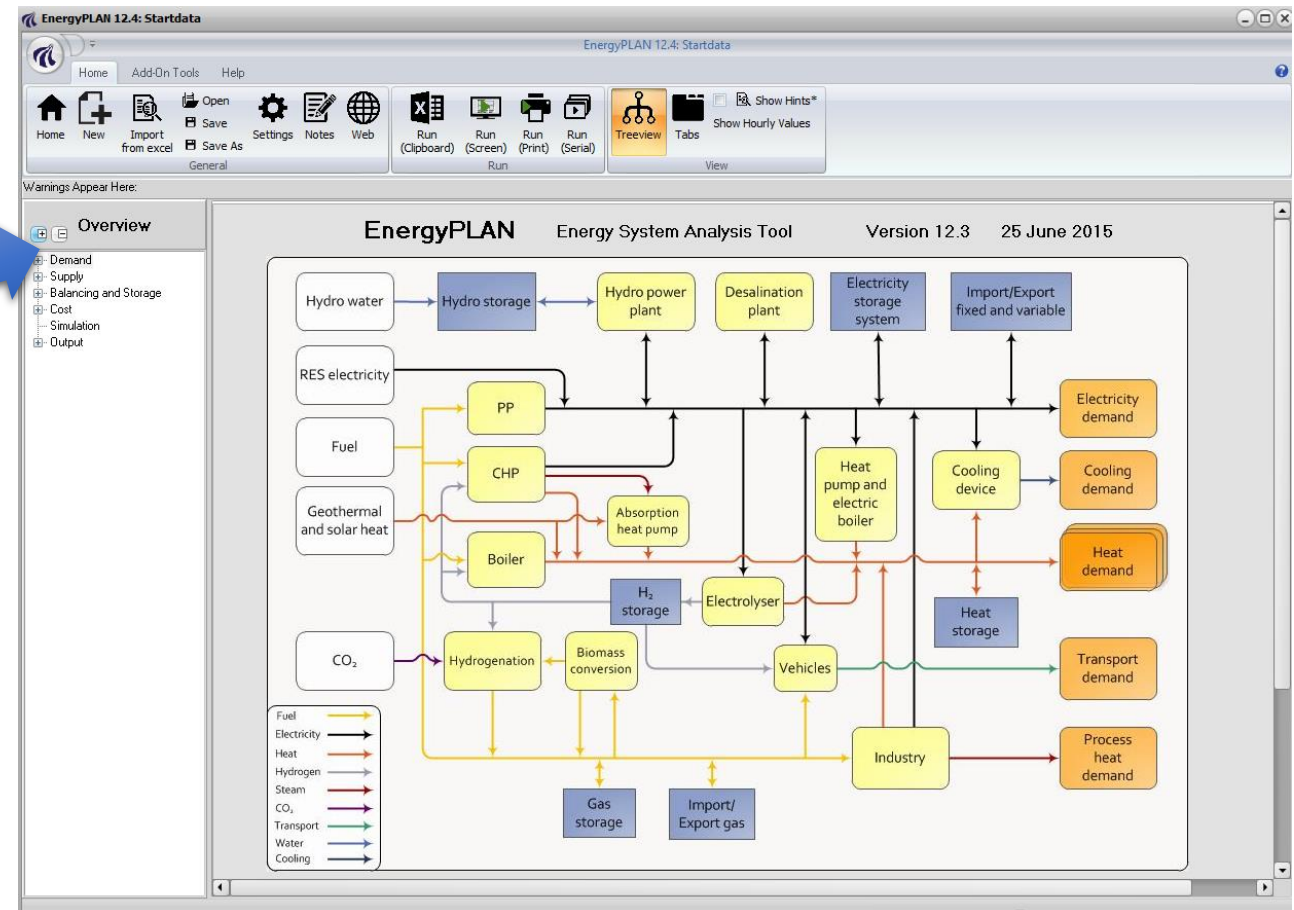
# EnergyPLAN

<https://www.energyplan.eu/download/>

## Main features

Home

The Home button on the home menu gives the user an overview of the components and synergies included in the EnergyPLAN model





# EnergyPLAN

## Step 1: Defining electricity demands

The electricity demand is defined by an annual value, (TWh per year) and it can be chosen the name of an hourly distribution data set

### Electricity Demand and Fixed Import/Export

Electricity demand:	<input type="text" value="20"/>	TWh/year	<input type="button" value="Change distribution"/>	Hour_electricity.txt
Electric heating (IF included)	- <input type="text" value="0"/>	TWh/year	Subtract electric heating using distribution from 'individual' window	
Electric cooling (IF included)	- <input type="text" value="0"/>	TWh/year	Subtract electric cooling using distribution from 'cooling' window	
Elec. for Biomass Conversion	<input type="text" value="0.00"/>	TWh/year	(Transferred from Biomass Conversion TabSheet)	
Elec. for Transportation	<input type="text" value="0.00"/>	TWh/year	(Transferred from Transport TabSheet)	
Sum (excluding electric heating and cooling)	<input type="text" value="20.00"/>	TWh/year		
Electric heating (individual)	<input type="text" value="0.00"/>	TWh/year		
Electricity for heat pumps (individual)	<input type="text" value="0.00"/>	TWh/year		
Electric cooling	<input type="text" value="0.00"/>	TWh/year		
Flexible demand (1 day)	<input type="text" value="0"/>	TWh/year	Max-effect	<input type="text" value="1000"/> MW
Flexible demand (1 week)	<input type="text" value="0"/>	TWh/year	Max-effect	<input type="text" value="1000"/> MW
Flexible demand (4 weeks)	<input type="text" value="0"/>	TWh/year	Max-effect	<input type="text" value="1000"/> MW
Fixed Import/Export	<input type="text" value="0"/>	TWh/year	<input type="button" value="Change distribution"/>	Hour_Tysklandsexport.txt
Total electricity demand*	<input type="text" value="20.00"/>	TWh/year		

# EnergyPLAN

Step 1: Defining heat demands



Inputs to individual houses are basically defined as fuel inputs, since such figures are normally basic data in statistics. When defining the efficiencies of boilers, heat demands are calculated. Electric heating is defined as electricity consumption. The same hourly distributions are used for all heat demands.

**Total Heat Demand (Individual plus District Heating) 17.50**

**Individual Heating:**

TWh/year	Fuel Consumption		Efficiency Thermal	Heat Demand Thermal	Efficiency Electric	Capacity Limit*	Estimated Electricity Production	Solar Thermal			
	Input	Output						Heat Storage*	Share*	Input	Output
Distribution: <input type="button" value="Heat"/> Hour_distr-heat.txt <input type="button" value="Solar"/> Hour_solar1_prod.txt											
Coal boiler:	<input type="text" value="0"/>	0.00	0.7	0.00				<input type="text" value="0"/>	<input type="text" value="1"/>	<input type="text" value="0"/>	0.00
Oil boiler:	<input type="text" value="0"/>	0.00	0.8	0.00				<input type="text" value="0"/>	<input type="text" value="1"/>	<input type="text" value="0"/>	0.00
Ngas boiler:	<input type="text" value="0"/>	0.00	0.9	0.00				<input type="text" value="0"/>	<input type="text" value="1"/>	<input type="text" value="0"/>	0.00
Biomass boiler:	<input type="text" value="0"/>	0.00	0.7	0.00				<input type="text" value="0"/>	<input type="text" value="1"/>	<input type="text" value="0"/>	0.00
H2 micro CHP:		0.00	0.5	<input type="text" value="0"/>	0.3	<input type="text" value="1"/>	0.00	<input type="text" value="0"/>	<input type="text" value="1"/>	<input type="text" value="0"/>	0.00
Ngas micro CHP:		0.00	0.5	<input type="text" value="0"/>	0.3	<input type="text" value="1"/>	0.00	<input type="text" value="0"/>	<input type="text" value="1"/>	<input type="text" value="0"/>	0.00
Biomass micro CHP:		0.00	0.5	<input type="text" value="0"/>	0.3	<input type="text" value="1"/>	0.00	<input type="text" value="0"/>	<input type="text" value="1"/>	<input type="text" value="0"/>	0.00
Heat Pump:				<input type="text" value="0"/>	3	<input type="text" value="1"/>	0.00	<input type="text" value="0"/>	<input type="text" value="1"/>	<input type="text" value="0"/>	0.00
Electric heating:				<input type="text" value="0"/>		<input type="text" value="1"/>	0.00	<input type="text" value="0"/>	<input type="text" value="1"/>	<input type="text" value="0"/>	0.00
<b>Total Individual:</b>		0.00		0.00			0.00				0.00

**District Heating:**

Production:	Group 1:	Group 2:	Group 3:	Total:	Distribution:
	<input type="text" value="0"/>	<input type="text" value="10"/>	<input type="text" value="10"/>		
Network Losses:	<input type="text" value="0.2"/>	<input type="text" value="0.15"/>	<input type="text" value="0.1"/>		
Heat Demand:	0.00	8.50	9.00	17.50	

# EnergyPLAN

## Step 2: Defining energy system (reference system)

	Group 1:	Group 2:	Group 3:	Total:	Unit:
Electricity Production:					
District Heating Production:	0.00	10.00	10.00	20.00	TWh/year

Group 1 represents district heating systems with no CHP  
Group 2 represents district heating systems based on small CHP plants  
Group 3 represents district heating systems based on large CHP extraction plants

**Boilers**

	Group 1:	Group 2:	Group 3:	Unit:
Thermal Capacity		5000	5000	MJ/s
Boiler Efficiency	0.9	0.9	0.9	Percent
Fixed Boiler share		0	0	Percent

**Combined Heat and Power (CHP)**

CHP Condensing Mode Operation\*

	Group 1:	Group 2:	Group 3:	Unit:
Electric Capacity (PP1)			4000	MW-e
Electric Efficiency (PP1)			0.45	Percent

CHP Back Pressure Mode Operation\*

	Group 1:	Group 2:	Group 3:	Unit:
Electric Capacity		1000	1500	MW-e
Thermal Capacity	Auto	1250	1875	MJ/s
Electric Efficiency		0.4	0.4	Percent
Thermal Efficiency		0.5	0.5	Percent

**Industrial CHP**

	Group 1:	Group 2:	Group 3:	Total:	Unit:
CHP Electricity	0	0	0	0.00	TWh/year
CHP Heat Produced	0	0	0	0.00	TWh/year
CHP Heat Demand	0	0	0	0.00	TWh/year
CHP Heat Delivered*	0.00	0.00	0.00	0.00	TWh/year

Distribution: Hour\_cshpel.txt

CHP plants are modelled as a combination of CHP back pressure and condensing plants so the Max CHP3 is the PP1 Capacity, which is:

Capacities and operation efficiencies of CHP units, power stations, boilers and heat pumps are defined as part of the input data. The size of heat storage capacities is also given here

# EnergyPLAN

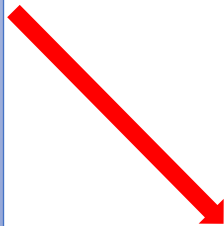
Step 2: Defining energy system (reference system)

The input data set defines input from RES and hydro power. One can choose inputs from up to four different renewable energy sources. By pressing the button, the following specification can be

attached to each RES:

- Wind
- Offshore Wind
- Photo Voltaic
- Wave Power
- River Hydro

Input to the electricity production is identified by the capacity of each RES and by the name of the distribution file



Central Power Plants	Capacity MW-e	Efficiency Percent	Correction Factor: Percent	Annual production: TWh/year	Distributions
PP1 (CHP3 Condensing Mode)*	4000.00			n/a*	
Condensing PP2	<input type="text" value="0"/>	<input type="text" value="0.45"/>		n/a*	
Nuclear	<input type="text" value="0"/>	<input type="text" value="0.33"/>	<input type="text" value="1"/>	0.00	<input type="button" value="Change"/> const.txt
Geothermal	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="1"/>	0.00	<input type="button" value="Change"/> const.txt
Dammed Hydro 'Water supply'				<input type="text" value="0"/>	<input type="button" value="Change"/> Hour_wind_1.txt
Dammed Hydro Power	<input type="text" value="0"/>	<input type="text" value="0.33"/>		0.00 (Estimated)*	

Intermittent Renewable Electricity	Capacity: MW	Stabilisation share	Distribution profile	Estimated Production TWh/year	Correction factor	Estimated Post Correction production	Estimated capacity factor
Wind	<input type="text" value="1000"/>	<input type="text" value="0"/>	<input type="button" value="Change"/> hour_wind_1.txt	2.07	<input type="text" value="0"/>	2.07	0.24
Photo Voltaic	<input type="text" value="500"/>	<input type="text" value="0"/>	<input type="button" value="Change"/> Hour_solar_prod1	0.35	<input type="text" value="0"/>	0.35	0.08
Offshore Wind	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="button" value="Change"/> hour_wind_2.txt	0.00	<input type="text" value="0"/>	0.00	0.00
River Hydro	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="button" value="Change"/> const.txt	0.00	<input type="text" value="0"/>	0.00	0.00
Tidal	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="button" value="Change"/> hour_tidal_power	0.00	<input type="text" value="0"/>	0.00	0.00
Wave Power	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="button" value="Change"/> Hour_wave_200*	0.00	<input type="text" value="0"/>	0.00	0.00
CSP Solar Power	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="button" value="Change"/> Hour_solar_prod1	0.00	<input type="text" value="0"/>	0.00	0.00

**Storage for Dammed Hydro**

Storage  GWh Storage difference:

Pump Back Capacity  MW-e Pump Back Efficiency  Percent

# EnergyPLAN

## Step 3: Defining THE TYPE OF SIMULATION

### Chose Simulation Strategy:

Technical Simulation

Market Economic Simulation

#### Technical Simulation Strategy

- 1 Balancing heat demands
- 2 Balancing both heat and electricity demands
- 3 Balancing both heat and electricity demands (Reducing CHP also when partly needed for grid stabilisation)
- 4 Balancing heat demands using tripple tariff

#### V2G Simulation Strategy

- 1 No limitations
- 2 Limitation: Smart Charge/V2G charge  $\leq$  PowerPlant-cap + import-max - electricity der
- 3 V2G seeks to minimise PP max

#### Individual Heat Pump Simulation

- 1 Individual Heat Pumps and Electric Boilers seek to utilise only Critical Excess Production
- 2 Individual Heat Pumps and Electric Boilers seek to utilise all electricity export

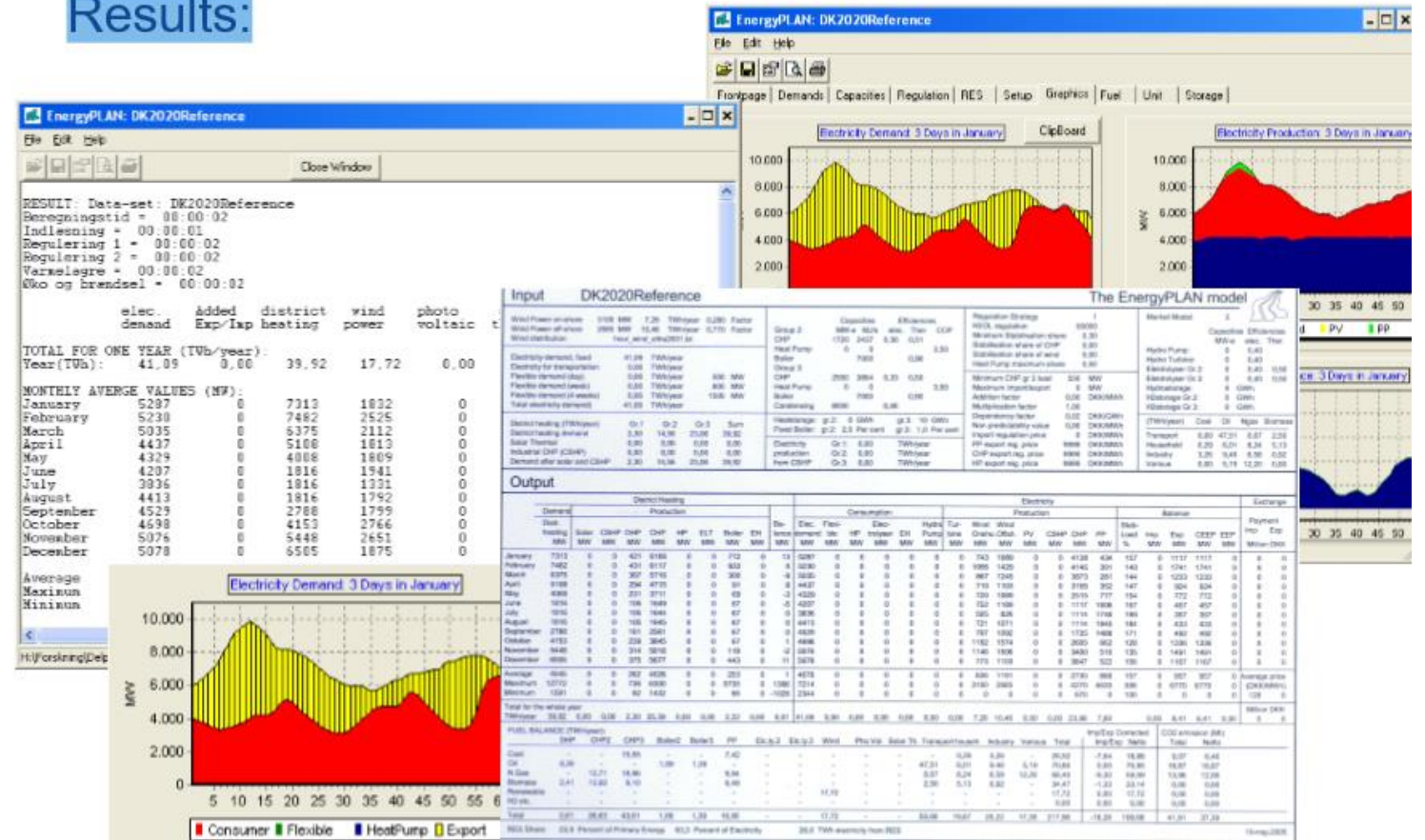
### Technical and Market Simulations

The Market economic simulation strategy is based on a short-term marginal price market model similar to the NordPOOL market design, so it focuses solely on bids to the electricity market while minimizing short-term electricity consumer costs and minimizing short-term district heating costs. As a result, this simulation strategy only uses variable costs and does not optimise based on the long-term costs of different energy supply technologies. Furthermore, it only optimises the supply side of the energy system, and not the demand side (although the user can manually change the demand and analyse the resulting impact of a market economic simulation). While mathematically it is possible using the price elasticity feature in EnergyPLAN to simulate 100% renewable energy scenarios using this current market design, represented by the market economic simulation, this may not accurately represent how future energy supply and demand markets should be designed. Today's markets are primarily designed for dispatchable plants, whereas 100% renewable energy systems will most likely depend on very high levels of non-dispatchable renewable energy. Therefore, using the technical simulation strategy is typically more accurate at simulating energy systems with very large penetrations of intermittent renewable energy, which in combination with the cost data for the technologies, makes it possible for the user to identify least cost solutions over their total lifetime.

# EnergyPLAN

Step 4: RESULTS

## Results:





MASTER IN ENTREPRENEURSHIP  
INNOVATION MANAGEMENT  
IN COLLABORATION WITH **MIT SLOAN**

IN COLLABORATION WITH

**MIT MANAGEMENT**  
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## EnergyPLAN

Next step....

Try yourself...!!!





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**Thank you!**