Enerdata intelligence + consulting

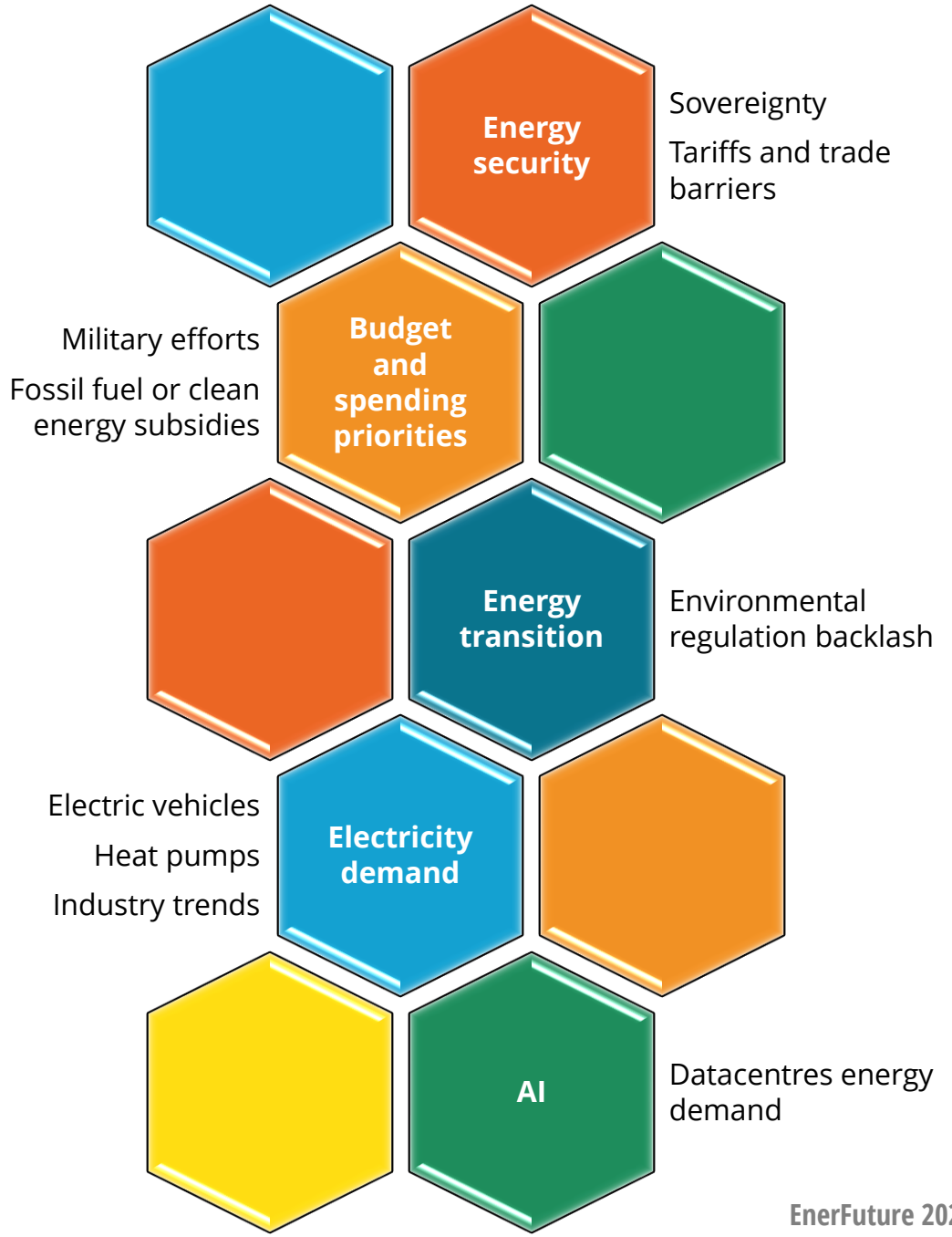
April 2025

The Future of Energy Transition and Independence

Evolution of Drilling, Electrification and Clean Technologies by 2050

Powered by our EnerFuture scenarios derived from the POLES-Enerdata model

A new energy world?



Since 1991, we have proven a renowned expertise in energy-climate scenario modelling services

- **Independent energy research & consulting company since 1991**
- Expert in analysis and **forecasting of global energy & climate issues**
- **In-house** and globally recognized **sectoral databases** and **forecasting models**

Enerdata intelligence + consulting

65+
committed Consultants and Experts

- **Headquartered in the Grenoble (French Alps) research cluster**; a subsidiary in **Singapore**
- **Global reach**: Clients and projects in Europe, Asia, Americas, Middle East, Africa
- **Connected** with **leading public institutions, financial and corporate actors, academia and NGO actors**

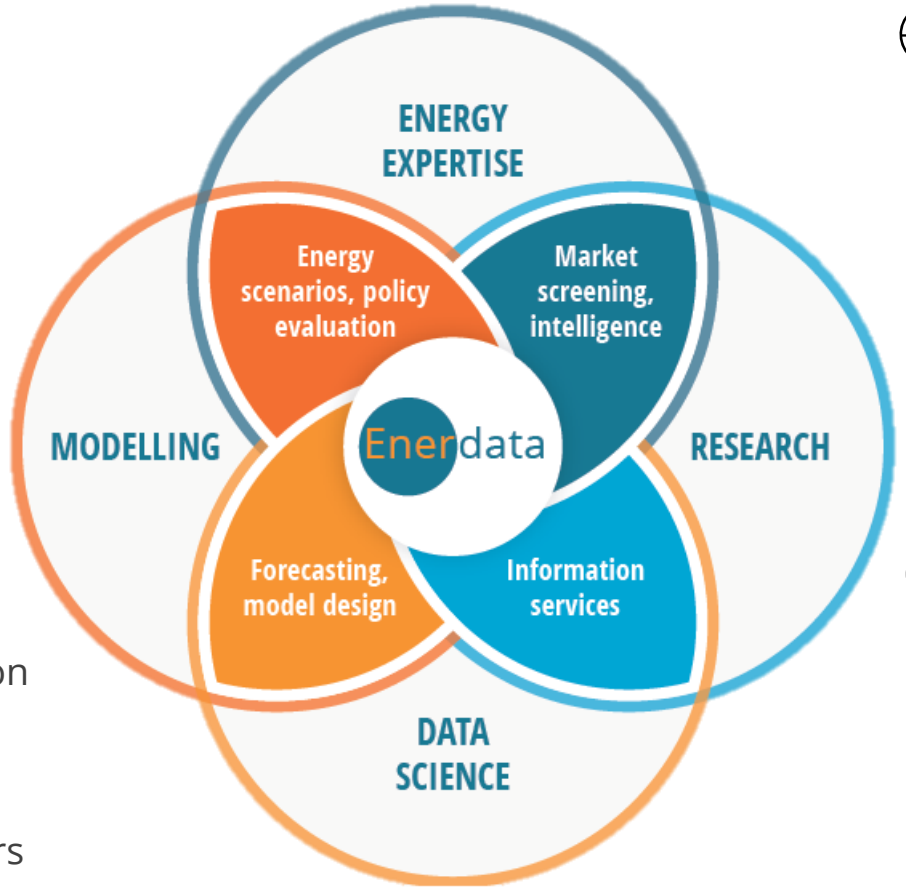
Our services – Combining fields of expertise from research, data science to modelling

Modelling

- Creation of E-C scenarios, climate alignment trajectories
- Identification of alignment pathways by sector and by country

Expert in energy / climate

- Knowledge of market drivers
- Expertise covering all energy transition pillars: mix decarbonisation, energy efficiency, sufficiency, and flexibility (assets and markets)
- Deep coverage: all energies, all sectors and 150+ countries



Market intelligence

- Market Research
- Business intelligence
- Energy market watch
- Tracking of E-C policies worldwide

Data science

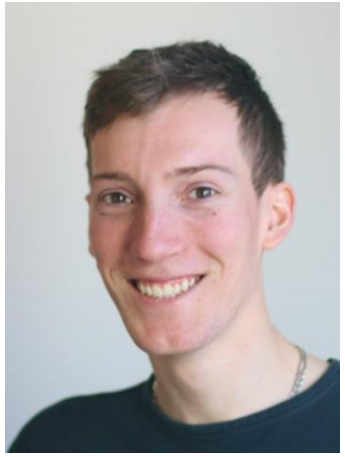
- Gathering, consolidating and analysing energy data
- Market forecasts: supply, demand and prices

Agenda of the webinar

1. Introduction
2. Drilling for fuels… Plugging more electricity…
3. Energy sovereignty
4. Broader picture
5. Takeaways and Q&A session

Speaker's introduction

Jacques DESPRES
Senior Energy Modelling Analyst



Esteban DROUET
Lead EnerFuture modeller

1 Introduction

Methodological approach,
Scenario definition

Enerdata

Scenario construction

Starting from today, we explore different pathways to 2050 relying on varying assumptions but a common framework

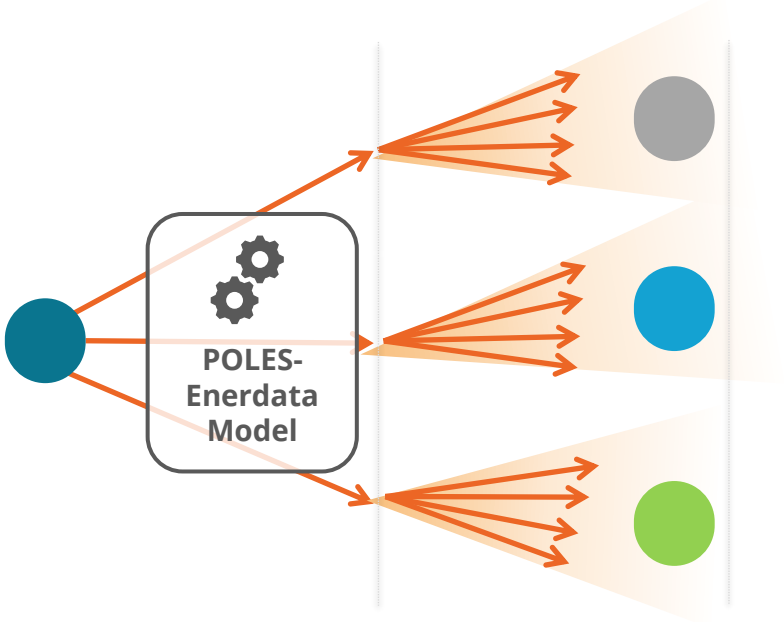
Today

Energy demand
Activity, technological description

Energy supply
Technologies

Energy prices
Several markets

GHG emissions



2050

Demand
Global & regional dynamics, fuel mix, efficiency…

Supply & Prices
Availability,
self-sufficiency, trade, bills…

Sustainability
GHG emissions…

- Use macroeconomic assumptions:
  - population (UN),
  - GDP growth (IMF, CEPII, OECD)
- Apply alternative assumptions for key drivers:
  - climate and energy policies,
  - available technological options, etc.
- Results in contrasted pathways

Scenario definition

Three energy-climate scenarios to explore possible futures of global energy systems

EnerBase

~ +3°C

Continuation of existing policies and trends

Temperature increase around 3°C

EnerBlue

+2-2.5°C

Achievement of new NDCs submitted up to end of 2024

Temperature increase in the 2-2.5°C range

EnerGreen

<+2°C

Ambitious GHG emissions budget in line with the Paris Agreement

Temperature increase well below 2°C

- EnerFuture is relying on the recognised **POLES-Enerdata model**, an energy-economy-environment model of the global energy system,
- 66 countries and regions, with global coverage and annual step until 2050,
- with dedicating modelling of the individual end-use sectors, energy supply, prices and GHG emissions

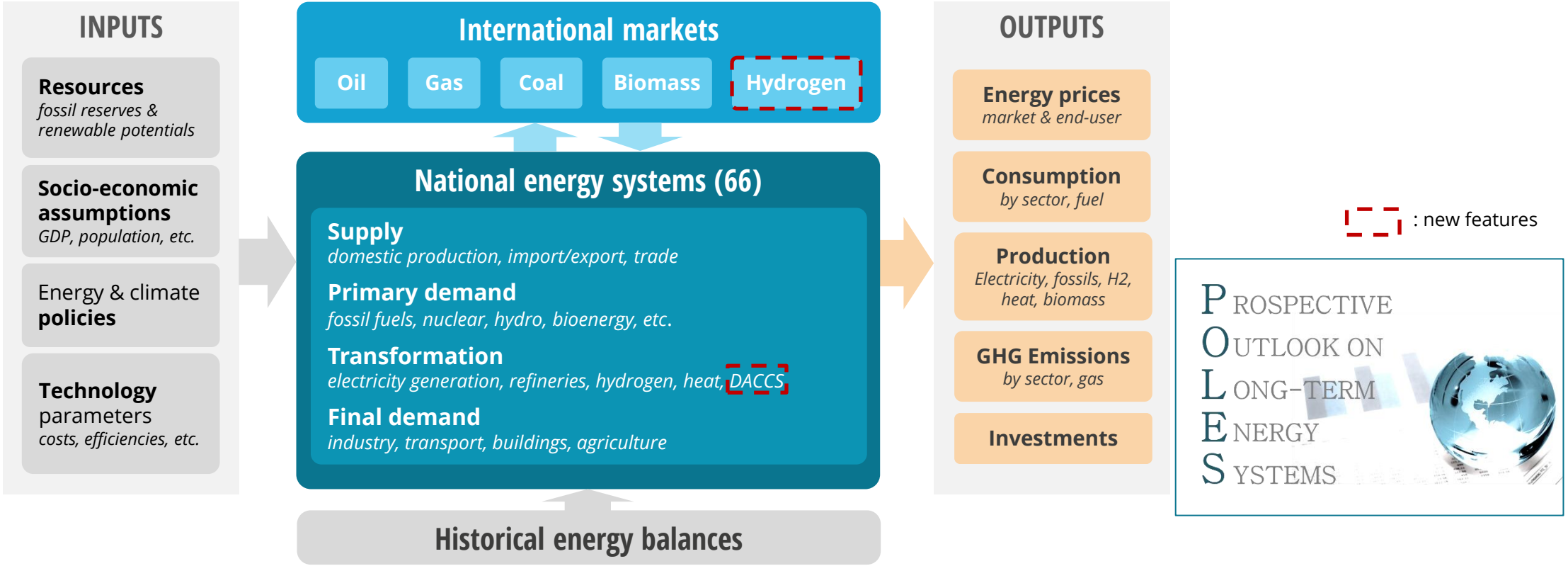
POLES
PROSPECTIVE
OUTLOOK ON
LONG-TERM
ENERGY
SYSTEMS

Note: The POLES model has been initially developed by the GAEL (Grenoble Applied Economics Lab) at the University of Grenoble Alpes

The POLES-Enerdata model

The EnerFuture scenarios are produced using our POLES-Enerdata global energy model

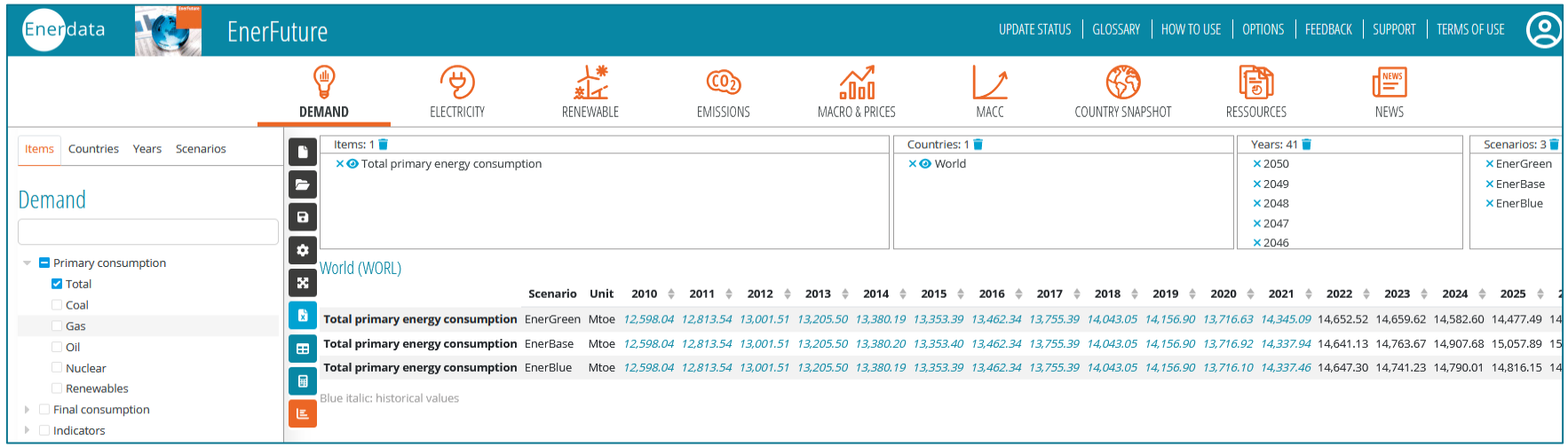
- POLES-Enerdata: Prospective Outlook on Long-term Energy Systems;
- Owned, maintained and operated by Enerdata



What's new in 2025?

- Integration of **up-to-date historical data up to 2023**
- Modelling developments on the POLES-Enerdata model have been performed, including:
  - Addition of hydrogen feedstock consumption
  - Improved modelling of international maritime freight
  - Development of e-fuels in transport
  - Integration of international H2 trade
- New projections:
  - Updated economic projections
  - **Fossil fuel prices**, **supply and demand** (taking into account the Ukrainian crisis)
  - Energy & climate policy developments, including **up-to-date NDCs** (e.g. Brazil)
  - **Electrification updated trends**

What can we say on energy transition and energy independence based on our latest scenarios?



2 Drilling for fuels... Plugging more electricity...

Pathways to energy independence?

Enerdata

2.1 The future of fossil fuel markets

Enerdata

Oil supply: peak production

- **EnerBase** **-10% by 2050**, our baseline scenario, is stabilising its energy-related emissions throughout 2050 – as well as its fossil fuel extractions.

Oil production plateaus centred around **2032**, then decreasing slowly.

- **EnerBlue** **-42% by 2050**, with NDCs implemented, reduces oil production by half
- **EnerGreen** **-65% by 2050**, our well-below 2°C scenario, reduces oil production by two-thirds

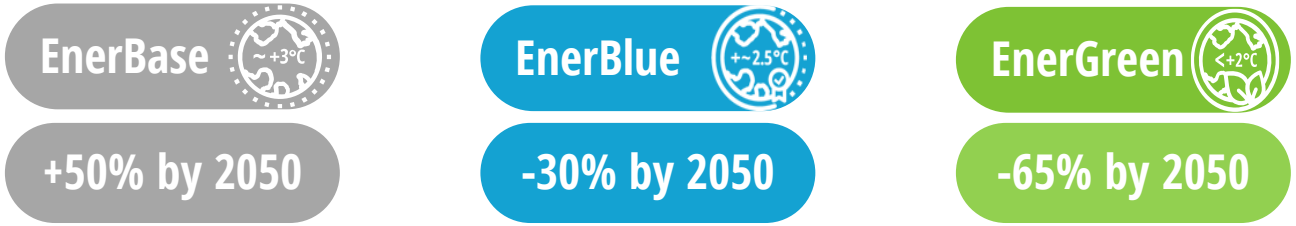
- The **world** would decrease oil production to **88 Mbd** in **EnerBase** and down to **34 Mbd** in **EnerGreen**
- The **USA** would decrease their oil production from a peak of 18 Mbd to **3.8** – **5.6** Mbd in 2050, depending on the scenario

> **The oil supply is decreasing in various proportions – depending on the scenario.**
>
> **Respecting the climate commitments, or even just the current engagements, does not leave space for increasing oil supply**

Source: Enerdata, EnerFuture

Gas supply: at a crossroad

- The future role of gas depends a lot on the pathway chosen



- In the USA, it could **increase by around 20% in EnerBase** or **reduce to close-to-zero in EnerGreen**
- In Europe EEA, it could **reduce by 30%** or **by up to ¾**
- The **Gulf** region represents around 21% of the global gas supply today and reaches 26-27% in 2050 in **EnerBase** and **EnerGreen** and up to 38% in **EnerBlue**
- **EnerBase** sees **Russia** and the **USA** each holding **roughly 13-15%** of gas production – keeping market concentration at current levels – as **China** joins the leading gas producers.

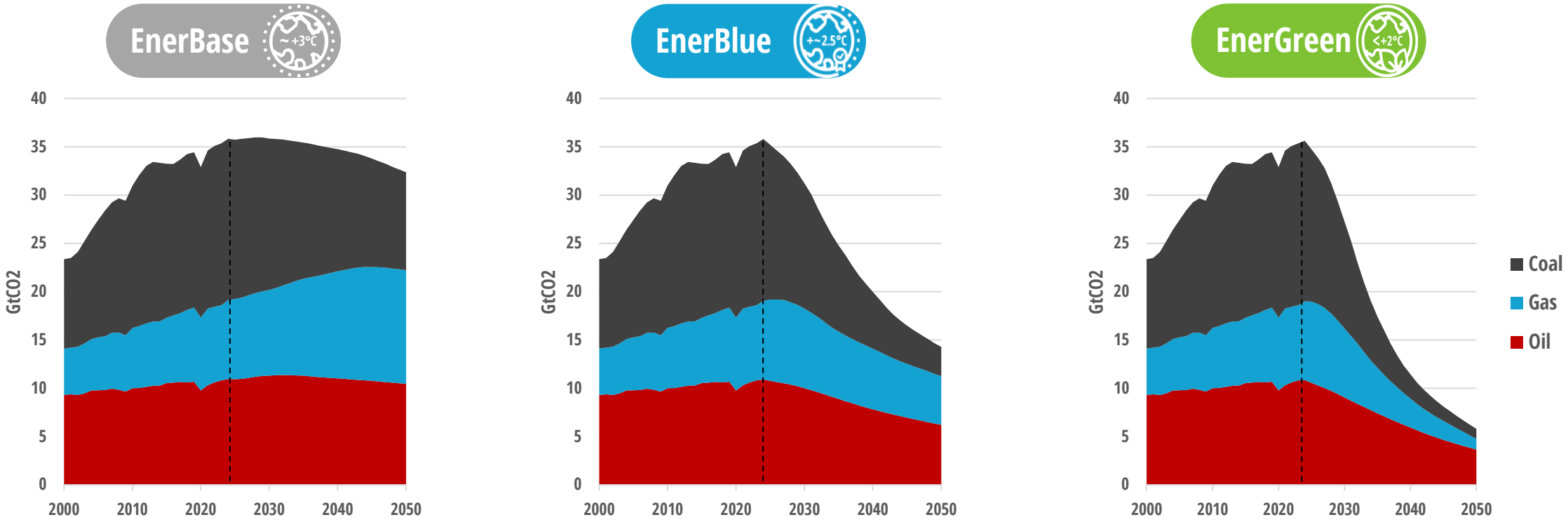
  …Yet, these market shares drop to **a mere 5-9% in EnerGreen**

The gas supply is very uncertain depending on the energy-climate scenario,
- **» with the Gulf region reinforcing its hegemony;**
- **» China potentially emerging as a key actor (EnerBase);**
- **» A smaller and more distributed market in EnerGreen.**

Fossil fuel emissions at a glance

- Oil, gas and coal all contribute to CO_2 emissions, in different proportions:

GLOBAL CO_2 EMISSIONS



Source: Enerdata, EnerFuture

CO_2 emissions, excluding international transport and AFOLU

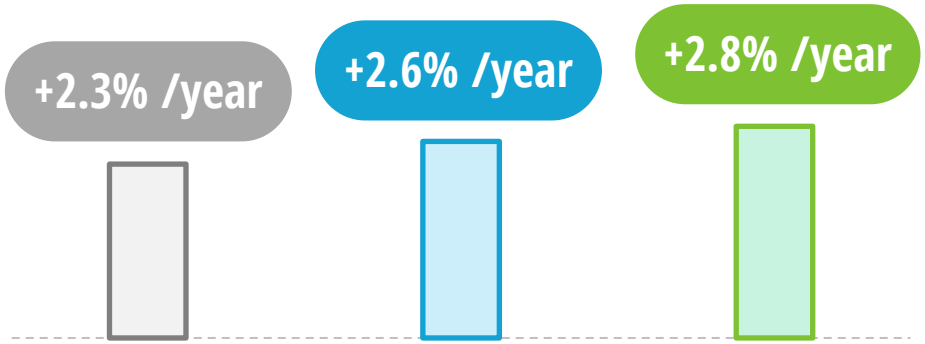
2.2 The pace of electrification

Enerdata

Powering the world?

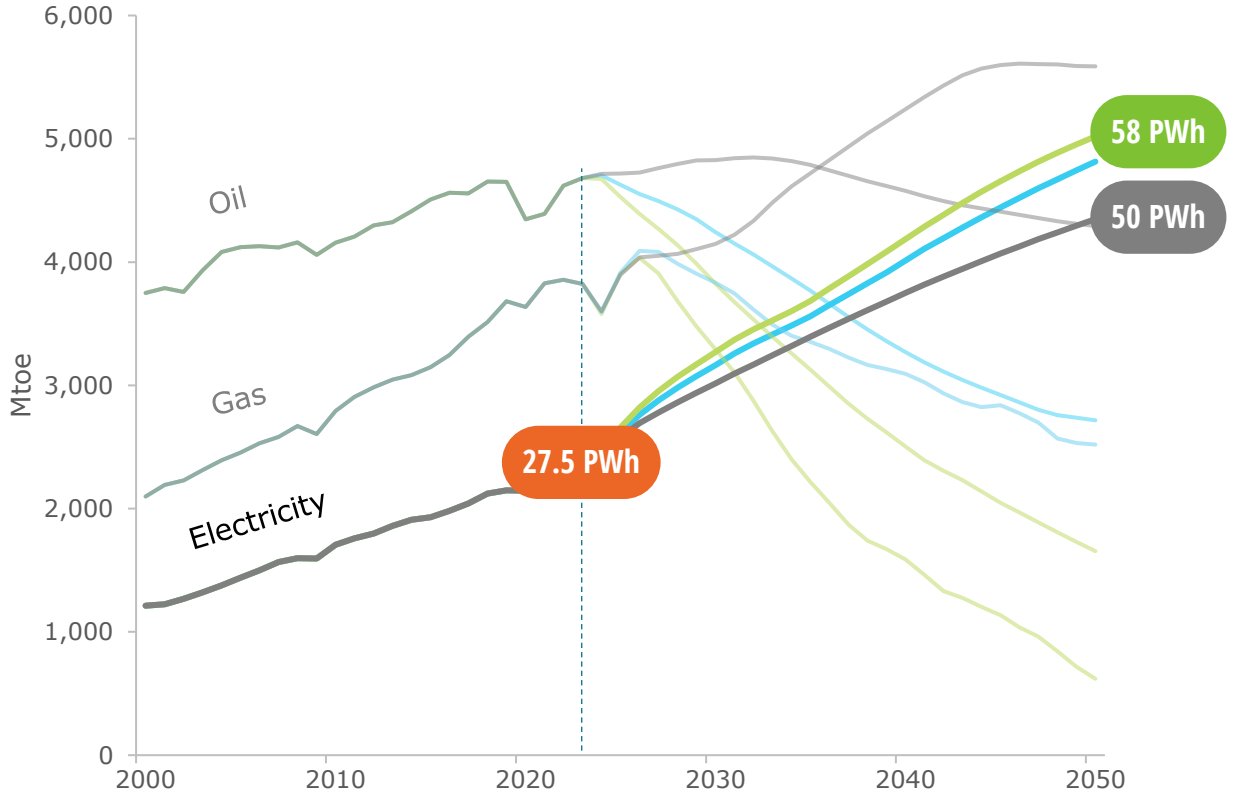
- Historically, all sources of energy have increased steadily
- In our scenarios, electricity supply increases in all scenarios, but faster when accounting for climate ambition:

ELECTRICITY ANNUAL GROWTH RATES



- Electrification allows decarbonisation
- In parallel, efficiency gains tend to restrain total energy demand
- Sector-by-sector trends need to be looked closely

SCENARIOS FOR THE ENERGY MIX



Source: Enerdata, EnerFuture

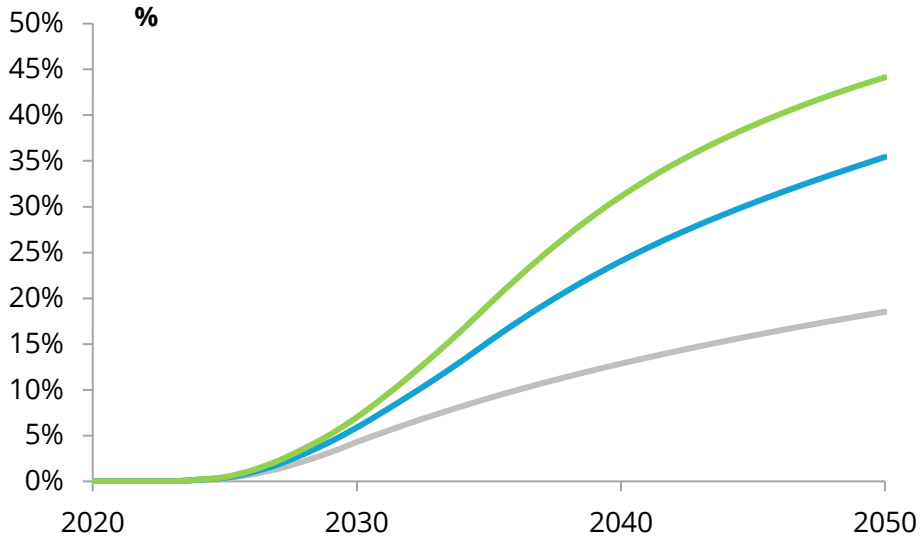
From 3.5 MWh/cap today...
- » to 5.2 MWh/cap
- » and up to 6 MWh/cap in 2050

Residential sector electrification

Heat pumps play a key role to help removing fossil fuels:

- They are approximately **3 times as efficient** as other fuel-based heating systems
- They are even more efficient in **renovated** homes, which develop at different rates depending on the scenario.

SHARE OF HEAT PUMPS IN SPACE HEATING

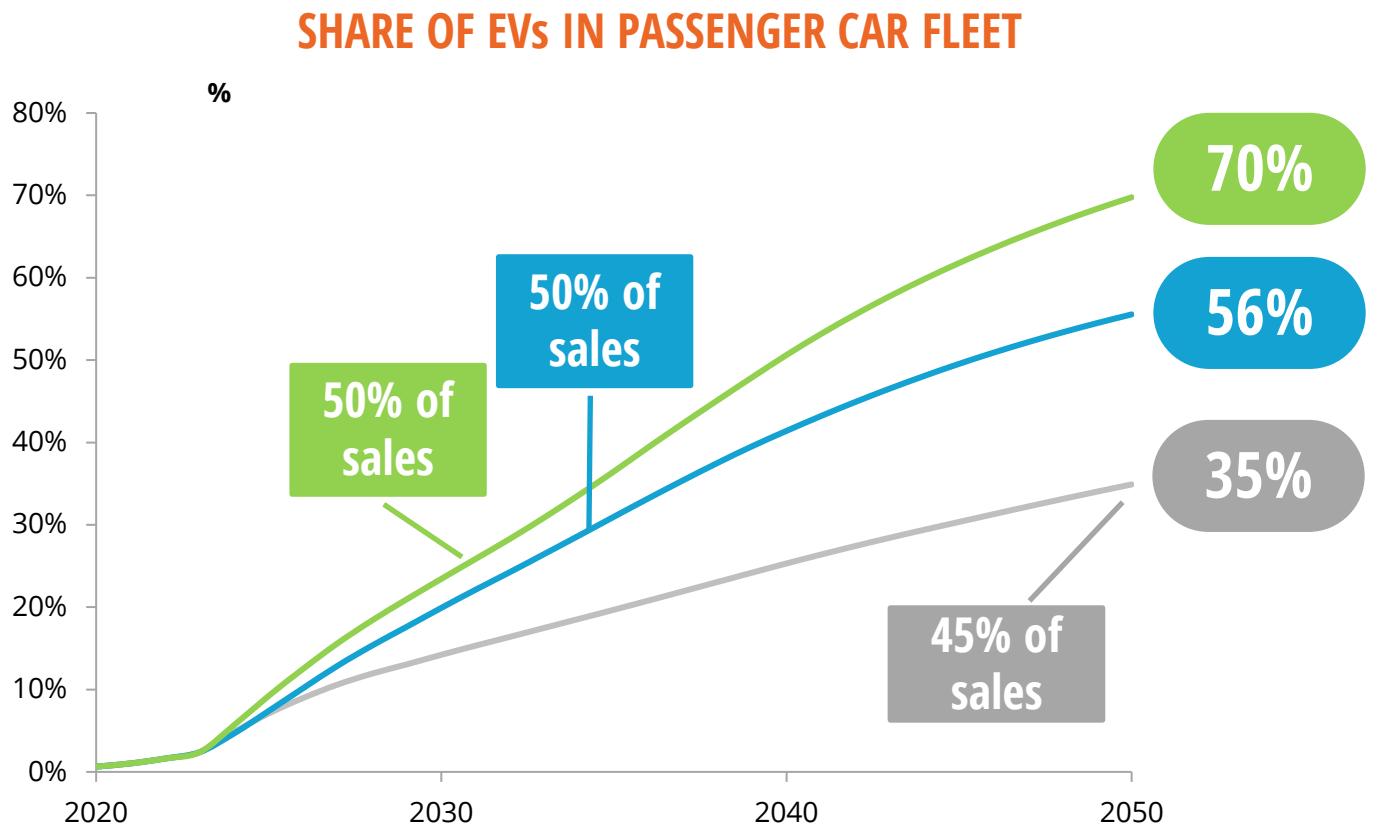


Source: Enerdata, EnerFuture

	RESIDENTIAL HEAT PUMPS STOCK IN 2050	RENOVATION MARKET
44% EnerGreen (<+2°C)	1.3 billion	*5.6 in 2050 compared to 2023
35% EnerBlue (+~2.5°C)	1.1 billion	*3.4 in 2050 compared to 2023
19% EnerBase (~+3°C)	560 millions	*2 in 2050 compared to 2023
	Estimated 4 millions in 2023	(increase of +33-37% dwelling in 2050 vs 2023)

In developing countries and especially in Africa, urgent action to support access to **clean cooking** is required.
Electricity access as well as **Air Conditioning** develops, also driving the global trends of electrification.

Road transport electrification



Source: Enerdata, EnerFuture

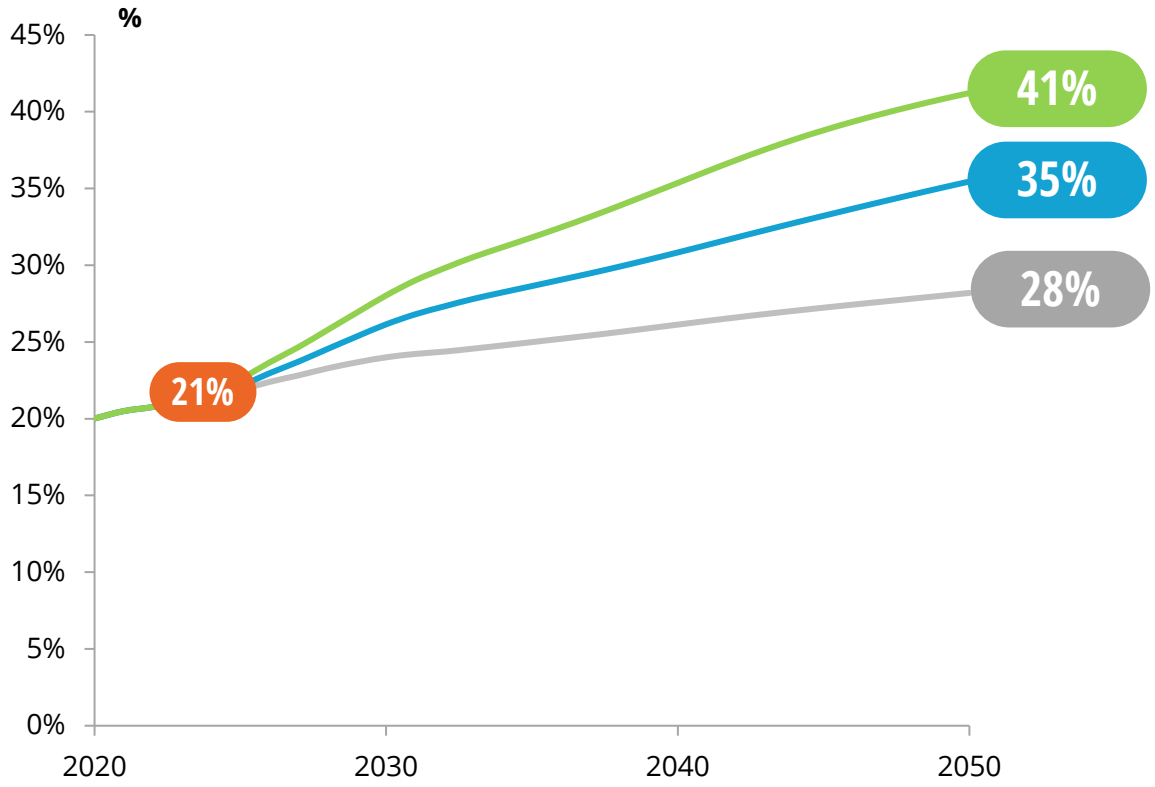
The development of **EVs** is key to decarbonise transports:

- **Electric Vehicles (EVs)** quickly become the major type of passenger cars in **EnerGreen**, where they represent 70% of the total car fleet in 2050.
- EVs are also a strong option for light and short-distance freight transport.
- In **EnerGreen**, priority is given to small EVs and car-sharing to avoid rebound effects, reduce material footprint and environmental impacts of lithium, cobalt and other critical materials.
- Hydrogen fuel cell vehicles are only developed in niche markets within heavy and long-distance freight transport

» **In EnerBase, electric vehicle sales overtake conventional engines by 2045**
» **In EnerGreen, it is already the case by 2030; or 2027 if plug-in hybrids are included**

Industry electrification

SHARE OF ELECTRICITY IN INDUSTRY



Source: Enerdata, EnerFuture

** including non-energy uses*

EFFICIENCY

CIRCULARITY SUFFICIENCY

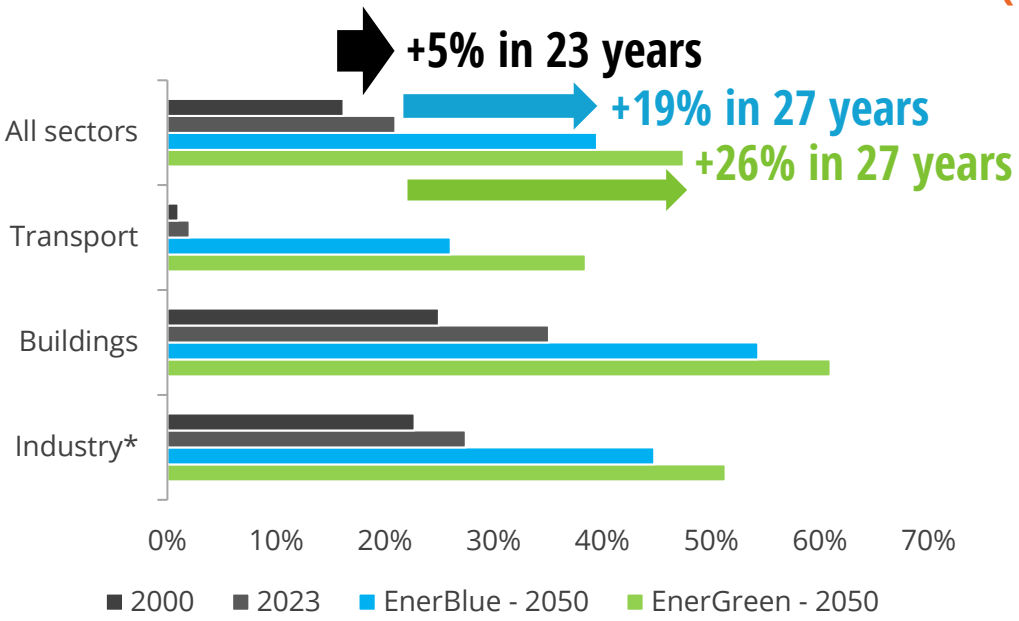
Industry's energy intensity drops by 47% in **EnerGreen** over 2023-2050:

- **Circularity**: higher recycling rates and better reusability of materials and products, with huge gaps and regional disparities in recycling.
- **Sufficiency**: extending lifetime of buildings and appliances, reducing car size, etc., allow to indirectly reduce industrial total demand, by curbing global material demand (steel, cement).
- **Electrification** keeps increasing, and doubles between 2023 and 2050 in **EnerGreen**: **heat pumps** for low temperature heat but also middle temperatures, with **other electric technologies** such as electric arc furnaces to decarbonise high temperature processes.

Electrification

Electrification is a main pillar of energy transition, in all sectors and across countries

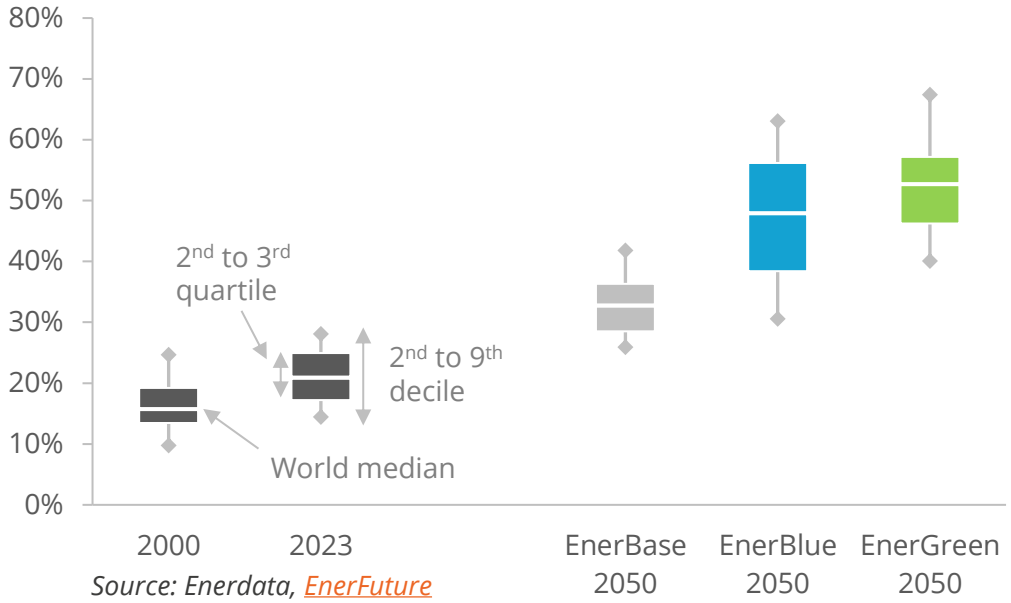
SHARE OF ELECTRICITY IN FINAL DEMAND BY SECTOR (WORLD)



Source: Enerdata, EnerFuture

** excluding non-energy uses*

SHARE OF ELECTRICITY IN FINAL DEMAND: DISPARITIES ACROSS COUNTRIES



Source: Enerdata, EnerFuture

The **share of electricity in final demand increases across all sectors and regions in all three scenarios**, reaching respectively **40% in EnerBlue** and **47% in EnerGreen** in 2050 globally, from the current 21%.

- The growth of electricity is most spectacular in **transports**, with an increase by **24-36%** from 2023 to 2050.
- **EnerGreen** converts **¼ of buildings and industry** fossil fuels to electricity between 2023 and 2050.
- Even the slowest countries electrify their energy system to **at least 40% in EnerGreen**

3 Energy sovereignty

Costs and bills

Enerdata

Shift towards renewables

Primary energy supply is composed of 15% renewables in 2023

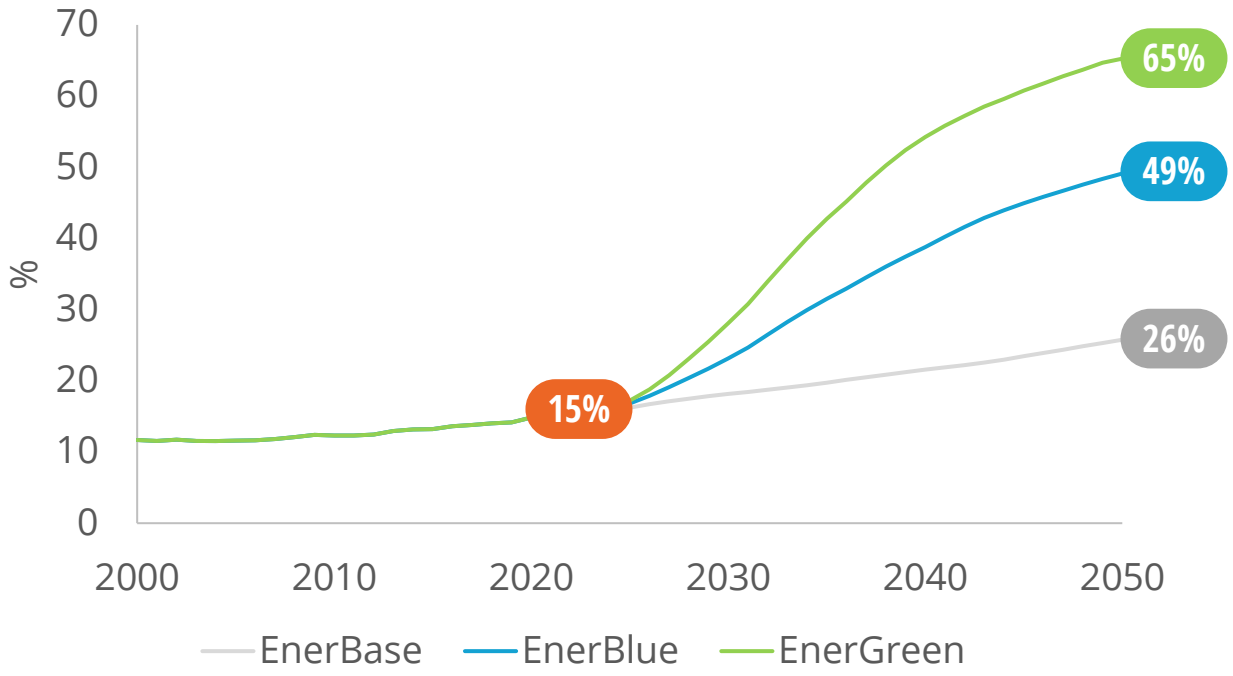
- 50% as reached as soon as 2038 in **EnerGreen**, 2/3 in 2050, with a tripling of renewable capacities by 2031
- 50% reached towards 2050 in **EnerBlue**
- These major transitions do not materialize in **EnerBase**

Focus on biomass:

- Historically the main renewable energy used: 10% of 2023's primary energy supply

- No major change in **EnerBase**
- Diversification of uses in **EnerBlue** and **EnerGreen**:
  - BECCS in power and industry sectors captures up to 0.5 $GtCO_2$ (**EnerGreen**)
  - Biofuels in transports, notably for international bunkers:
    25-29% in aviation fuel mix
  - Biomethane will help to reduce remaining natural gas uses:
    Up to **59%** of the grid gas is covered in **EnerGreen**
- But its overall use remains at a sustainable level:
  - 17% of the primary mix in **EnerBlue**, up to 23% in **EnerGreen**

SHARE OF RENEWABLES IN PRIMARY ENERGY



Source: Enerdata, EnerFuture

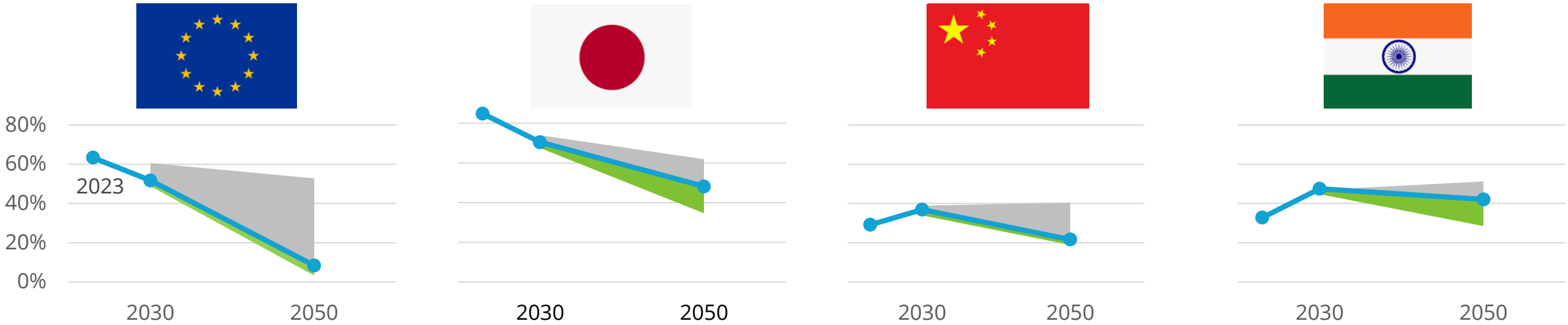
Renewable electricity is converted to primary energy with a factor of 1

Total bioenergy exploited does not exceed 110 EJ by 2050, well below sustainable potentials

Foreign dependency on fossil fuels

- Fossil fuel exporters concentrate 15% of global population… supplying the other 85%

ENERGY IMPORTED as a % of total primary energy demand



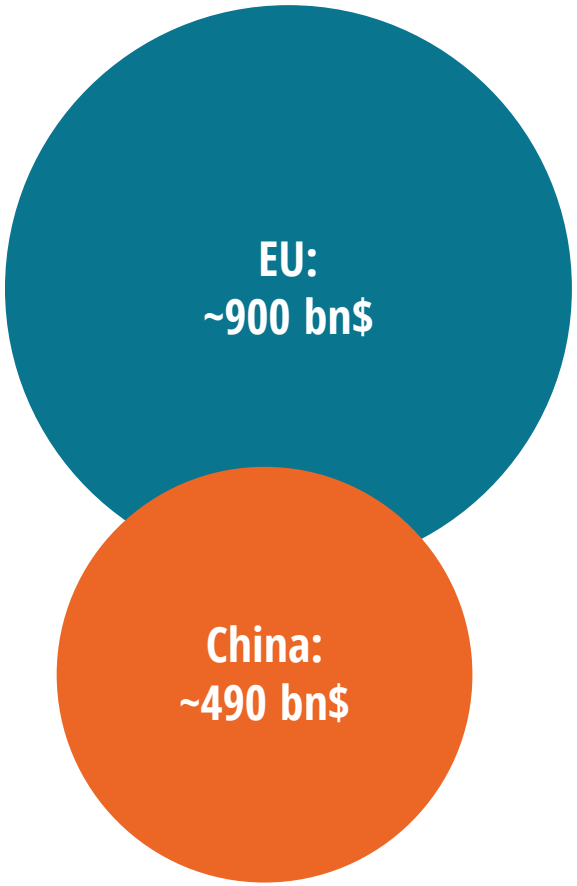
Source: Enerdata, EnerFuture

- Huge revolution for the European energy mix, immensely improving the energy independence
- Very large potential for improving the energy balance of Japan
- China and India have potential to mitigate their energy imports
  through efficiency, electricity and renewables
  despite a strong energy demand growth (+73% final energy demand in India)

Decarbonising to increase energy sovereignty!

Fossil fuel trading: a huge energy budget

Imports in 2023



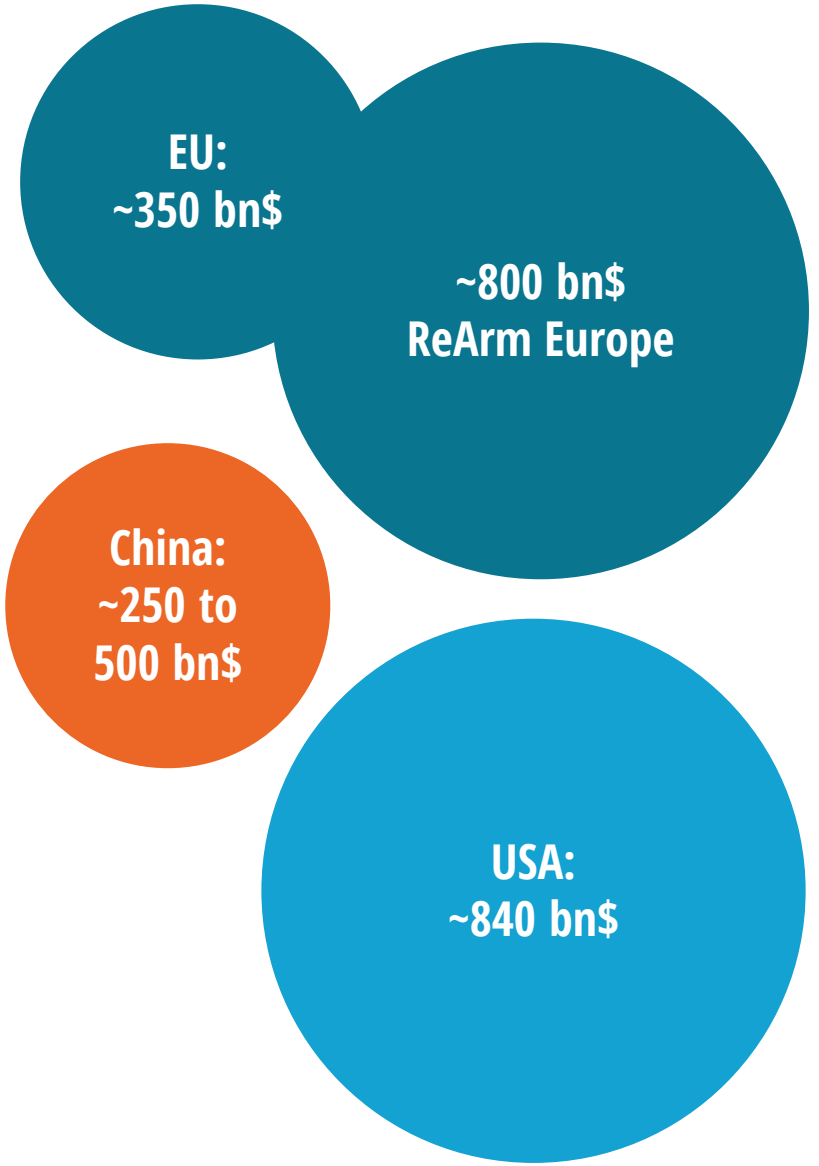
Exports in 2023

~45 bn$

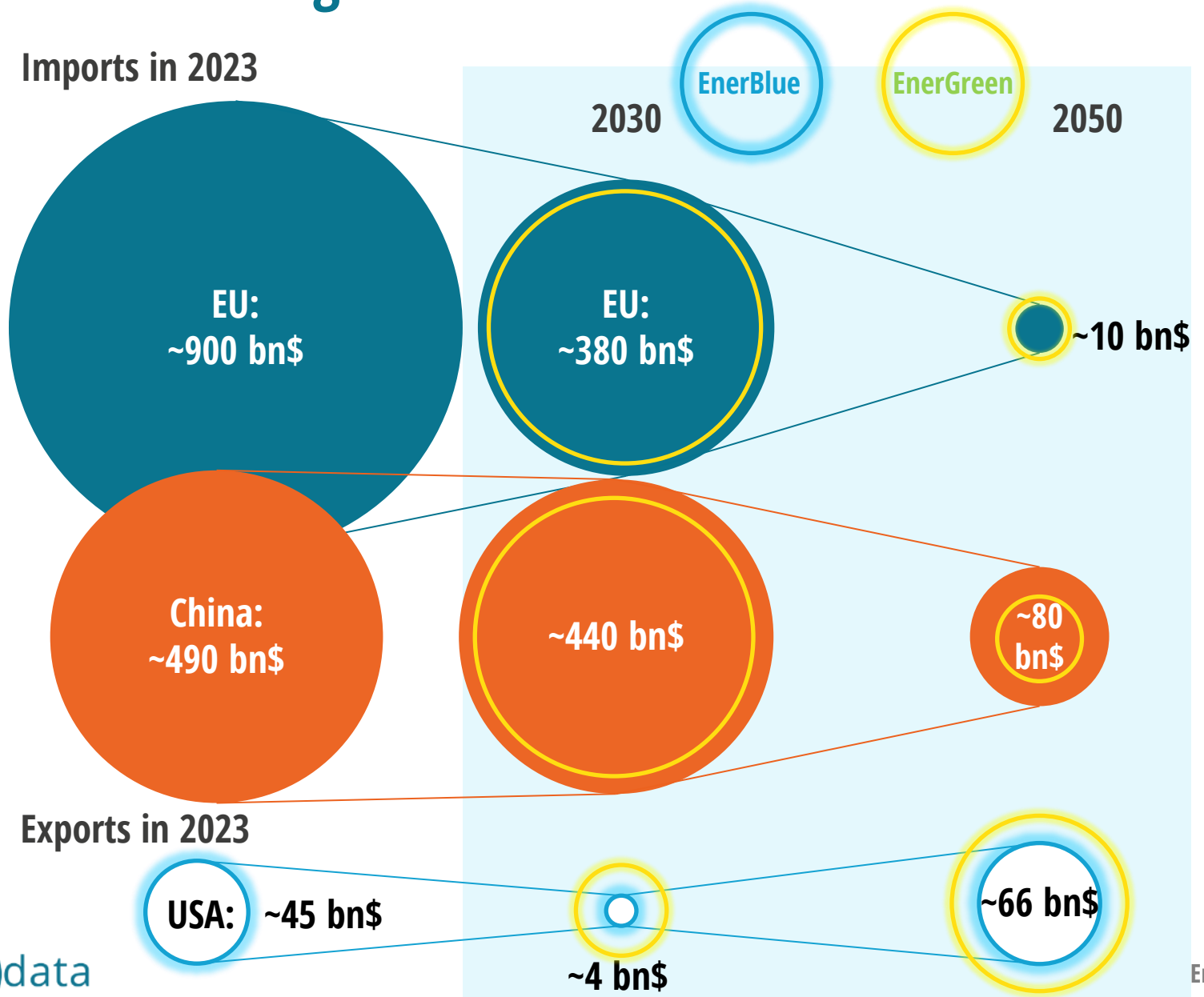
Big energy importers:
Fossil fuel imports **exceed** military budgets
Reducing fossil fuel dependency = **sovereignty**

Energy exporters:
Reducing their national consumption = savings
+on the long-term, need to find other sources of incomes, e.g. services, energy transition industries…

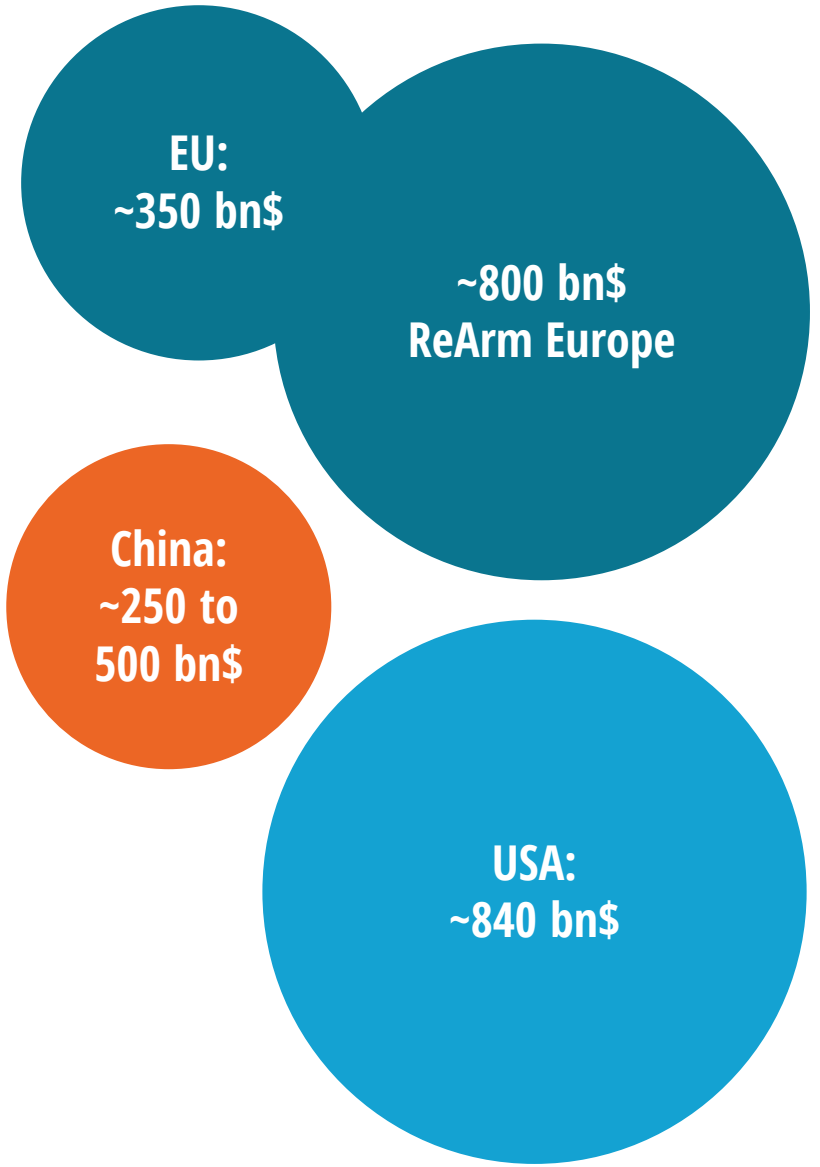
Current military budgets



Fossil fuel trading in the future



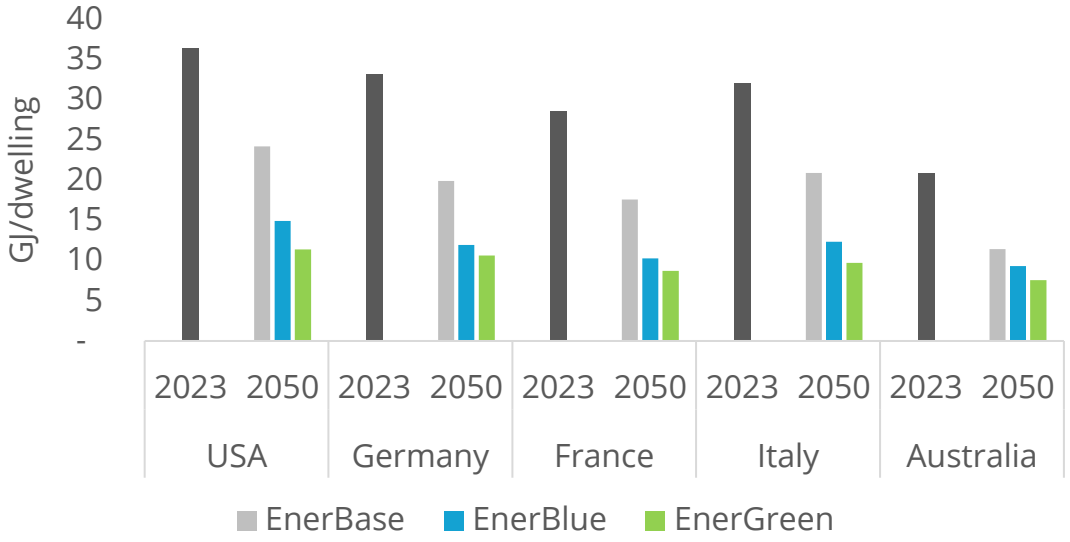
Current military budgets



Household energy bills: less energy demand, lower bills

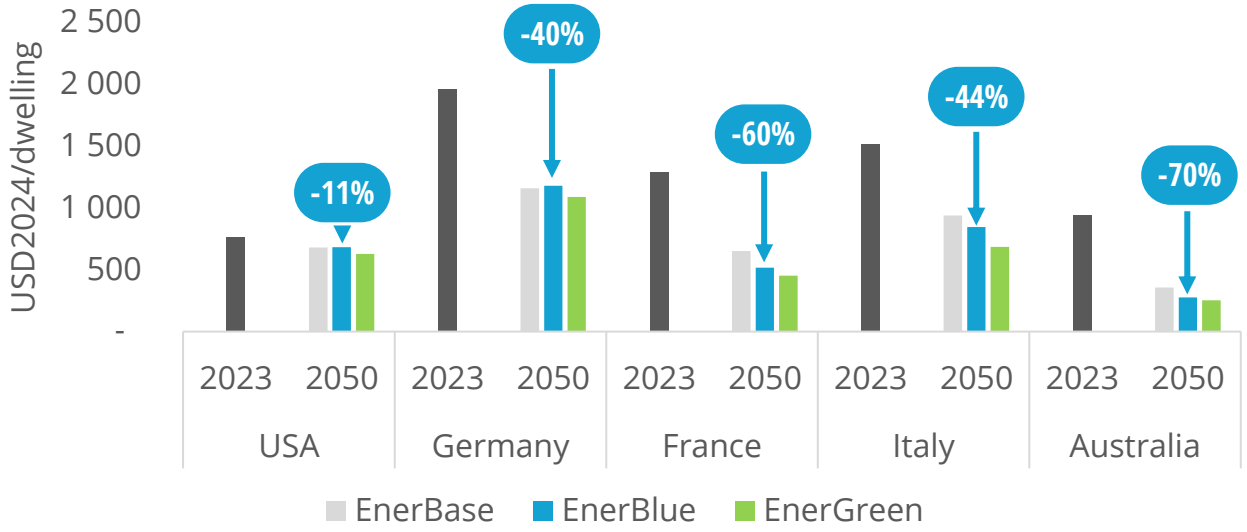
- Significant reduction of the heating bill
- Heat pump CAPEX extra cost is more than offset by a much higher efficiency
- Sufficiency measures impact significantly the bill in **EnerGreen**: approx. 10% reduction in the EU, i.e. about 100$

HOUSEHOLD HEATING ENERGY DEMAND



Source: Enerdata, EnerFuture

HOUSEHOLD HEATING ENERGY BUDGET



Source: Enerdata, EnerFuture

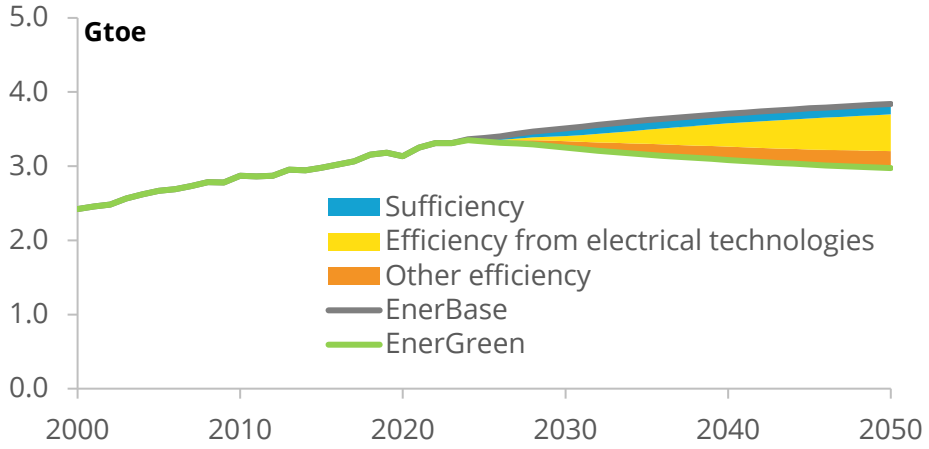
Includes equipment and operating costs

Towards a more affordable world

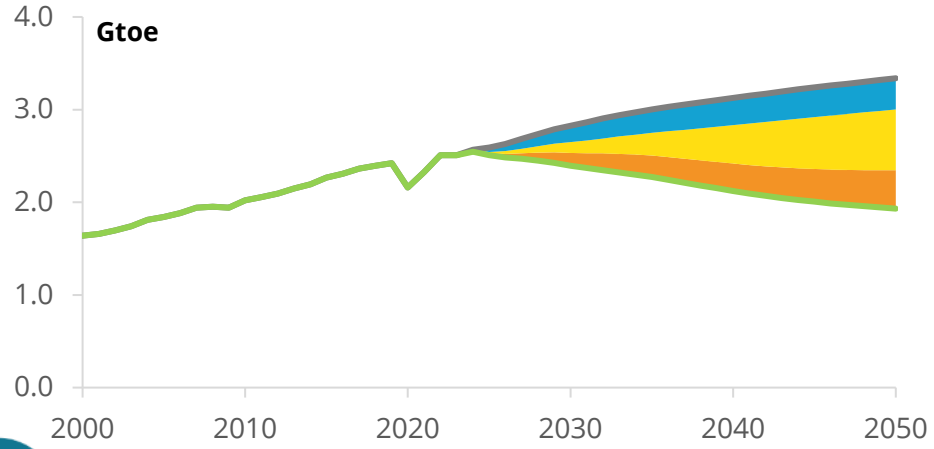
Sufficiency and efficiency

Both technological improvements and societal changes play a significant role to limit energy consumption

ENERGY CONSUMPTION IN BUILDINGS



ENERGY CONSUMPTION IN TRANSPORT



Sufficiency policies could allow to reduce the energy demand in buildings and transport by **up to 9%** through behavioural, organisational & cultural changes:

- Better control of **temperature in buildings** for heating and cooling, limiting appliances (number and size)
- **14% reduction of passenger car traffic** in EnerGreen vs. EnerBase
  - **Modal shift** (active mobility, public transport) – important regional differences
  - **Distances travelled decrease** in developed countries thanks to **spatial planning and lifestyle changes** (15 min model city, teleworking, carpooling, sustainable leisure travels, etc)
- Other policies could also indirectly impact **industry production**… while also reducing pressure on **other environmental issues** (metal production, resources, critical minerals, etc.)

Energy efficiency could help reducing the final energy consumption in buildings and transport by **up to 23%**

- Heat pumps & EVs reduce by a factor of 3 the final energy demand
- Buildings insulation, improvements of engines, appliances & equipment, optimisation of supply chains

Source: Enerdata, EnerFuture

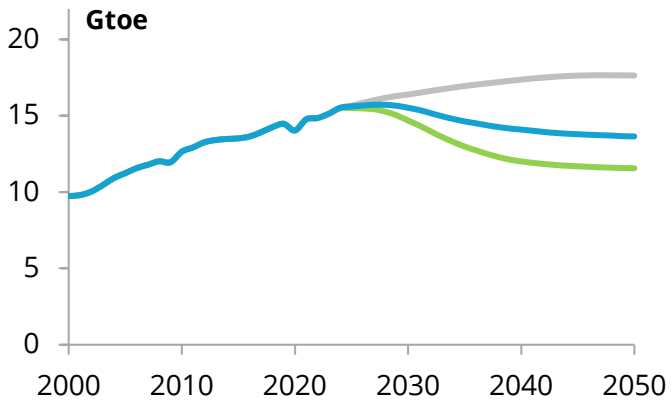
4 Broader picture

Enerdata

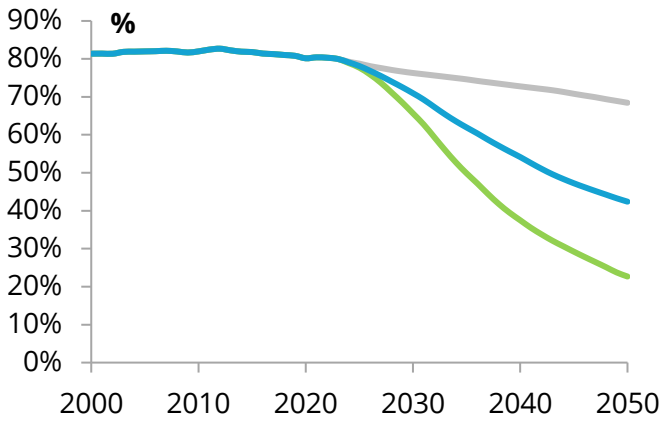
Global key indicators

Main results from our 3 scenarios at a glance

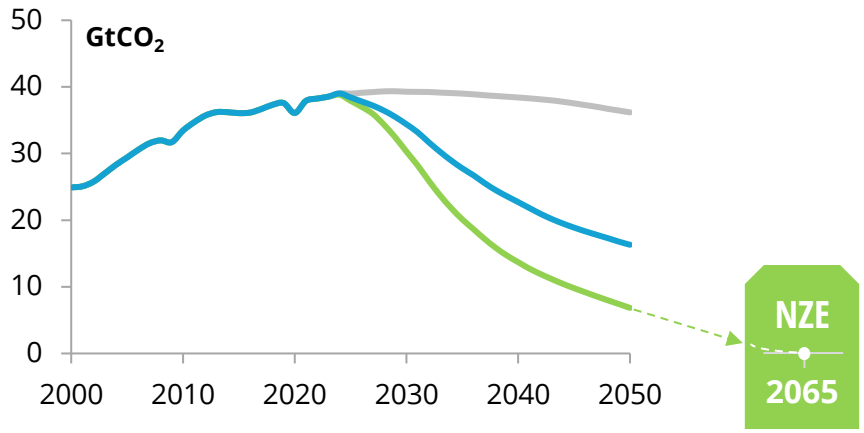
PRIMARY ENERGY CONSUMPTION



SHARE OF FOSSIL IN ENERGY MIX



CO_2 EMISSIONS



Source: Enerdata, EnerFuture

Average evolution (%/y)	2011-2023	2023-2050		
		EnerBase	EnerBlue	EnerGreen
Carbon intensity CO_2 emissions released to produce one unit of gross domestic product (GDP)	-2.1%	-2.8%	-5.6%	-8.6%
Energy intensity of GDP (final) Energy consumption necessary to produce one unit of gross domestic product (GDP)	-1.5%	-1.8%	-2.5%	-3.1%
Carbon factor CO_2 emissions released for an average unit of energy consumption	-0.4%	-0.8%	-2.8%	-5.3%

Source: Enerdata, EnerFuture

Global primary energy mix

How quick do we shift away from fossil fuels depending on our global climate ambition?

EnerBase

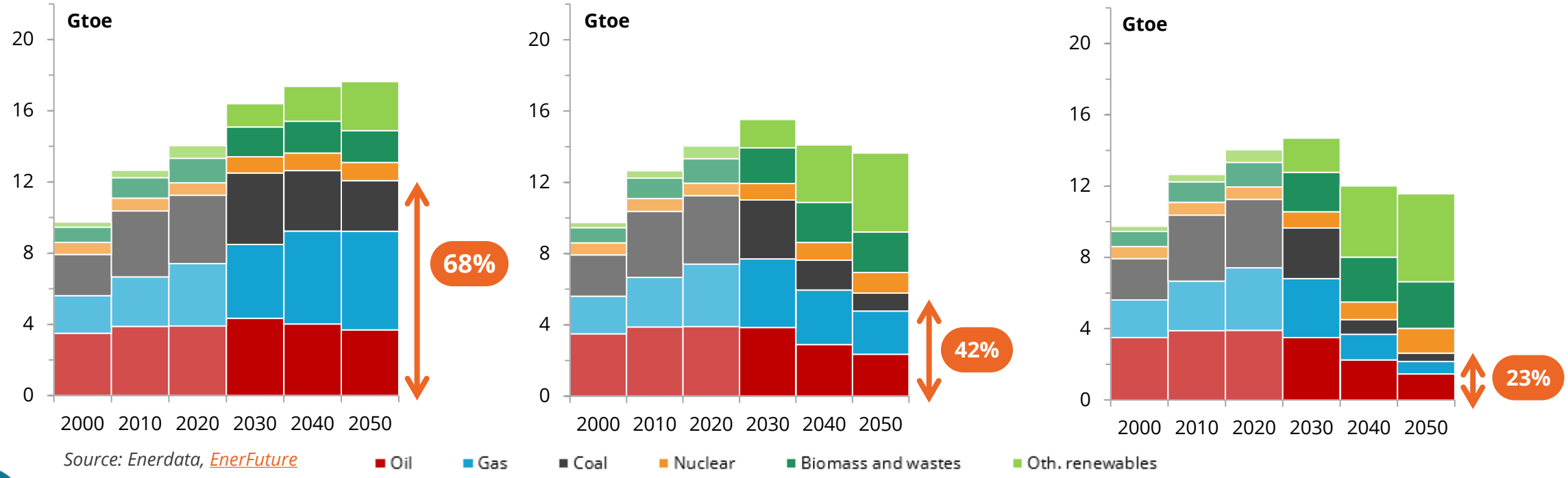
In a **BAU** scenario, fossil fuels keep growing and account for 12 Gtoe or 68% by 2050

EnerBlue

Announced policies and objectives allow to quickly curb fossil fuel consumption, limiting it to 6 Gtoe or 42% by 2050

EnerGreen

To obtain a trajectory compatible with **below 2°C**, fossil fuels should rapidly decrease to 3 Gtoe or 23% by 2050

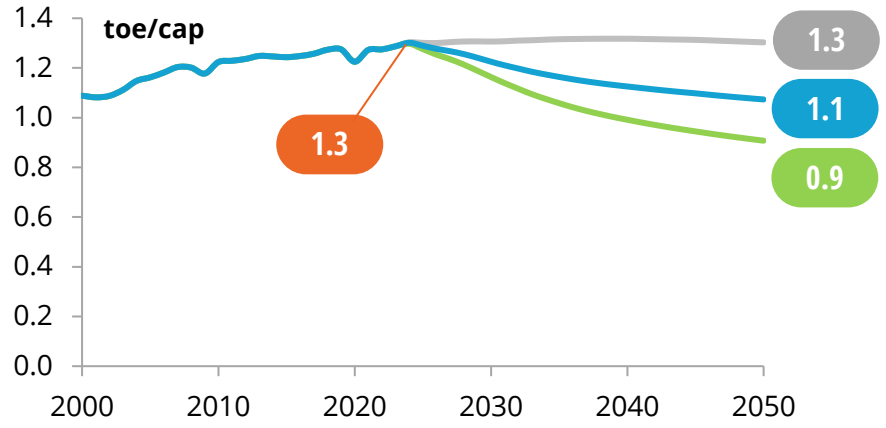


Source: Enerdata, EnerFuture

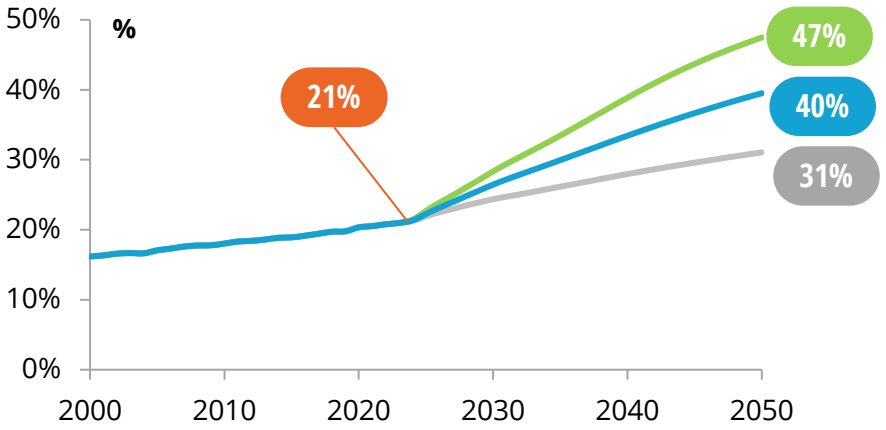
Global final energy consumption

How should we transform the way we consume energy to reach our climate commitments?

FINAL ENERGY PER CAPITA



SHARE OF ELECTRICITY IN FINAL ENERGY



Source: Enerdata, EnerFuture

Reducing energy needs is a necessary component of decarbonisation

- **Energy efficiency** is certainly a key lever across all end-uses
- **Sufficiency and behavioural changes** are also key to reduce energy consumption, especially in advanced economies
- Combined, these two effects allow to decrease final energy per capita in 2050 by 17% in **EnerBlue** and 30% in **EnerGreen**

Electricity emerges as the main fuel in final consumption

- **Electricity develops in most final end-uses**, and notably:
  - Buildings heating (e.g. heat pumps)
  - Passenger & light freight transport (electric vehicles)
  - Low temperature processes in industry (heat pumps)
  - High temperature industrial processes (e.g. electric arc furnaces)
- In a BAU trajectory, electrification keeps progressing to 31% by 2050. Its rise is much accelerated in **EnerBlue** (**40%**) and even more in **EnerGreen** (**47%**).

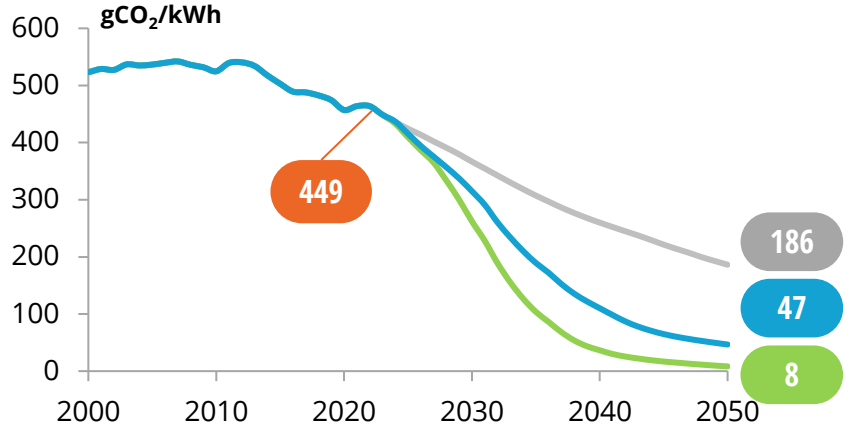
Global electricity generation mix

Decarbonising the electricity systems is required for a successful reduction of our emissions

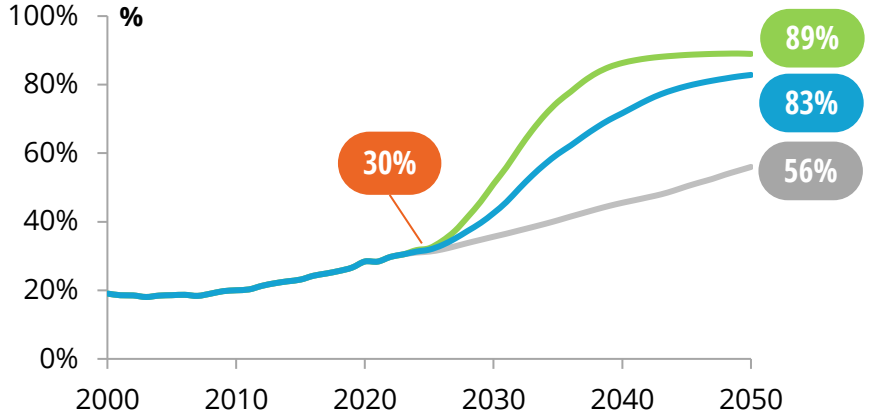
Electricity generation needs to be quickly decarbonised to reach ambitious climate targets.

- In **EnerBase**, despite the absence of strong climate policies, we observe a **continued development of renewables** to produce electricity, helping the average electricity emission factor to decline by almost 60% from 2023 to 2050.
- In **EnerBlue**, the additional ambition from NDC objectives and national policies lead to a **stronger deployment of renewable technologies**, and hence to lower emissions per kWh: -90% over 2023-2050.
- To achieve a below 2°C scenario in **EnerGreen**, the **push towards renewables needs to be even deeper**, especially in the medium term. This leads specific emissions to drop by 98% by 2050.

CO_2 INTENSITY OF ELECTRICITY GENERATION



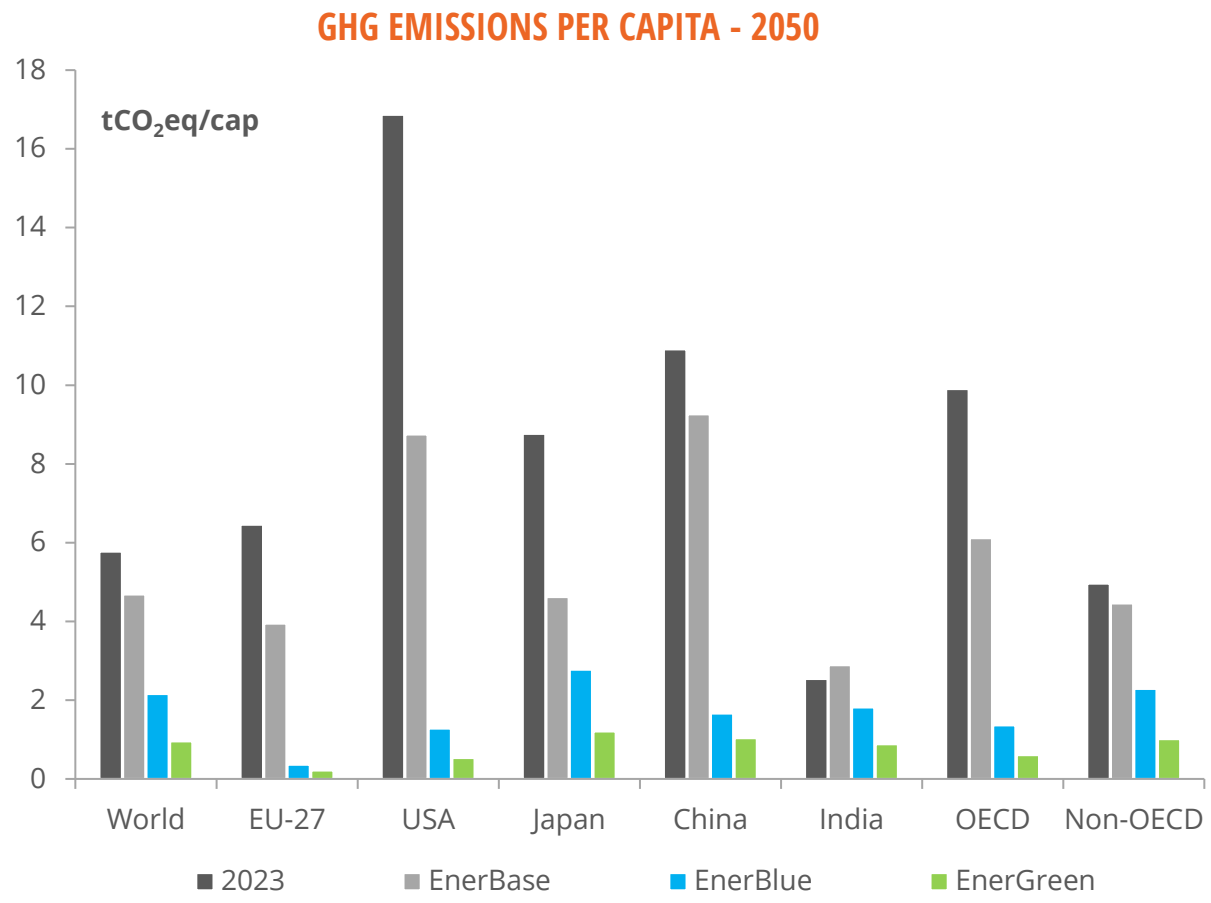
SHARE OF RENEWABLES IN ELECTRICITY GENERATION



Source: Enerdata, EnerFuture

Global emissions per capita

To what extent does the global picture hide regional discrepancies?



Source: Enerdata, EnerFuture

Large historical discrepancies in emissions per capita reflect different **development levels** and **share of fossil** in the primary mix:

- Advanced economies are typically higher than developing countries
- Countries heavily relying on coal are also higher (e.g. USA, China)

The continuation of historical trends in **EnerBase** does not allow for a change in this picture, with marginal evolution of these differences by 2050

The **mitigation actions** undertaken in **EnerBlue**, and even more so in **EnerGreen**, lead to **a completely different picture in 2050**:

- OECD countries, and particularly the EU and the USA, see their emissions per capita decrease to low levels by 2050 (1.36 tCO_{2eq}/cap in **EnerBlue**)
- Non-OECD countries also decrease their emissions per capita, but less rapidly so, reaching about 2.28 tCO_{2eq}/cap in 2050 in **EnerBlue**

What could a « well below 2°C » world look like in 2050?

EnerGreen 2050 snapshot

EFFICIENCY & SUFFICIENCY

-15% Final energy demand vs. 2023

- **12%** Efficiency gains
- **3%** Sufficiency gains

ELECTRIFICATION

x2.3 Electricity share vs 2023

- **70%** Electric cars in the fleet
- **44%** Heat pumps in space heating

CLEAN ENERGY SUPPLY

÷5 Fossil fuel consumption vs 2023

- **95%** CO_2-free electricity
- **76%** H_2 from electrolysis

5 Takeaways and Q&A

Wrapping up the analysis

- Energy transition and Energy sovereignty go hand-in-hand for most regions:
  - Approx. 70% of countries see a decreased trade risk with lower oil, gas, and coal needs
- This is only partly replaced by new dependencies for minerals and equipment in electricity and transportation systems, for approx. 82% of countries
  - China, Australia… a new energy-related trading map
- The system becomes much more renewable overall, with potential for dependency mitigation
  - Technological improvements
  - Sufficiency
  - Recycling

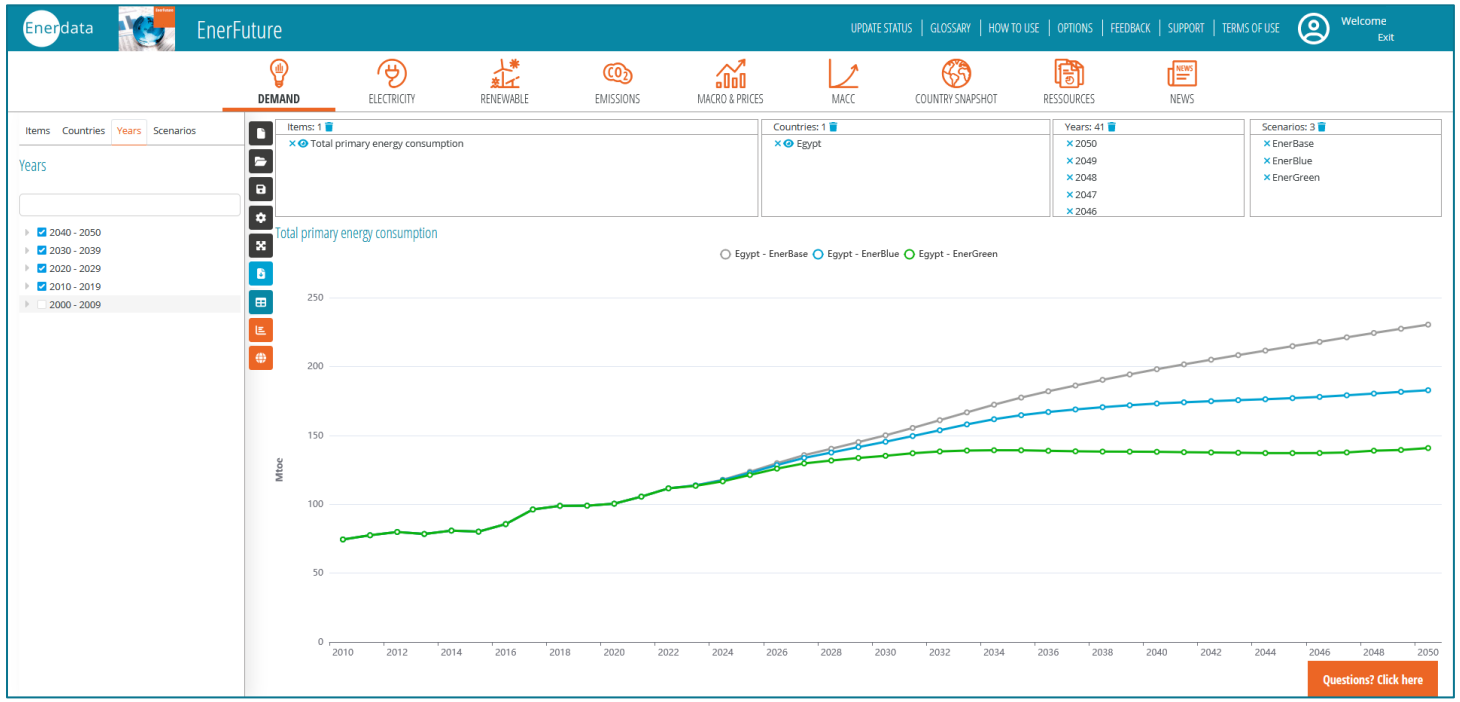
Source: Cheng, J., Tong, D., Zhao, H. et al. Trade risks to energy security in net-zero emissions energy scenarios. Nat. Clim. Chang. (2025). https://doi.org/10.1038/s41558-025-02305-1

Enerdata

EnerFuture interface

Benefit from instantaneous access to POLES-Enerdata model outputs

- **Annual projections to 2050 for 55 countries/aggregates**
  - 3 Enerdata scenarios: **EnerBase**, **EnerBlue**, **EnerGreen**
  - Demand, prices and emissions forecasts for all energies at sector level
  - Power generation forecasts by fuel (both capacities and production)



- Insightful indicators and country-level dashboards
- Intuitive online interface for visualisation, table & graph generation and data queries
- Yearly update to include latest historical statistics and developments in the energy sector
- Option: Marginal Abatement Cost Curves for CO_2 by sector and industrial branches
- Option: **deep dive on energy demand** with end-use level results and indicators

Wrap-up

EnerFuture scenarios in a few key points

EnerBase

CLIMATES OBJECTIVES

- Climate change mitigation efforts limited to existing trends
- NDCs objectives not reached
- *~3°C temperature increase*

KEY OUTCOMES

- Demand continues to grow: +17% over 2023-2050.
- Fossil fuels keep growing and still account for 68% of primary mix in 2050.
- RES power production multiplies by 3.4 over 2023-2050, and represents 56% of the mix in 2050.
- CO_2 emissions peak between 2030 and 2035, before decreasing to 45 $GtCO_2$ in 2050.

EnerBlue

CLIMATES OBJECTIVES

- Climate ambition in line with newest NDC targets (as of 2024)
- Progressive policy enforcement
- *Between 2 and 2.5°C temperature increase*

KEY OUTCOMES

- Demand decreases by 10% over 2023-2050 (+6% in non-OECD).
- Energy mix transformation: less fossil (42% in 2050), RES share 49% by 2050.
- Final energy intensity of GDP drops by 50% over 2023-2050.
- CO_2 emissions halve to around 16 $GtCO_2$ by 2050, thanks to energy sufficiency, efficiency and development of renewables.

EnerGreen

CLIMATES OBJECTIVES

- Strong global efforts towards climate change mitigation
- Ambitious GHG emissions budgets
- *< 2°C temperature increase*

KEY OUTCOMES

- Global demand decreases by 23% between 2023 and 2050.
- Fossil fuels represent around 23% of the energy mix in 2050, with a share of coal that decline by 89% over 2023-2050.
- RES and nuclear represent 98% of power generation in 2050.
- CO_2 emissions reach around 7 $GtCO_2$ in 2050 and net zero in 2065; with very strong reduction efforts in non-OECD.

HELPING YOU SHAPE THE ENERGY TRANSITION

About Enerdata:

Enerdata is an independent research company that specialises in the analysis and forecasting of energy and climate issues. We do this at a variety of different geographic and business / sector levels.

Leveraging our globally recognised databases, business intelligence processes, and prospective models, we assist our clients – which include companies, investors, and public authorities around the world – in designing their policies, strategies, and business plans.

Enerdata

EnerFuture 2025

Global Energy Scenarios Through 2050

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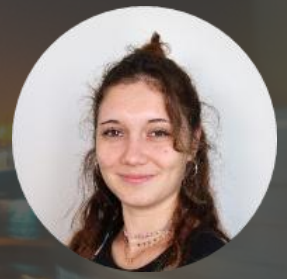

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