Enerdata intelligence + consulting

October 2023

Global Energy Scenarios Through 2050

with focus on Asia-Pacific region

An In-Depth Look at the Future of Energy

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

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Enerdata

1 Approach

Methodology and scenario definition

Enerdata

Scenario definition

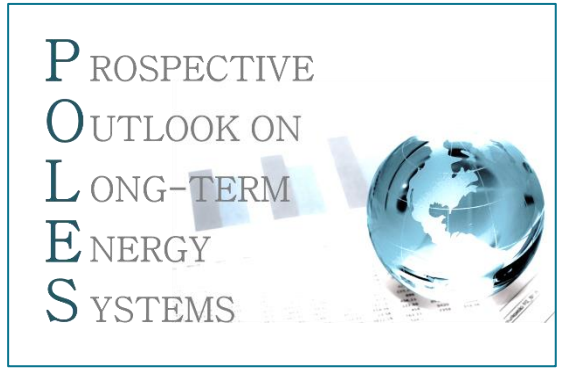
Three energy-climate scenarios to explore possible futures of global energy systems

- Enerdata has prepared **three contrasted energy-climate scenarios** up to 2050 to explore **possible pathways for the global energy sector**

EnerBase	EnerBlue	EnerGreen
Continuation of existing policies and trends	**Achievement of new NDCs submitted up to end of 2022**	**Ambitious GHG emissions budget in line with the Paris Agreement**
Temperature increase above 3°C	*Temperature increase around 2.5°C*	*Temperature increase well below 2°C*

- EnerFuture is relying on the recognised **POLES-Enerdata model:**
  - energy-economy-environment model
  - global coverage, with 66 countries and regions
  - dedicating modelling of: final demand sectors, energy supply, prices and GHG emissions
  - time horizon: 2050

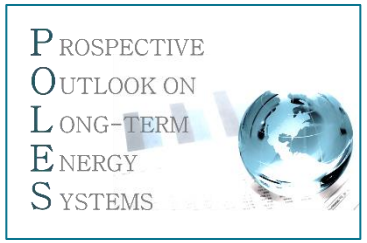
Note: The POLES model has been initially developed by IEPE (Institute for Economics and Energy Policy), now GAEL lab (Grenoble Applied Economics Lab)

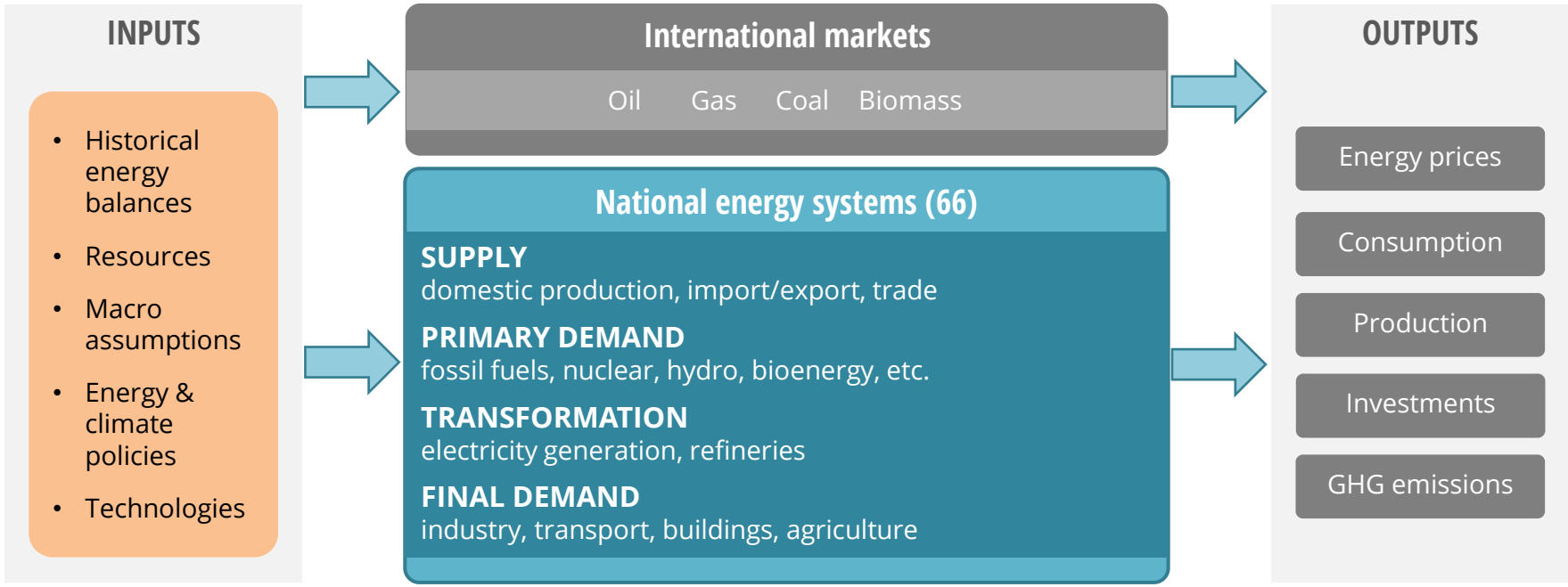


The POLES-Enerdata model

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

- POLES-Enerdata is the version of the POLES (Prospective Outlook on Long-term Energy Systems) model **owned, maintained and operated by Enerdata**
- POLES is a **recursive simulation** model, with **partial equilibrium**
- The model is running, and scenarios are prepared, for **66 countries and regions** with **global coverage** and **annual step until 2050**

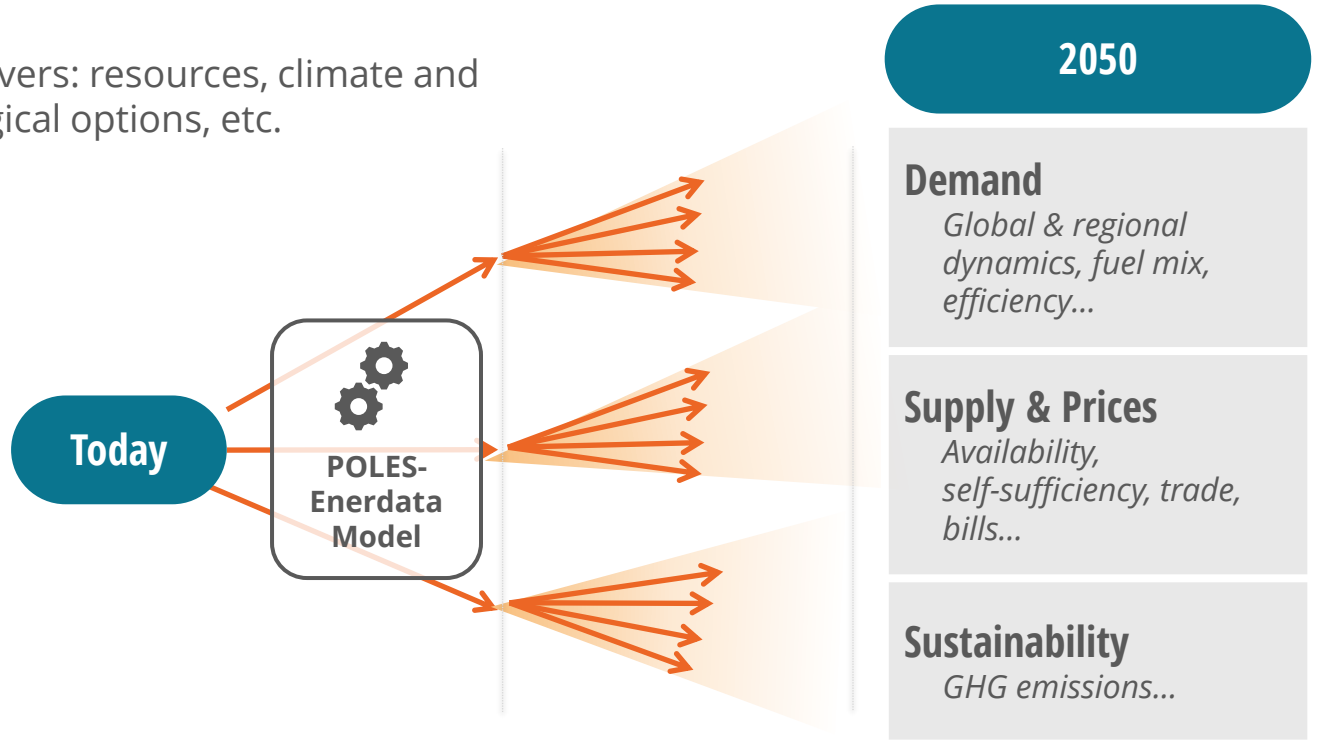




Scenario construction

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

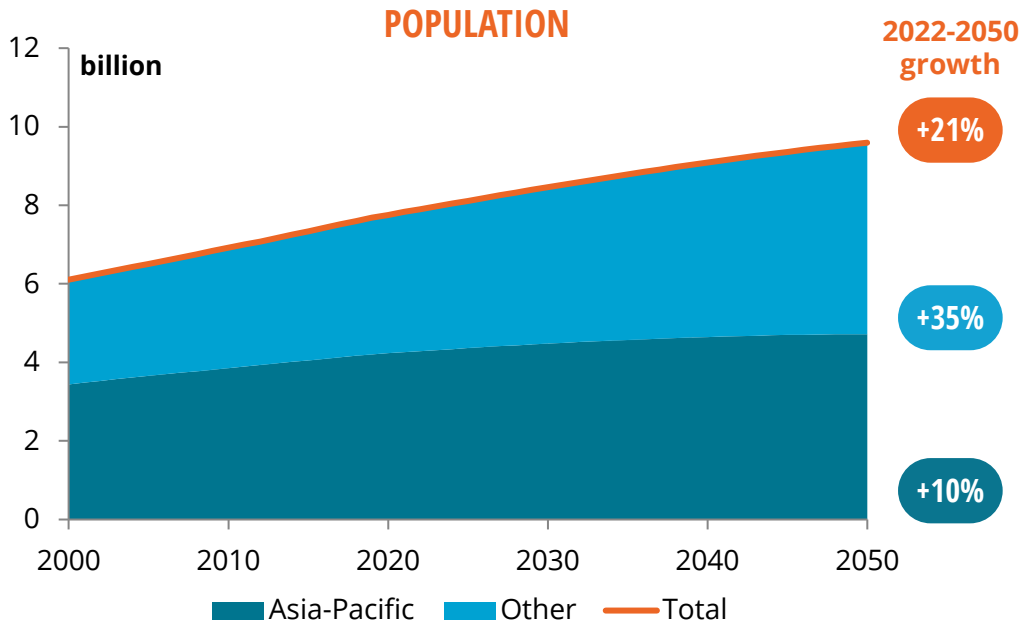
- Alternative assumptions for key drivers: resources, climate and energy policies, available technological options, etc.
- With identical macroeconomic context: population, GDP growth
- Allowing to explore different pathways for energy markets



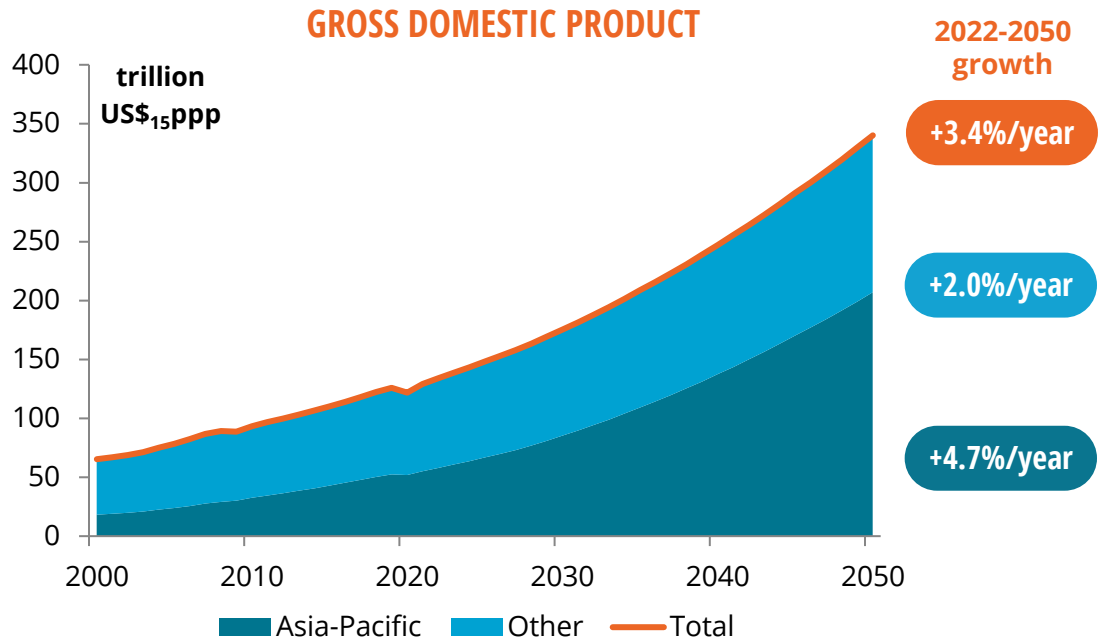
Socio-economic framework

Our assumptions in terms of macro-economic drivers

- The three EnerFuture scenarios rely on **a common initial macro-economic framework**
- **Population** is assumed to grow by **21% over 2022-2050**, with most of the growth in non-OECD countries
- **GDP** is assumed to grow at an average **3.4%/year**, mostly driven by emerging and developing countries, notably in **Asia-Pacific with almost 5%/year** in average.



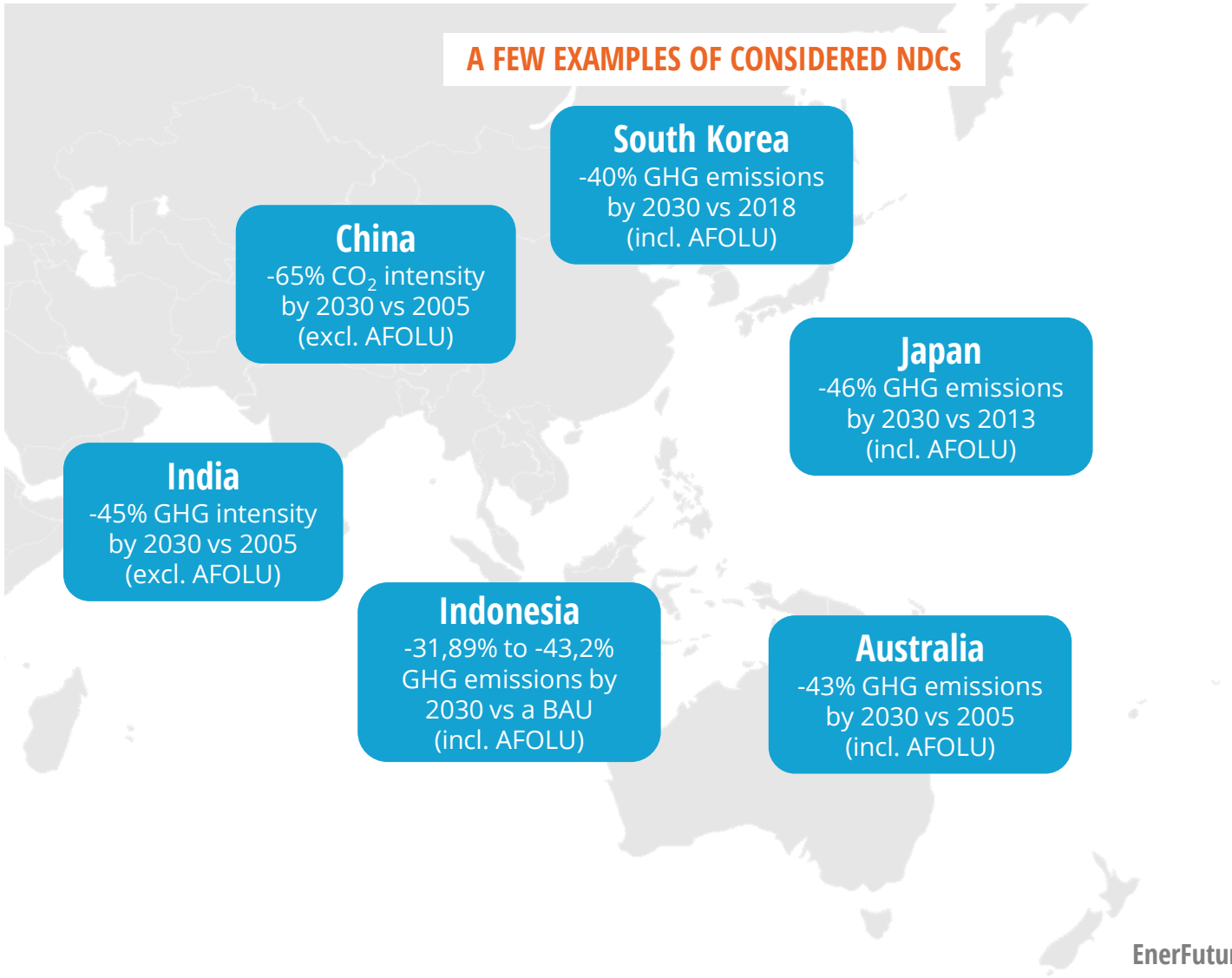
Source: UN World Population Prospects (2022 revision)



Source: WB, IMF, CEPII EconMap

Updated NDCs in EnerBlue

Updated NDCs were considered in EnerBlue, with their new mitigation targets often revised upwards



Notes:

No harmonised definitions of NDCs target, with different scopes or reference years.

Large range of efforts by country through conditional vs unconditional targets, which leads to uncertainty in ambition levels.

Source: UNFCCC, submitted NDCs
AFOLU = Agriculture, Forestry & Land-Use

2 Global overview

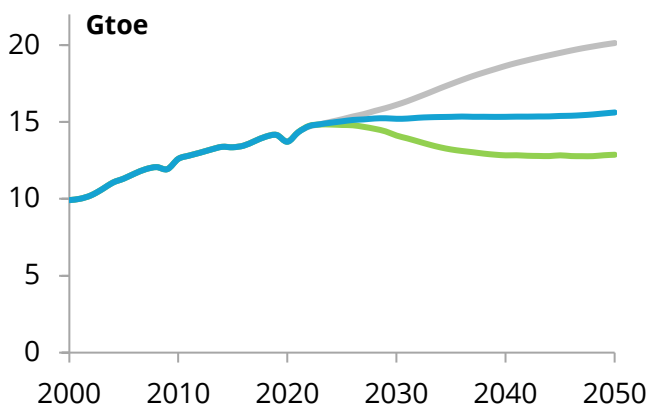
EnerFuture key outcomes

Enerdata

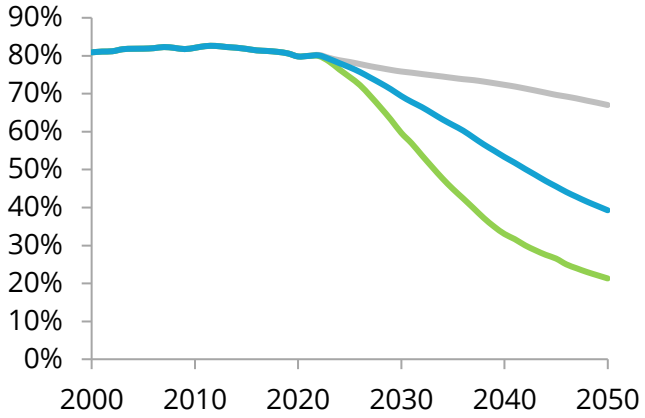
Key indicators

Main results from our 3 scenarios at a glance

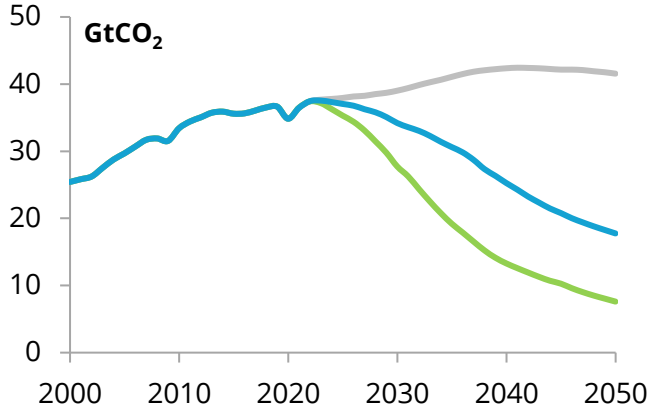
PRIMARY ENERGY CONSUMPTION



SHARE OF FOSSIL IN ENERGY MIX



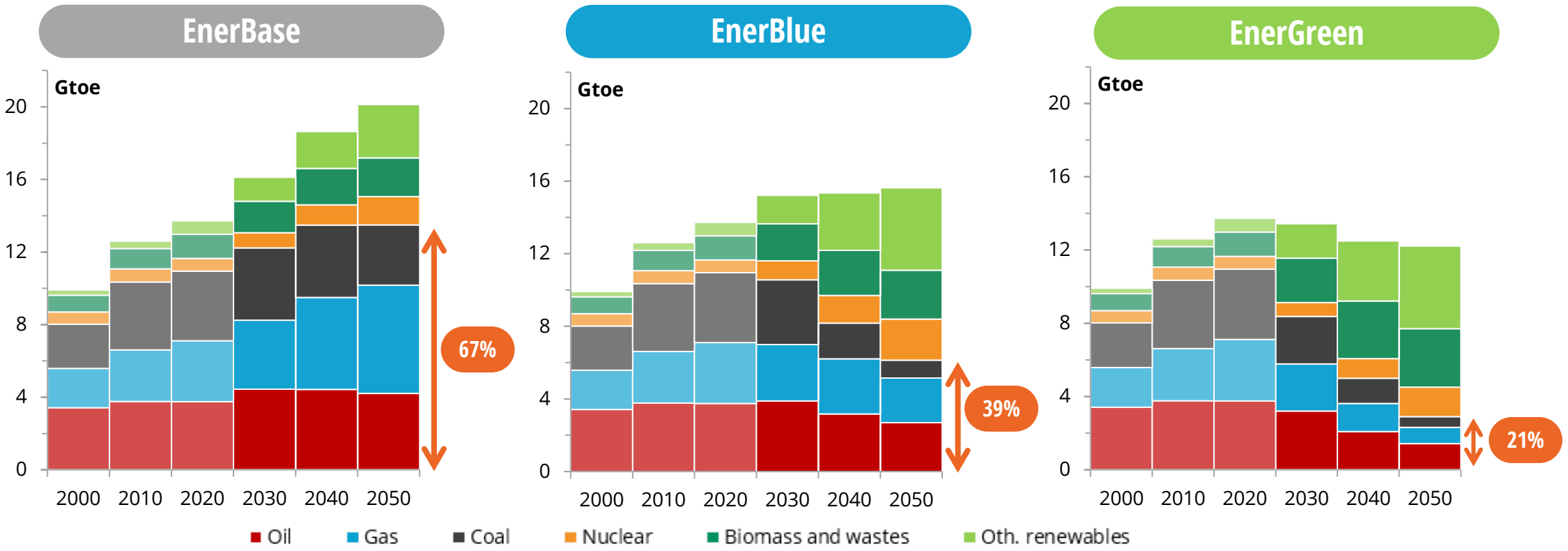
CO_2 EMISSIONS



Average evolution (%/y)	2011-2022	2022-2050		
		EnerBase	EnerBlue	EnerGreen
Carbon intensity CO_2 emissions released to produce one unit of gross domestic product (GDP)	**-2.2%**	**-2.9%**	**-5.8%**	**-8.6%**
Energy intensity of GDP (final) Energy consumption necessary to produce one unit of gross domestic product (GDP)	-1.6%	-2.3%	-3.0%	-3.7%
Carbon factor CO_2 emissions released for an average unit of energy consumption	-0.5%	-0.7%	-2.8%	-5.1%

Primary energy mix

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



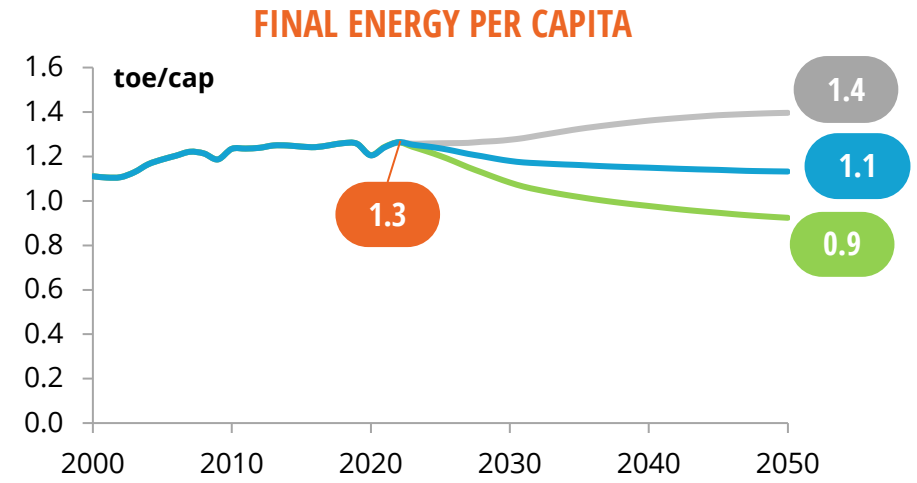
In a BAU scenario, fossil fuels still account for 13 Gtoe or 67% by 2050

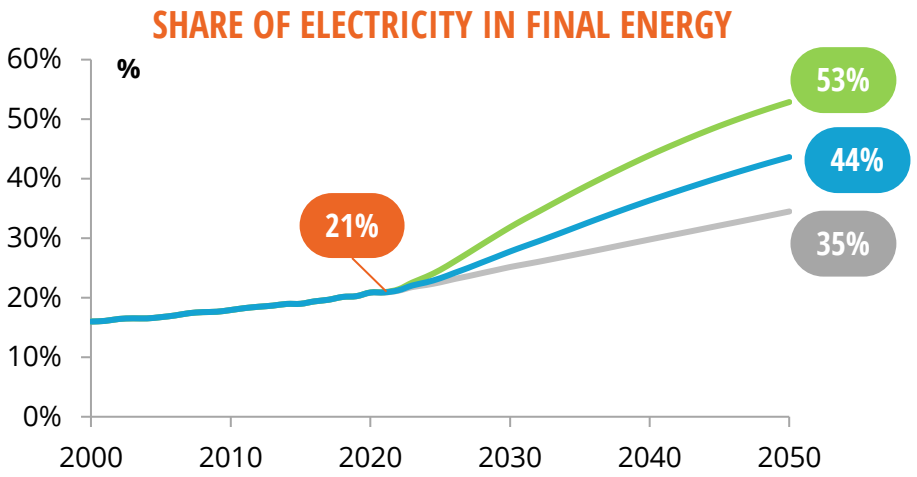
Annouced policies and objectives allow to quickly curb fossil fuel consumption, limiting it to 6 Gtoe or 39% by 2050

To obtain a trajectory compatible with below 2°C, fossil fuels should rapidly decrease to 3 Gtoe or 21% by 2050

Final energy consumption

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



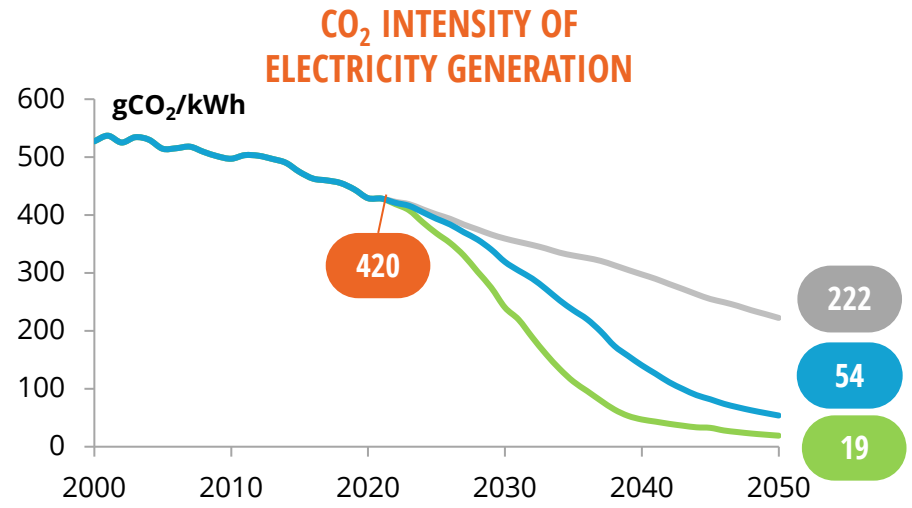


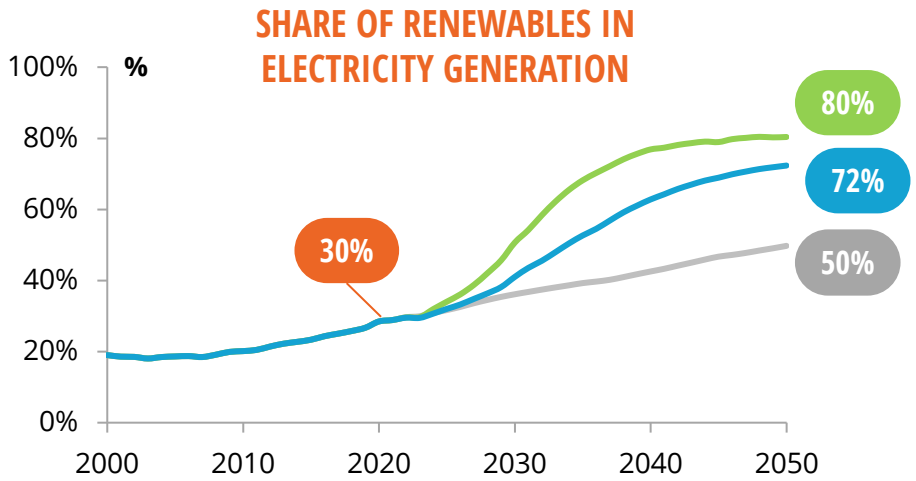
- **Reducing energy needs has to be a focus towards decarbonisation**
  - **Energy efficiency** across all end-uses
  - **Sufficency and behavioural changes** especially in advanced economies
  - Hence, final energy per capita decreases by 10% in EnerBlue and 27% in EnerGreen, in 2050

- **Electricity emerges as the main fuel in final consumption in most end-uses**
  - **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)

Electricity generation mix

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





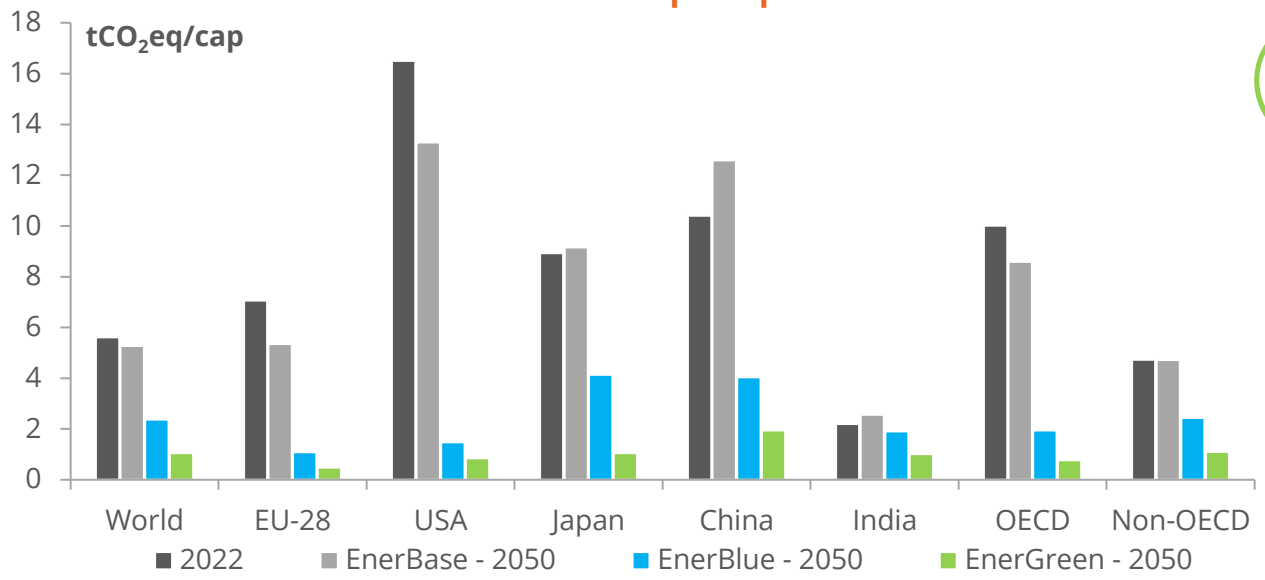
- **Electricity generation needs to be quickly decarbonised to reach ambitious climate targets**
  - **Continued development of renewables** in EnerBase, 50% decrease in emission factor from 2021 to 2050
  - In **EnerBlue**, a **stronger deployment of renewable technologies** leads to lower emissions per kWh: -87% over 2021-2050
  - To achieve a below 2°C scenario, the **push towards renewables needs to be even deeper**. This helps specific emissions to drop by 95% by 2050.

Emissions per capita

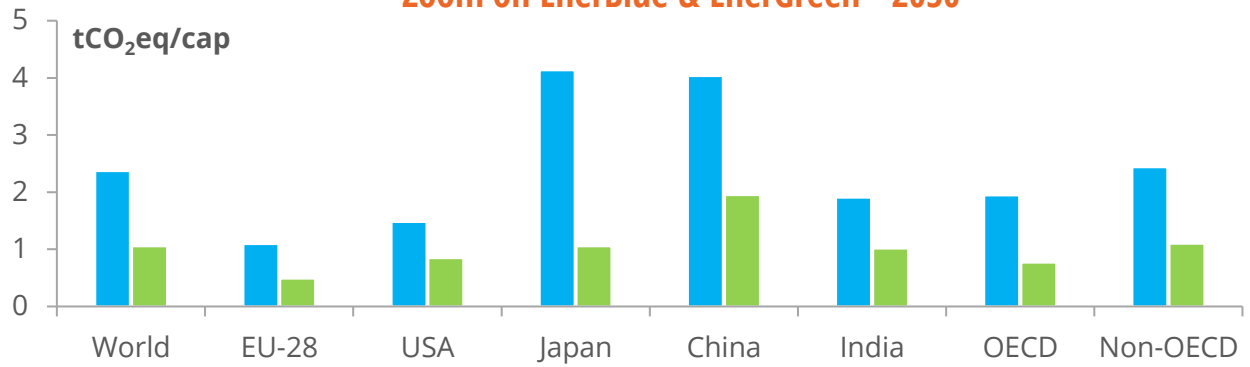
To what extent does the global picture hide regional discrepancies?

- **Large historical discrepancies in emissions per capita**
  - Reflecting different **development levels**
  - And different **shares of fossil** in the primary mix
- **No significant change in EnerBase**
  - Marginal evolution of these differences by 2050
- **A completely different picture in 2050 in EnerBlue, and EnerGreen**
  - Low emissions per capita in OECD countries by 2050 (1.9 tCO_2/cap in EnerBlue)
  - Large decrease also, albeit slightly slower, in non-OECD countries (2.4 tCO_2/cap in 2050 in EnerBlue)

GHG emissions per capita - 2050



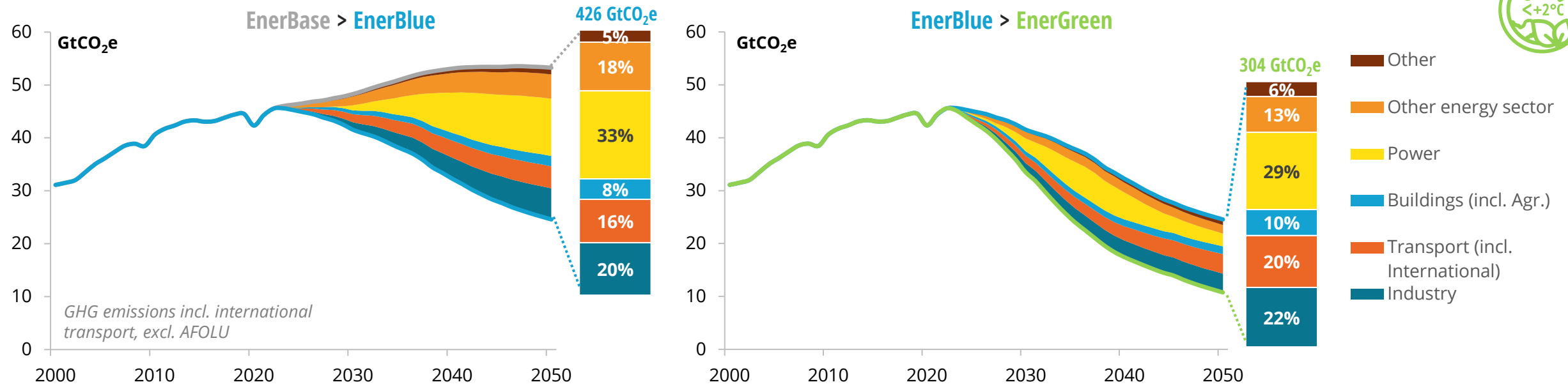
Zoom on EnerBlue & EnerGreen - 2050



Decarbonisation in sectors

To what extent are sectors of the economy contributing to GHG emission reductions?

GHG EMISSION REDUCTIONS BY SECTOR AND SHARE IN CUMULATED REDUCTIONS

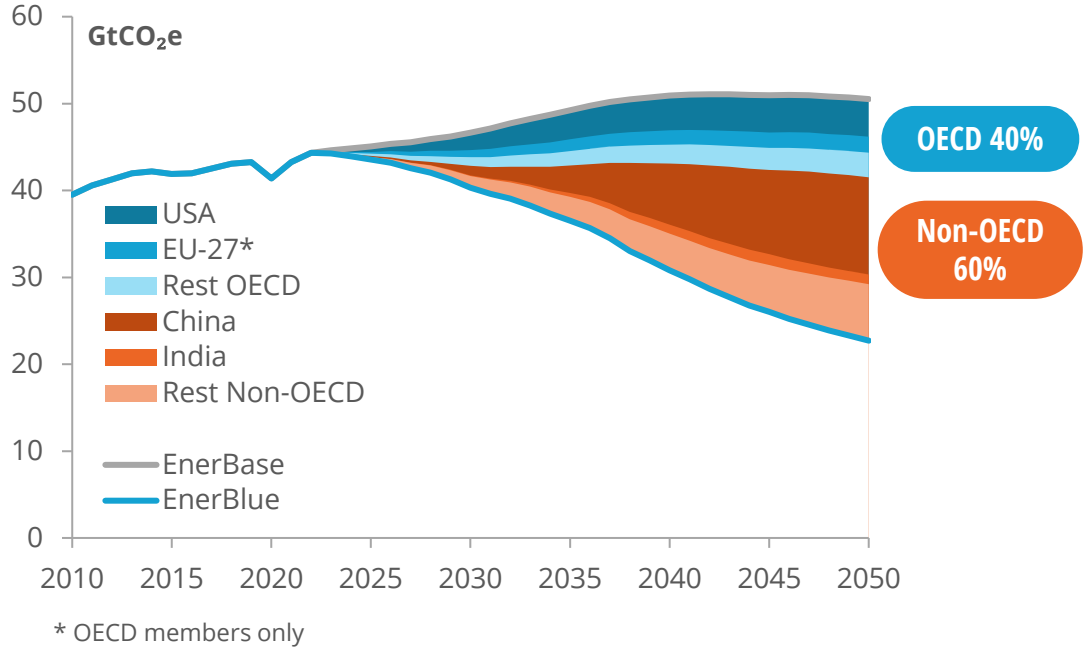


- **Energy supply sectors, and notably power generation, are major contributors to global decarbonisation**
  - The power sector presents relatively low abatement costs, hence its higher share of reduction in EnerBlue than in EnerGreen
- **But all sectors have to contribute, and notably industry and transport with large reduction potentials**

Current pledges

To what extent regions contribute to mitigation efforts according to their pledges?

GHG EMISSION REDUCTIONS BY REGION



* OECD members only

Cumulated reductions, 2022-2050		
USA	84 $GtCO_2e$	21%
EU-27*	34 $GtCO_2e$	8%
Rest OECD	47 $GtCO_2e$	11%
China	139 $GtCO_2e$	34%
India	17 $GtCO_2e$	4%
Rest Non-OECD	89 $GtCO_2e$	22%

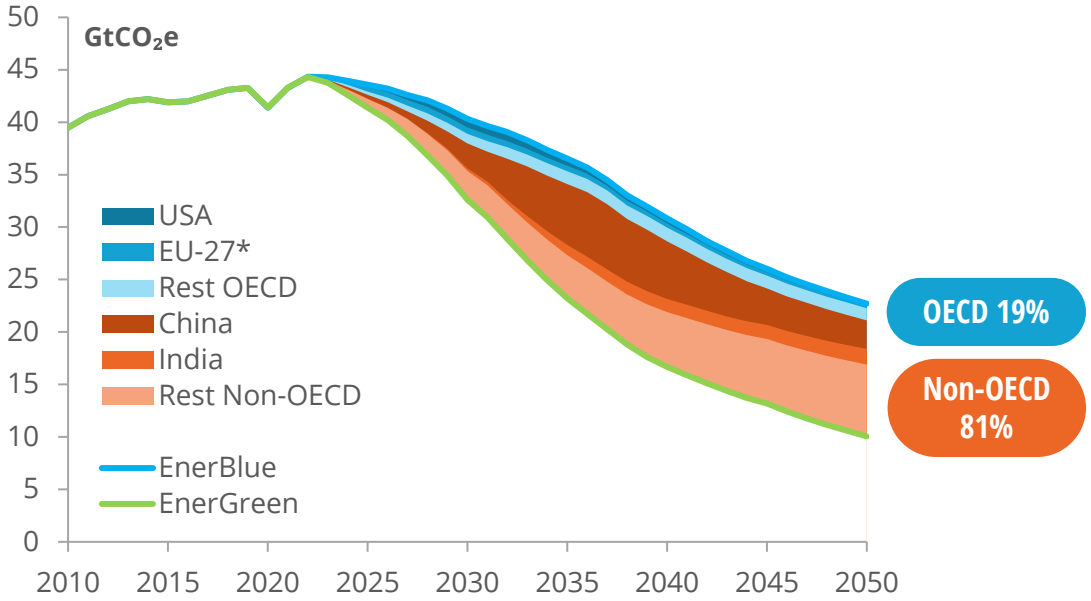
GHG emissions excl. international transport, excl. AFOLU

- According to currently announced policies and pledges, **non-OECD countries** should account for about **60% of cumulative emission reductions by 2050**
- **China alone** represents **more than a third** of intended emission reductions, with around 140 $GtCO_2e$ less in EnerBlue compared to EnerBase – although its GHG emissions per capita remain substantially higher than the global average.

Ambition gap

Over 80% of additional decarbonisation efforts in EnerGreen should be done by non-OECD countries

GHG EMISSION REDUCTIONS BY REGION



* OECD members only

Cumulated reductions, 2022-2050		
USA	13 $GtCO_2e$	5%
EU-27*	12 $GtCO_2e$	4%
Rest OECD	28 $GtCO_2e$	10%
China	96 $GtCO_2e$	33%
India	23 $GtCO_2e$	8%
Rest Non-OECD	115 $GtCO_2e$	40%

GHG emissions excl. international transport, excl. AFOLU

- The gap between current NDCs and a below 2°C scenario is mostly concentrated in Non-OECD countries, with China alone accounting for 33% of the total ambition gap
- The question of **global climate finance** is key: enabling developing countries to access financing in order to limit their emissions while continuing to develop is a must

3 Focus on Asia-Pacific

A deep dive analysis on a major economic region

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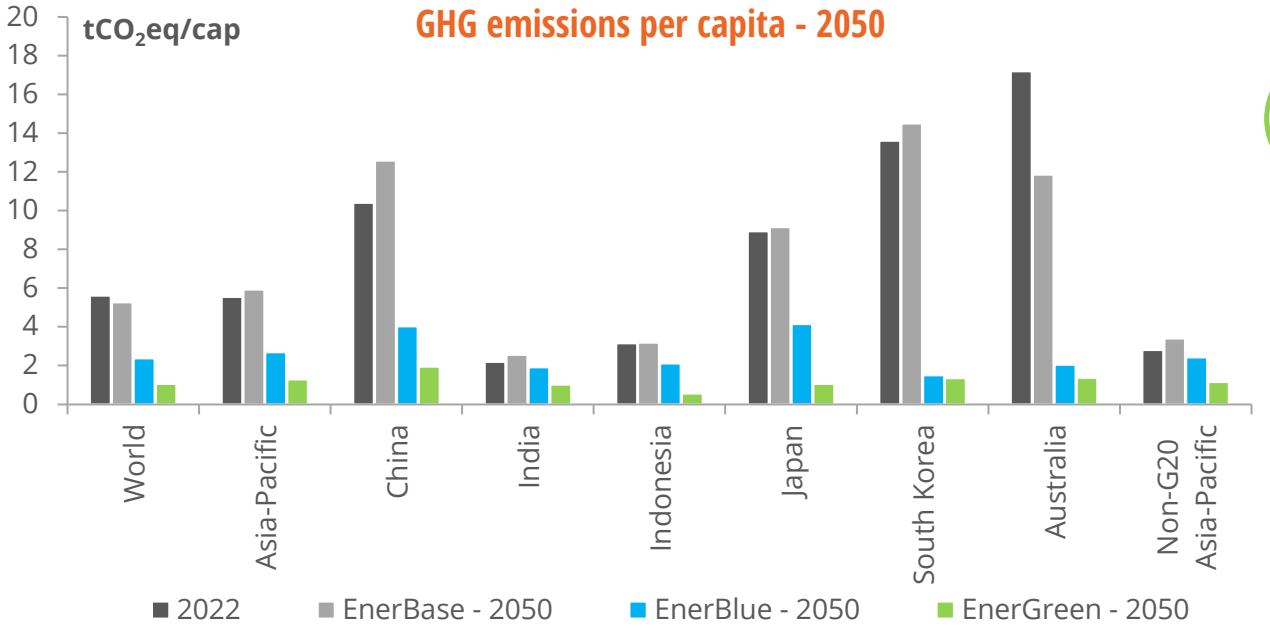
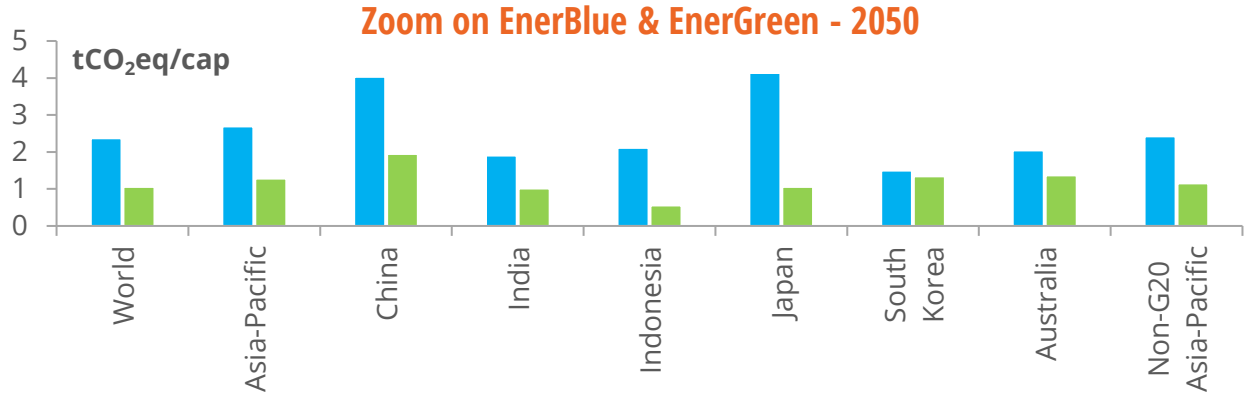
Emissions per capita

What to expect from individual countries in the Asia-Pacific region?

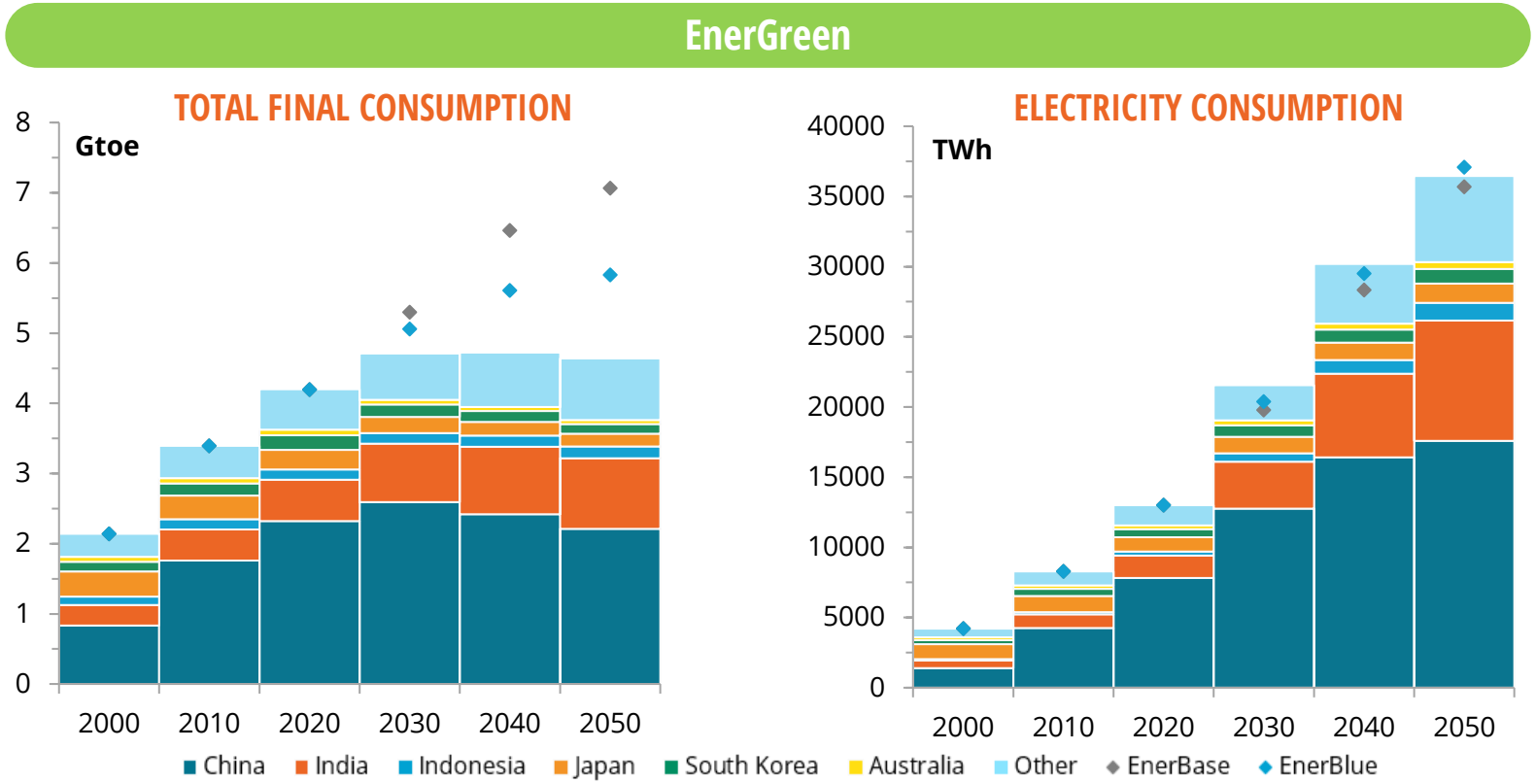
- **Contrasted historical situations with China, Japan, South Korea and Australia far above the others in emissions/capita**
- **No major change in EnerBase, as expected**
- **Convergence of the emissions per capita with increasing climate ambition, as demonstrated by EnerBlue and EnerGreen**





Final energy & electricity demand

Final energy demand is stabilizing in EnerGreen, but electricity keeps surging

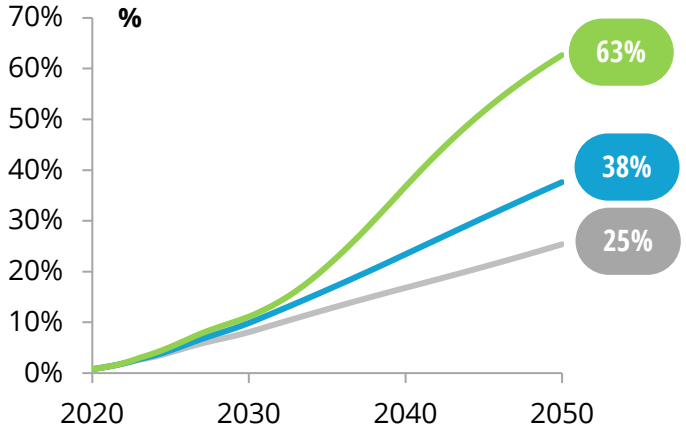


- **Electricity consumption** evolution in **similar in all 3 scenarios**
- **Different trends in countries**, with electricity consumption stabilizing in China vs increasing in India by 2050 in EnerGreen

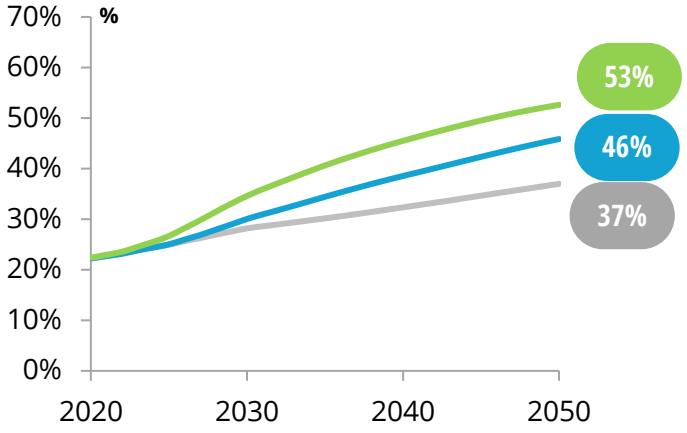
Electrification in sectors

Electric vehicles, heat pumps for heating and cooling, and electric processes in industry will drive electricity demand in all sectors

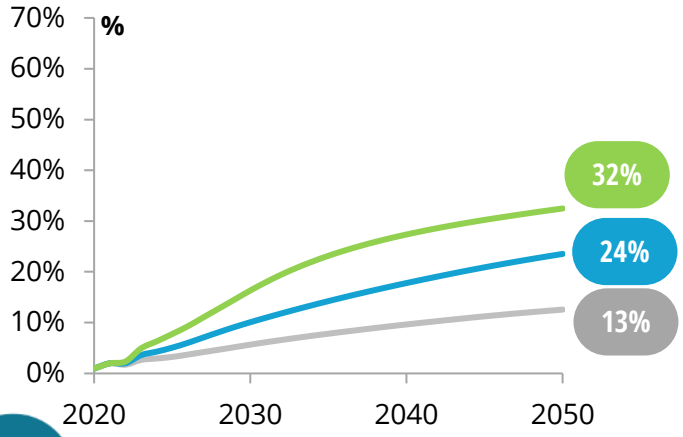
SHARE OF EVs IN PASSENGER CAR FLEET



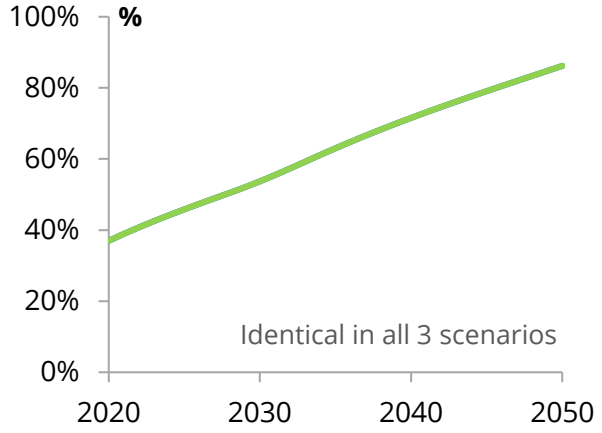
SHARE OF ELECTRICITY IN INDUSTRY



SHARE OF HEAT PUMPS IN SPACE HEATING



AC DIFFUSION RATE

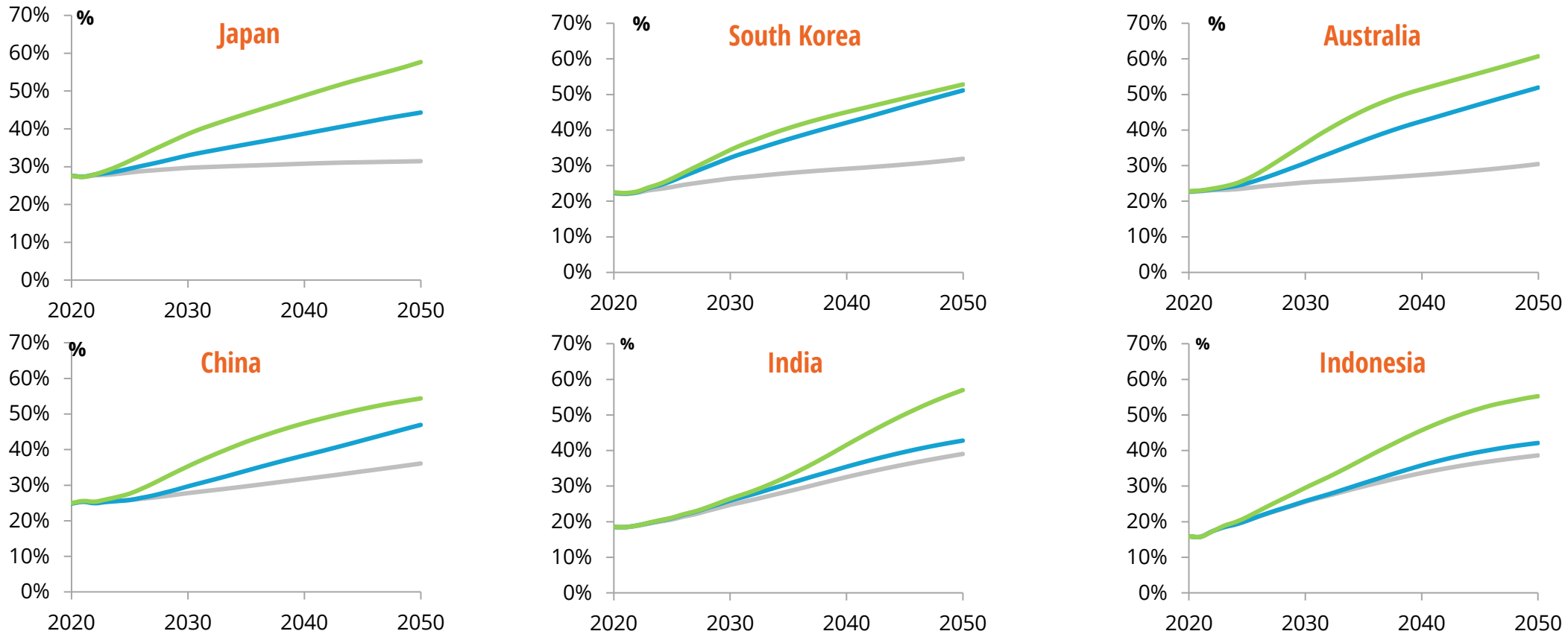


- **EVs will pick up in passenger and light freight transport**
- **In buildings, diffusion of AC systems will continue expanding quickly**
- **Heat pumps with play a large role for heating uses**
- **Industrial processes will transform to use more electricity**
  - for low temperature uses (e.g. heat pumps)
  - and for high temperature uses (e.g. electric arc furnaces)

Electrification in countries

The push towards electrification will happen simultaneously in all countries of the region

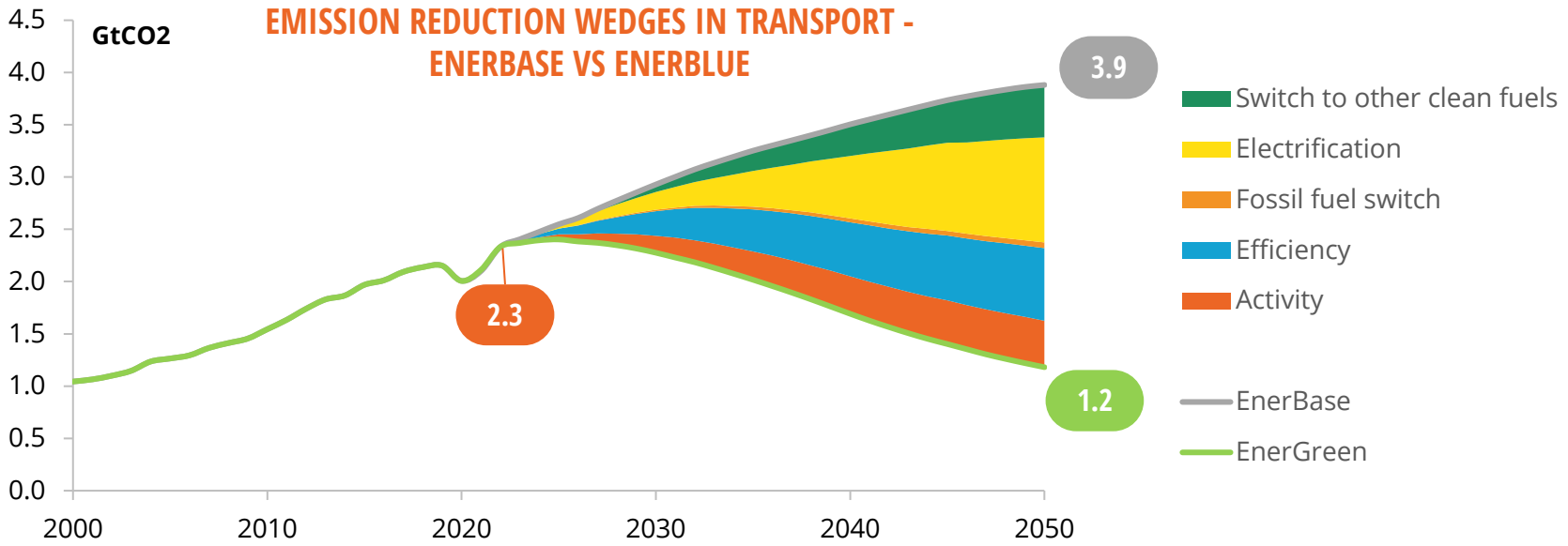
SHARE OF ELECTRICITY IN FINAL ENERGY DEMAND



- **All six countries end up with a share of electricity in final demand between 53 and 61% by 2050 in EnerGreen**

Focus on the transport sector

What levers to decarbonise this historically large emitting sector?

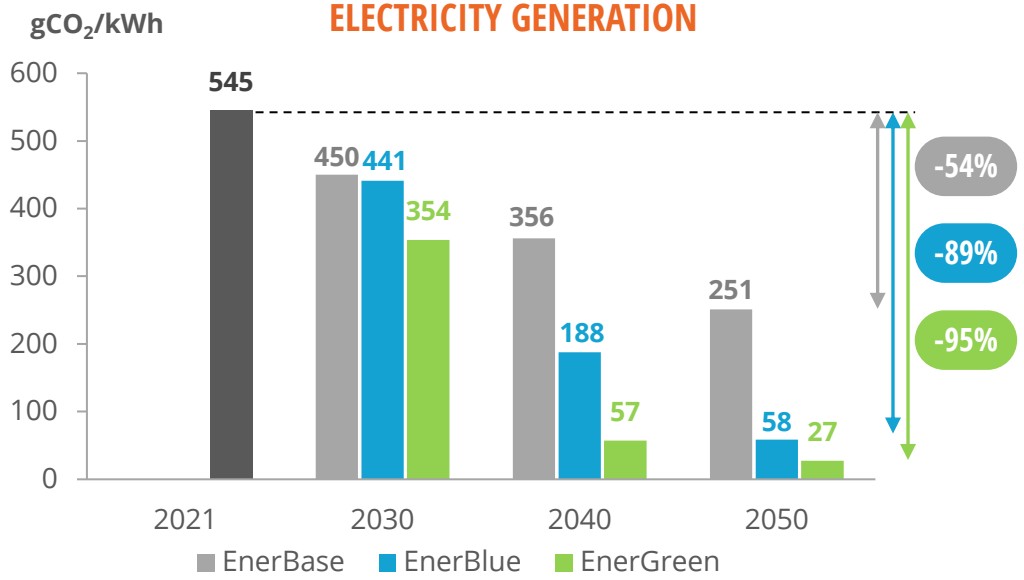


- **Deployment of EVs is the main lever to decarbonise domestic transportation**
- **Improved efficiency of motors & use of biofuels and hydrogen also play a substantial rôle**
- **Preventing a high growth in traffic could also prove very useful**

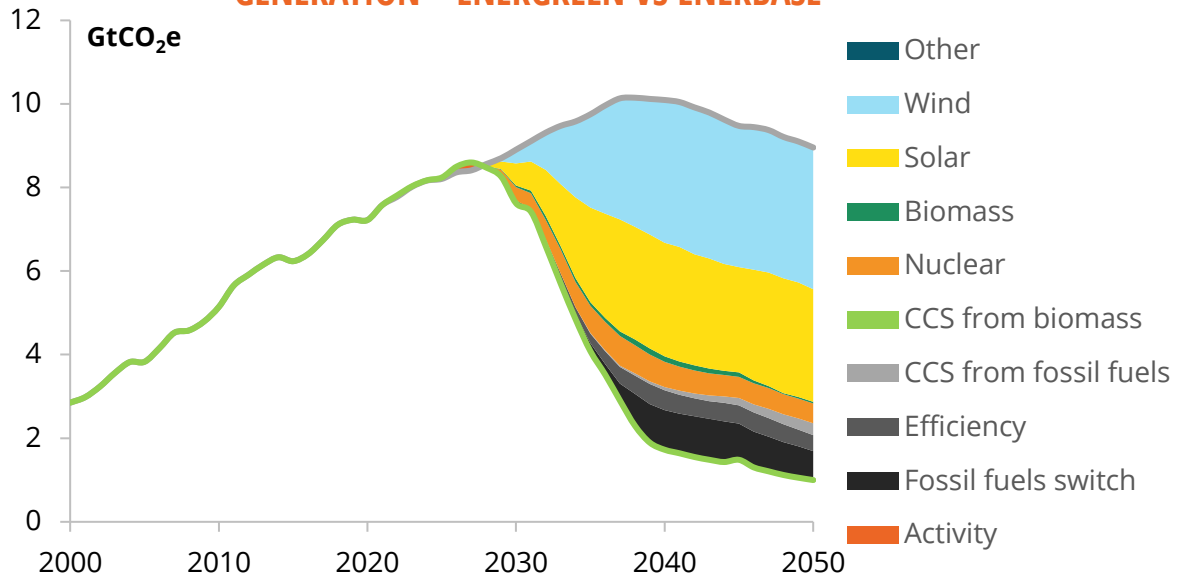
Electricity generation

A massive push towards renewables is required in order to decarbonise electricity generation

AVERAGE CO_2 EMISSION FACTOR OF ELECTRICITY GENERATION



EMISSION REDUCTION OPTIONS IN POWER GENERATION – ENERGREEN VS ENERBASE



Reduction options are calculated using our AERO model based on EnerFuture scenario results

- **Emissions from electricity generation have to drop very low in a climate-friendly scenario**
  - Current objectives and pledges in EnerBlue already point towards significant improvements (although slower than in EnerGreen)
- **Wind and solar electricity are the two main contributing technologies to global emission reductions from the power sector**
  - Nuclear power also has a more limited role to play, as well as CCS and coal-to-gas switch

4 Conclusions

Wrapping up the analysis

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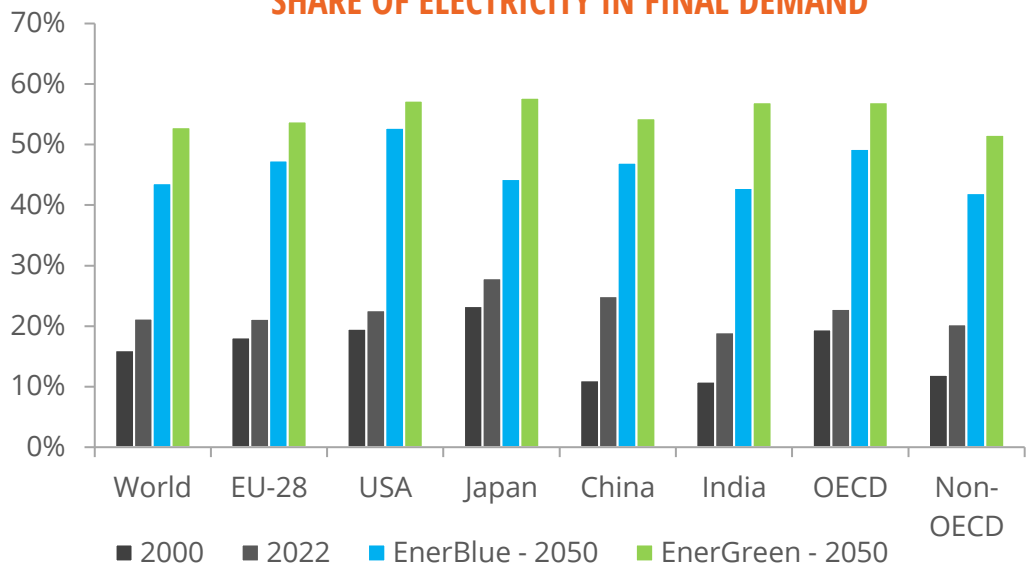
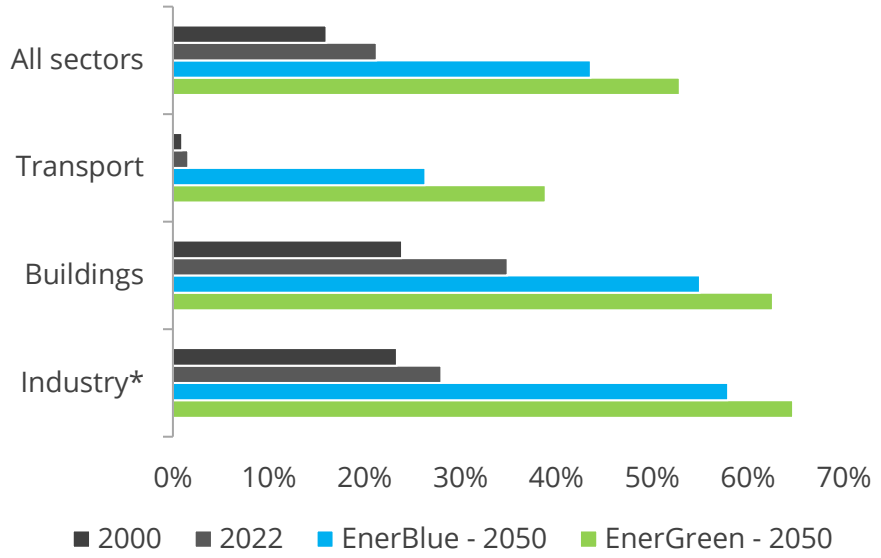
Electrification

Electrification appears as a main pillar of energy transition in all sectors

SHARE OF ELECTRICITY IN FINAL DEMAND



SHARE OF ELECTRICITY BY SECTOR (WORLD)



** excluding non-energy uses*

- The **share of electricity in final demand increases across all sectors and regions in all three scenarios**, reaching respectively 44% in EnerBlue and 53% in EnerGreen in 2050 globally, from the current 21%.
- Electrification notably relies on deployment of new technologies, including for instance **heat pumps** in buildings and industry and of **electric vehicles** in the transport sector.

Role of CO_2-free electricity

The share of decarbonised(*) electricity generation surges in all regions in EnerBlue and EnerGreen

(*) including renewable and nuclear technologies

USA

	2022	2050	2050
Solar	4%	22%	24%
Wind	8%	50%	52%
Hydro	6%	4%	4%
Nuclear	17%	16%	13%
	34%	91%	92%

EU-27

2022	2050	2050
8%	19%	24%
15%	53%	55%
11%	7%	6%
20%	14%	13%
53%	92%	97%

China

2022	2050	2050
6%	29%	49%
7%	32%	27%
14%	7%	6%
4%	9%	11%
32%	77%	93%

Latin America

2022	2050	2050
4%	34%	45%
9%	26%	25%
46%	21%	19%
2%	5%	4%
61%	87%	94%

Africa & Middle-East

2022	2050	2050
2%	57%	60%
1%	15%	19%
8%	7%	7%
1%	5%	7%
12%	84%	92%

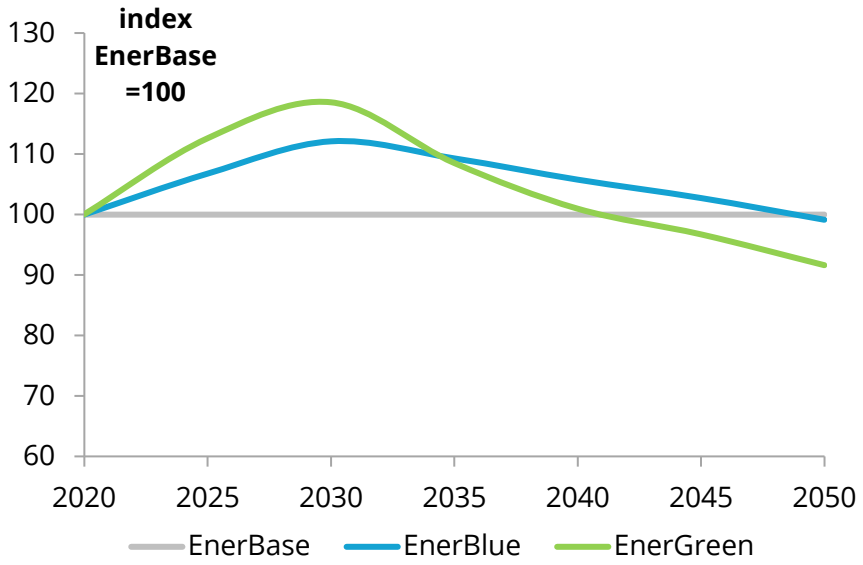
India

2022	2050	2050
4%	18%	26%
5%	32%	35%
9%	5%	6%
3%	32%	25%
21%	88%	92%

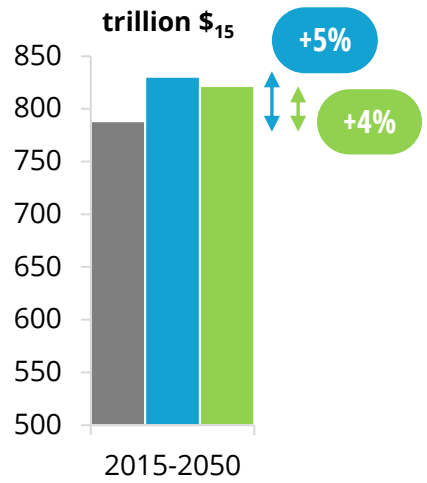
Comparative cost of scenarios

How much more expensive is a 2°C-compatible pathway compared to a reference?

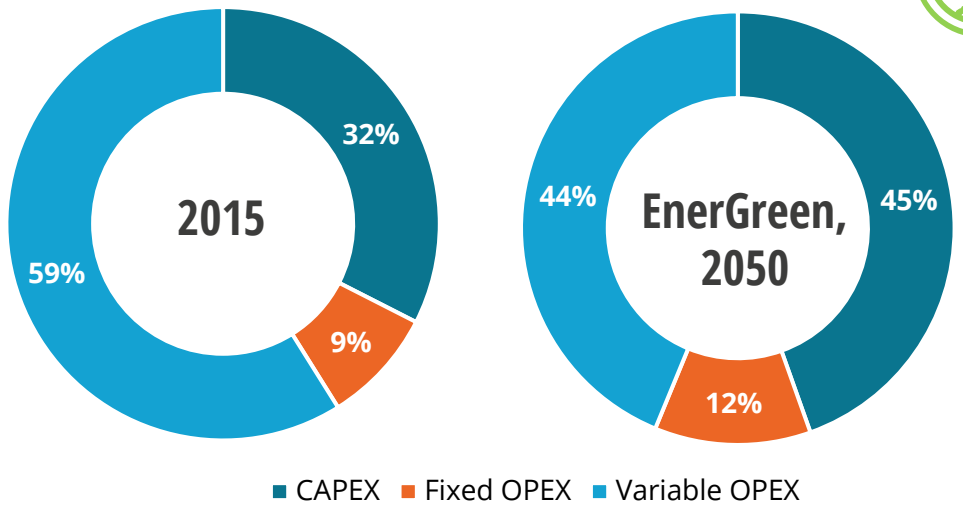
TOTAL SCENARIO COSTS COMPARED TO ENERBASE



CUMULATED SCENARIO COSTS 2015-2050



SCENARIO COST STRUCTURE



- The transition to low-carbon energy systems requires large **short-term investments that could become profitable after 2050** compared to a baseline scenario. **Unlocking short-term investments** is a key issue for countries with limited debt capacity.
- Energy systems are moving from an OPEX cost structure to a CAPEX cost structure as renewable power generation is developing
- Cumulated cost of the global energy system shall increase by about 5% to limit the temperature increase. But the environmental cost of inaction is much higher.

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: +37% over 2022-2050
- Fossil fuels still account for 67% of primary mix by 2050
- RES power production multiplies by 3.7 over 2022-2050, but remains just below 50% of the mix in 2050
- CO_2 emissions grow by 11% over 2022-2050, reaching 42 $GtCO_2$

EnerBlue

CLIMATES OBJECTIVES

- Climate ambition in line with newest NDC targets (as of 2022)
- Progressive policy enforcement
- *~ 2.5°C temperature increase*

KEY OUTCOMES

- Demand grows by 6% over 2022-50 (+28% in non-OECD)
- Energy mix transformation: less fossil (39% in 2050), RES share 46% by 2050
- Final energy intensity of GDP drops by 57% over 2022-2050
- CO_2 emissions halve to around 18 $GtCO_2$ 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*

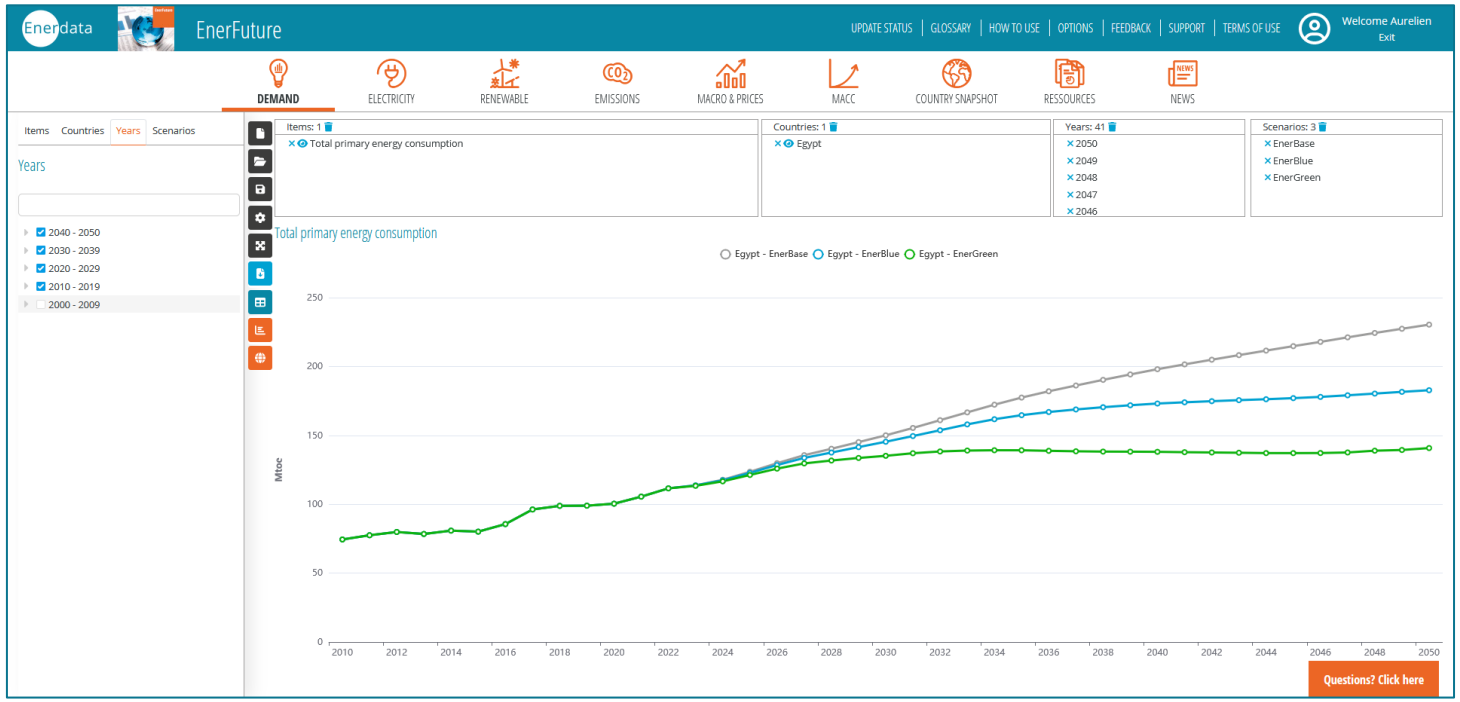
KEY OUTCOMES

- Global demand decreases by 13% between 2022 and 2050
- Fossil fuels share around 21% by 2050, coal production declines by 87%
- RES and nuclear represent 93% of power generation in 2050
- CO_2 emissions reach around 8 $GtCO_2$ in 2050; very strong reduction efforts in non-OECD

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: CO_2 Marginal Abatement Cost Curves by sector and industrial branches

EnerFuture 2023

Global Energy Scenarios Through 2050

HELPING YOU SHAPE THE ENERGY TRANSITION

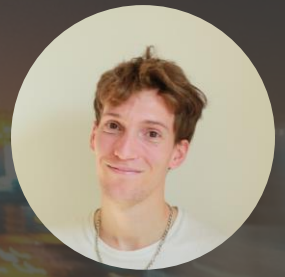
About Enerdata:

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

PUBLICATION AUTHORS



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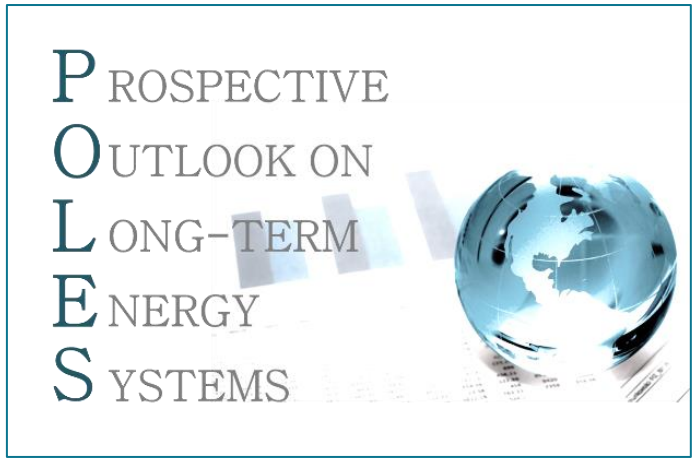
5 Annexes

Additional EnerFuture materials

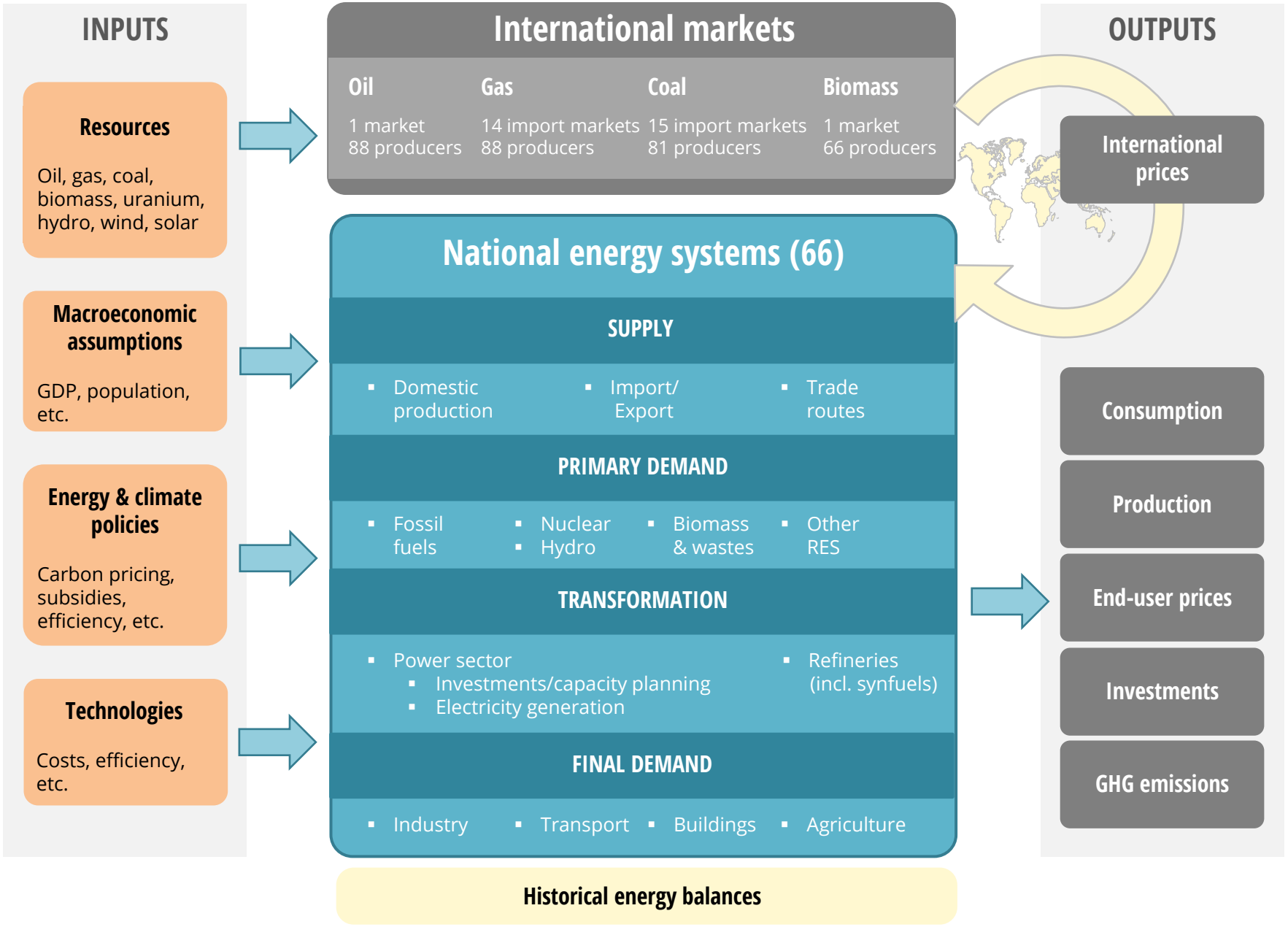
Enerdata

POLES-Enerdata: origins and objectives

- The objective of **POLES (Prospective Outlook on Long-term Energy Systems)** is to produce prospective analyses of the supply & demand of energy commodities, energy prices, as well as the impact of climate change and energy policies on energy markets
- The POLES model has been initially (early 1990s) developed by IEPE (Institute for Economics and Energy Policy), now GAEL lab (Grenoble Applied Economics Lab)
- Originally financed by the JOULE II and III programs of the EC's 3rd and 4th Framework Programs (FP) for Research and Technological Development (1990-1998) as well as the CNRS
- Since then, POLES has been further developed by Enerdata, the GAEL lab, and the JRC Seville of the European Commission
- POLES draws on practical and theoretical developments in many fields such as mathematics, economics, engineering, energy analysis, international trade, and technological change
- POLES-Enerdata is the version of the POLES model owned, maintained and operated by Enerdata



POLES-Enerdata: model structure



POLES-Enerdata: World coverage with 66 countries or aggregates

Regions	Sub-regions	Countries	Country aggregates
North America		USA, Canada	
Europe	EU27	France, Italy, Germany, Austria, Belgium, Luxembourg, Denmark, Finland, Ireland, Netherlands, Sweden, Spain, Greece, Portugal Hungary, Poland, Czech Republic, Slovak Republic, Estonia, Latvia, Lithuania, Slovenia, Malta, Cyprus, Croatia, Bulgaria, Romania United Kingdom, Iceland, Norway, Switzerland, Turkey	 Rest of Europe
Japan – South Pacific		Japan, Australia, New Zealand	Rest of South Pacific
CIS		Russia, Ukraine	Rest of CIS
Latin America	Central America South America	Mexico Brazil, Argentina, Chile	Rest of Central America Rest of South America
Asia	South Asia South-East Asia	India China, South Korea, Indonesia, Malaysia, Thailand, Viet Nam	Rest of South Asia Rest South-East Asia
Africa / Middle East	North Africa Sub-Saharan Africa Middle-East	Egypt, South Africa Saudi Arabia, Iran	Rest of North Africa x2; Rest of Sub-Saharan Africa; Gulf countries; Rest of Middle East

POLES-Enerdata: overview of modules