Enerdata intelligence + consulting

June 2022

EnerFuture 2022

Global Energy Scenarios Through 2050

An In-Depth Look at the Future of Energy

Powered by the POLES-Enerdata model

Contents

1 Summary and Key Outcomes

EnerFuture Key Takeaways

Enerdata

Three Energy & Climate Scenarios to Explore Possible Futures of Energy Systems

- Enerdata has prepared three contrasted energy & climate scenarios up until 2050 to explore the possible pathways of the global energy sector

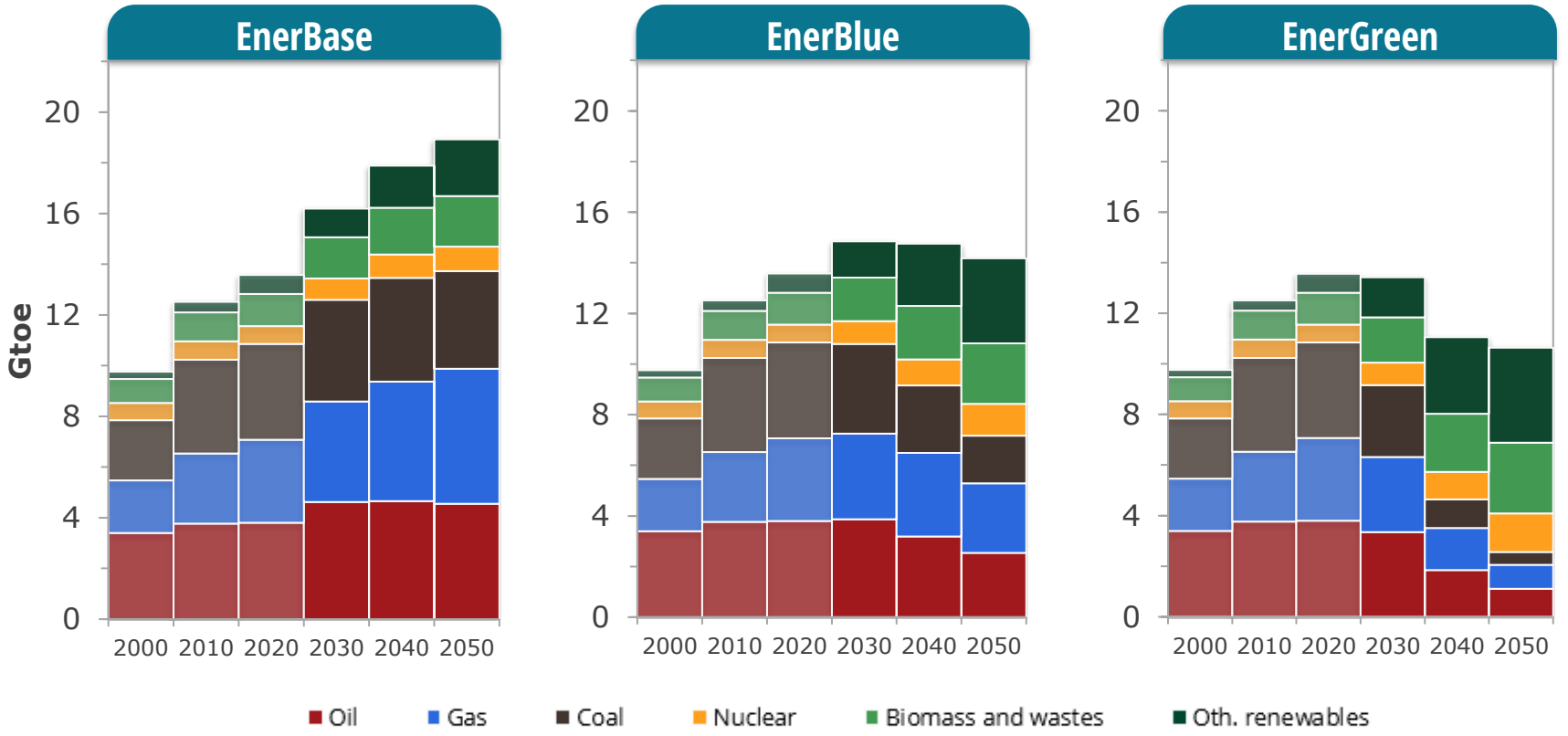
EnerBase	EnerBlue	EnerGreen
Continuation of existing policies and trends	Achievement of new NDCs submitted up to end of 2021	Ambitious GHG emissions budget in line with the Paris Agreement

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

What's New in this Edition?
Further Upgrades of EnerFuture 2022

- **New projections/scenarios** covering all EnerFuture data: energy demand and supply, emissions, etc. **in light of the most recent developments:**
  - ✓ The **Ukrainian crisis** and its impacts on fossil fuel supply and prices
  - ✓ Energy & climate policy developments, including **up-to-date NDCs**
  - ✓ Electrification trends
- Integration of **up-to-date historical data up to 2020** and projections up to 2050
- Modelling developments on the POLES-Enerdata model have been performed, including:
  - ✓ A refined **techno-economic approach** of the different energy uses in the buildings sector
  - ✓ Enhancement of the coverage of the iron and steel sector
  - ✓ Detailed integrated assessment of natural decarbonization potential from biogas and hydrogen
- New approach to scenario construction: better account for the role of demand-side drives in decarbonisation

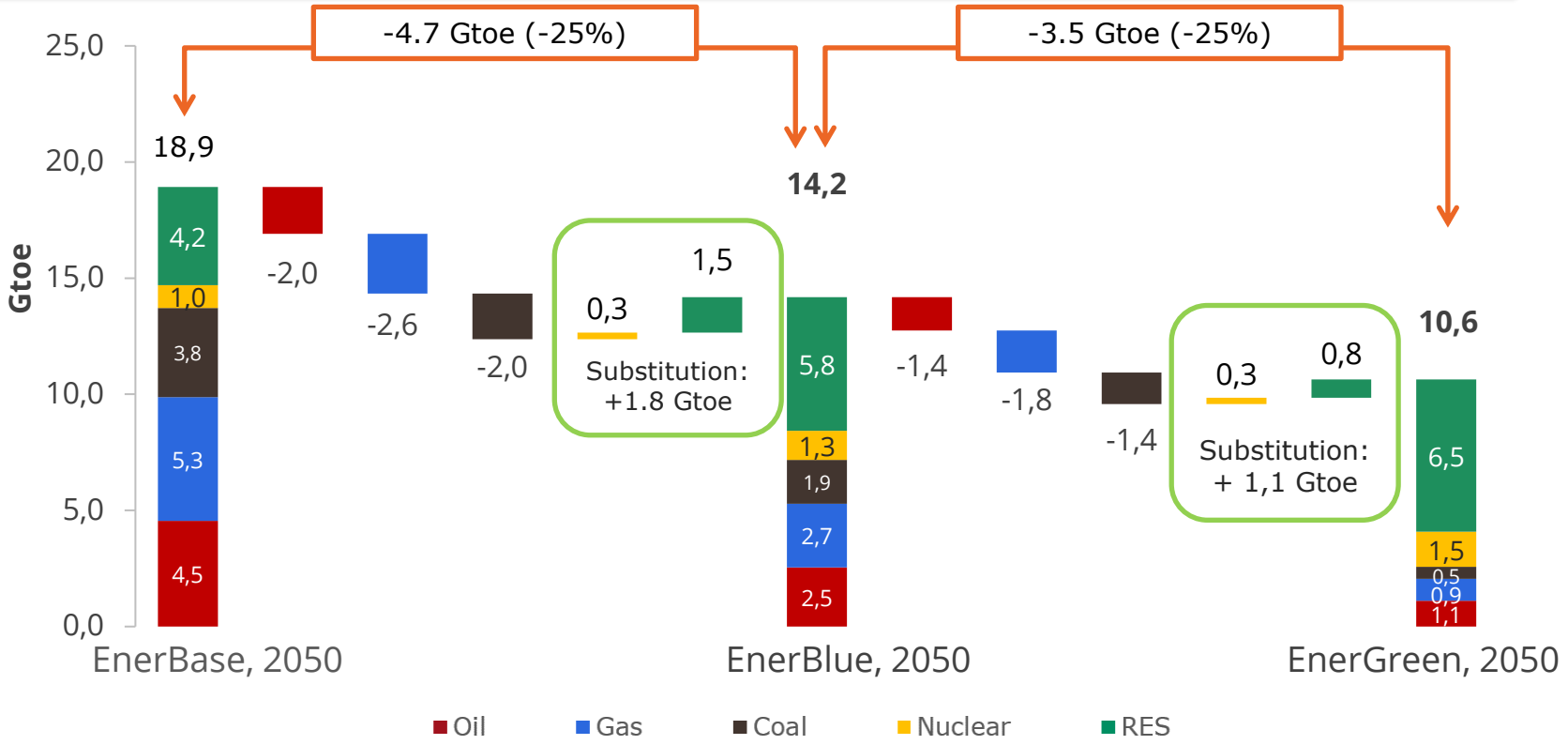
Primary Energy Mix



- From 80% now, fossil fuels stay at 73% in 2050 in EnerBase and 51% in EnerBlue but fall down to 24% in EnerGreen
- RES + nuclear reach 76% in EnerGreen vs 27% in EnerBase

Significant reduction in fossil fuels consumption only possible through constraining climate policies

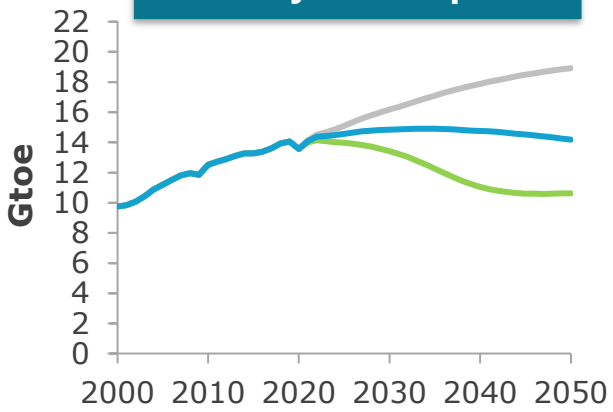
World primary consumption in 2050 and relative reduction by fuel between scenarios



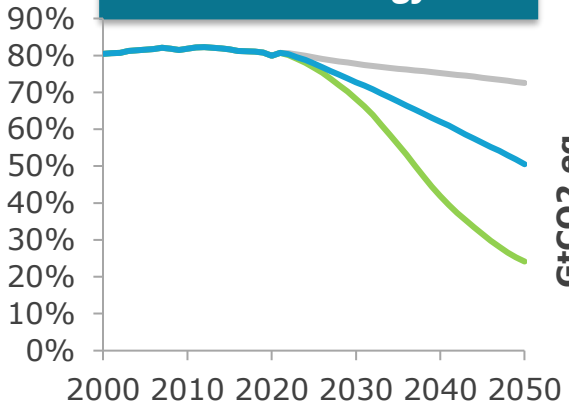
- Substitution to renewables, especially from coal, combined with higher energy efficiency allows to comply with ambitious climate target

Key Scenario Indicators

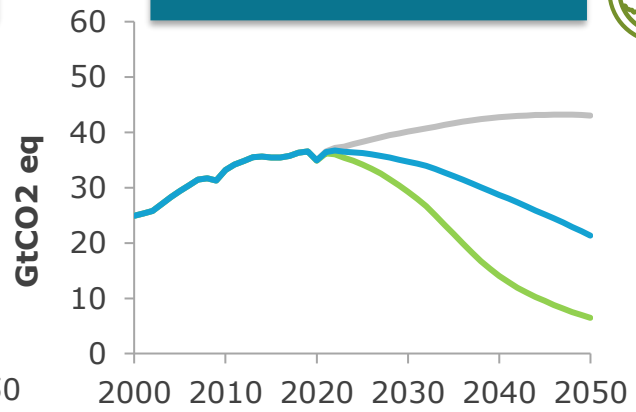
Primary consumption



% fossil in energy mix



CO2 emissions level



Average evolution (%/y)	2010-2019	2021-2050		
	-	EnerBase	EnerBlue	EnerGreen
Carbon intensity	**-2.2%**	**-2.1%**	**-4.4%**	**-8.2%**
Energy intensity of GDP (final)	-1.9%	-1.6%	-2.4%	-3.5%
Carbon factor	-0.2%	-0.4%	-1.9%	-4.8%

CO_2 emissions released to produce one unit of gross domestic product (GDP)

Energy consumption necessary to produce one unit of gross domestic product (GDP)

CO_2 emissions released for an average unit of energy consumption

2 Scenario Approach & Definition

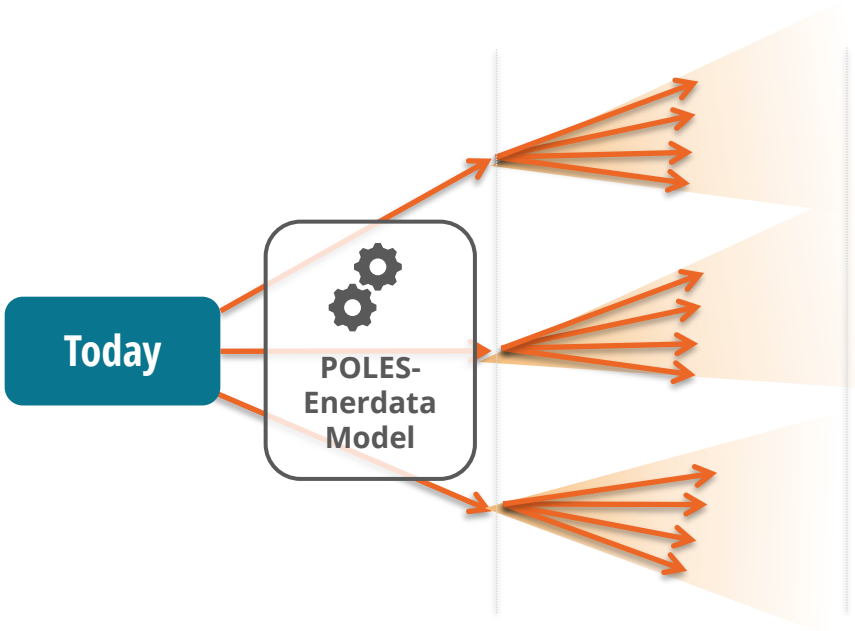
Methodology and Scenario Definition

Enerdata

EnerFuture: Global Energy Scenarios Through 2050

- Alternative assumptions for key drivers: resources, climate and energy policies, available technological options, etc.

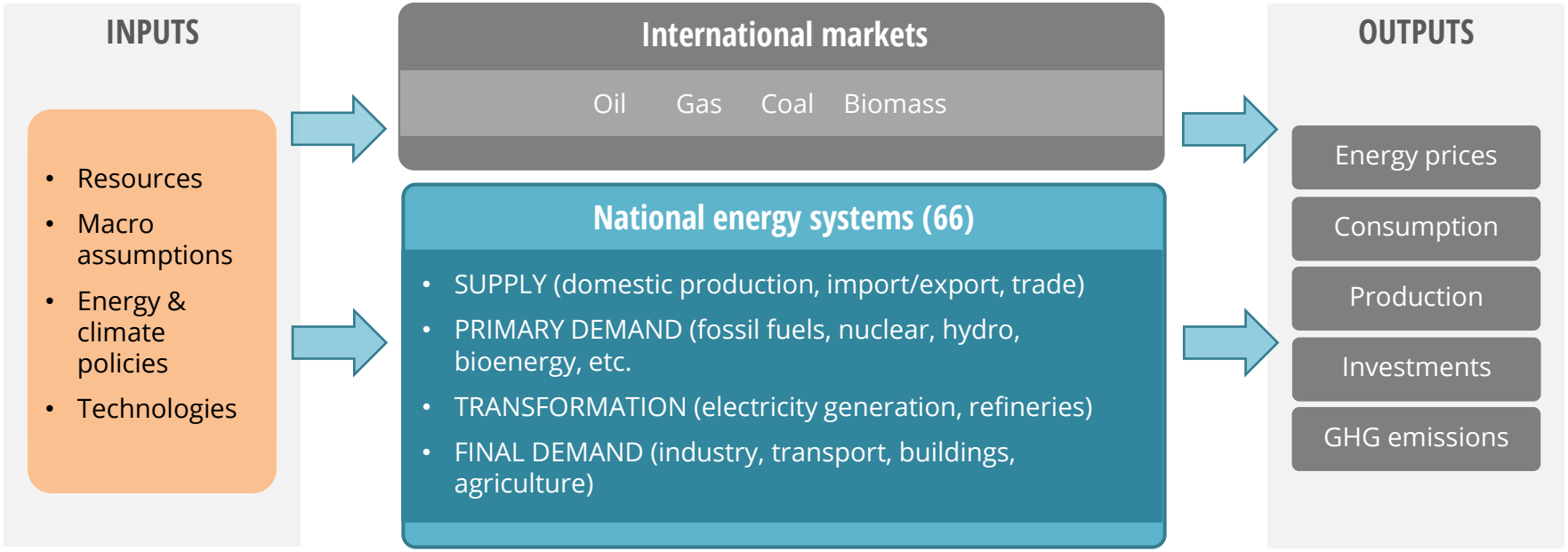
- With identical macroeconomic context: population, GDP growth



- Allowing to explore different pathways for energy markets

The POLES-Enerdata Model

- The scenarios are based on the use of the POLES-Enerdata model, allowing for detailed assessment and forecasting of energy supply and demand, prices and the impact of energy and climate policies on energy markets
- POLES-Enerdata is the version of the POLES (Prospective Outlook on Long-term Energy Systems) model owned, maintained and operated by Enerdata
- The model is running, and scenarios prepared, for 66 countries and regions with global coverage and annual step until 2050



Scenario Definitions

EnerBase

Climate and energy policies

- Limited and delayed efforts to mitigate GHG emissions
- Policies lacking climate ambition, not compatible with NDC targets

Energy demand

- Limited improvements in energy efficiency
- High demand growth in developing countries, stable in OECD

Energy supply

- Fossil fuels remain heavily dominant
- Minor renewables development due to lack of support
- Fossil fuel prices increase in a context of moderate demand growth

CO2 emissions

- CO_2 emissions continue increasing by 2050 in emerging economies, but are slightly curbed in OECD

EnerBase leads to a temperature increase above 3°C.

EnerBlue

Climate and energy policies

- Reinforced GHG emissions mitigation efforts
- Climate policies based on new NDC objectives (updated end of 2021)

Energy demand

- Demand growth controlled through energy efficiency and sufficiency
- Consumption increasing moderately in non-OECD and decreasing in OECD countries

Energy supply

- Fossil fuel share on a slow decreasing trend due to significant move towards renewables
- Slowly increasing international fuel prices, reflecting lower demand

CO2 emissions

- In developing countries, CO_2 emissions peak around 2030 and fall afterwards. Meanwhile they are largely decreasing in OECD

EnerBlue leads to a temperature increase between 2°C and 2.5°C.

EnerGreen

Climate and energy policies

- Ambitious GHG emissions budget, in line with Paris Agreement goals
- Very stringent climate policies, in line with ambitious new NDCs

Energy demand

- Significant energy efficiency improvements
- Implementation of substantial energy sufficiency measures
- Energy demand decreases globally

Energy supply

- Fossil fuel supply strongly decreases
- Renewables account for majority of primary energy demand
- Fuel prices driven down by collapsing demand

CO2 emissions

- CO_2 emissions are down to extremely low levels globally

EnerGreen explores a world in which temperature increase is limited to below 2°C.

3 EnerBase

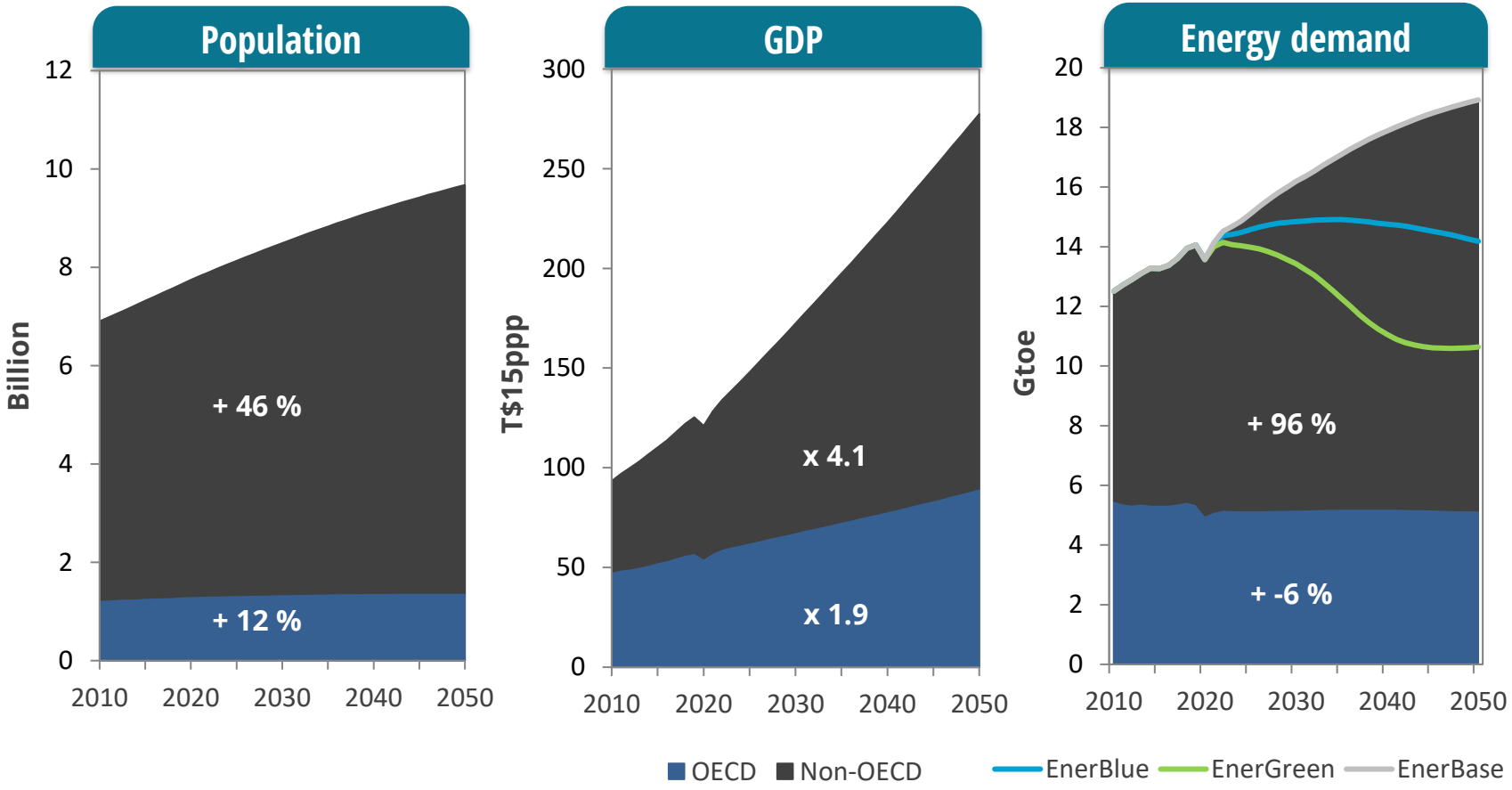
What happens if existing policies and trends continue?

Enerdata

EnerBase: Scenario Definition

- EnerBase is a scenario in which **existing policies are tendentially continued** and **trends recently observed are pursued**
- The **efforts to mitigate carbon emissions are globally very limited**
- The global pathways integrate risk premia for fossil fuel prices as a way to reflect a rather **tense geopolitical context**, accompanied by a high demand for oil and gas
- Energy **consumption is driven up** by economic and population growth, while a **moderate progress on decarbonised solutions** contributes to contain the impact on emissions
- This leads to a slight **decrease in emissions in developed countries** and an **increase in developing countries**, which corresponds to long-term trajectories that are, respectively, above and below historical trends
- *EnerBase leads to a temperature rise above 3°C*

Expected economic growth drives up energy consumption, pulled by non-OECD countries

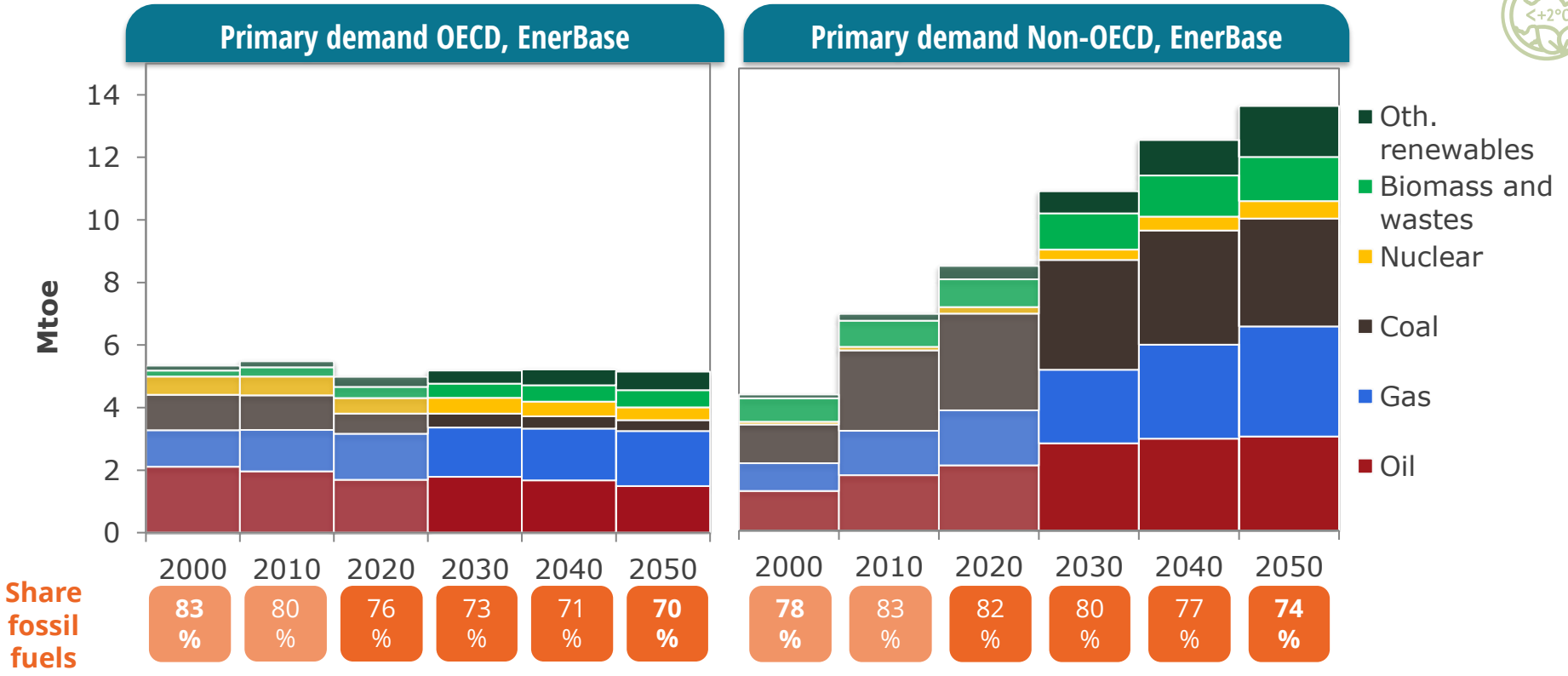


Source: UN World Population Prospects (2019 Revision)

Sources: IMF, Oxford Economics

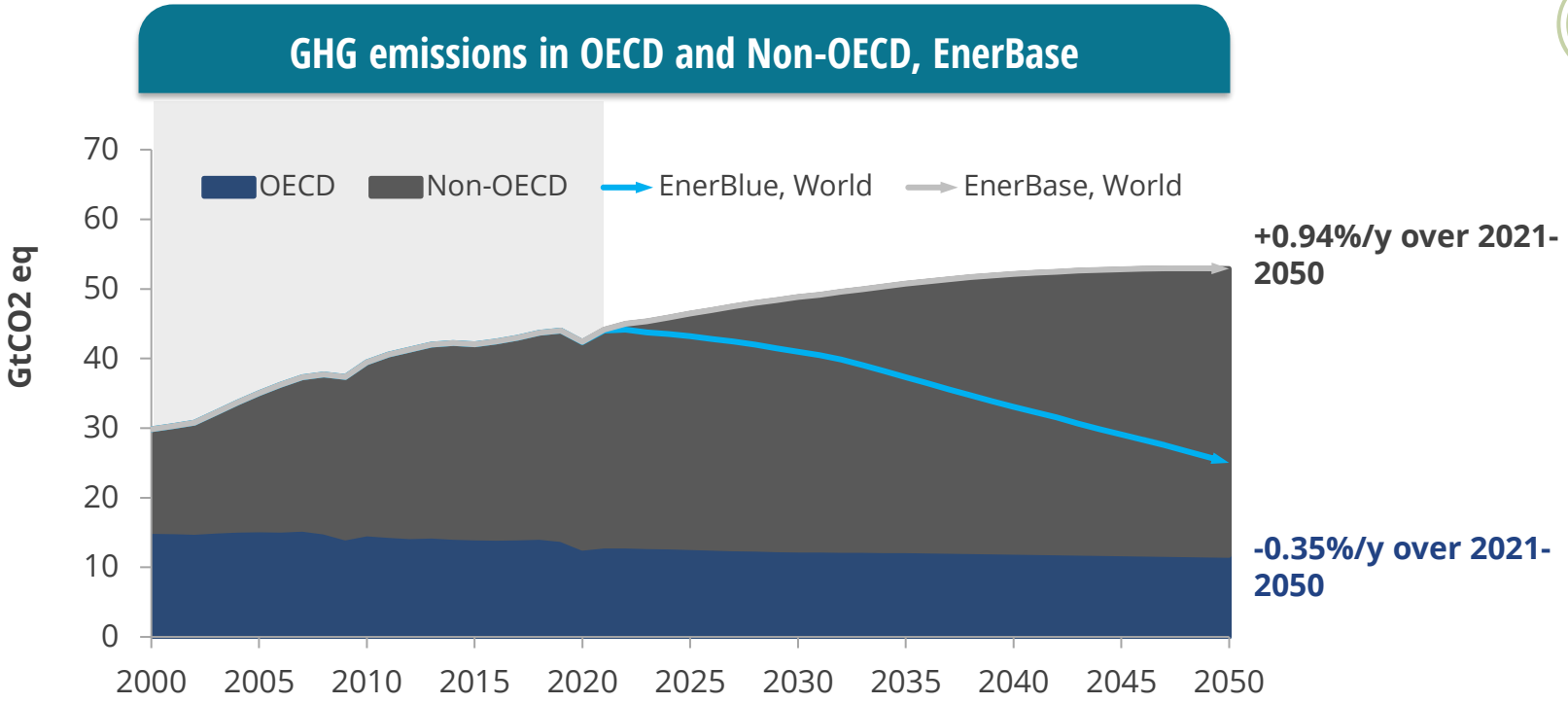
Source: EnerFuture
Comparison base year: 2010

Fossil fuel remain dominant in both OECD and non-OECD



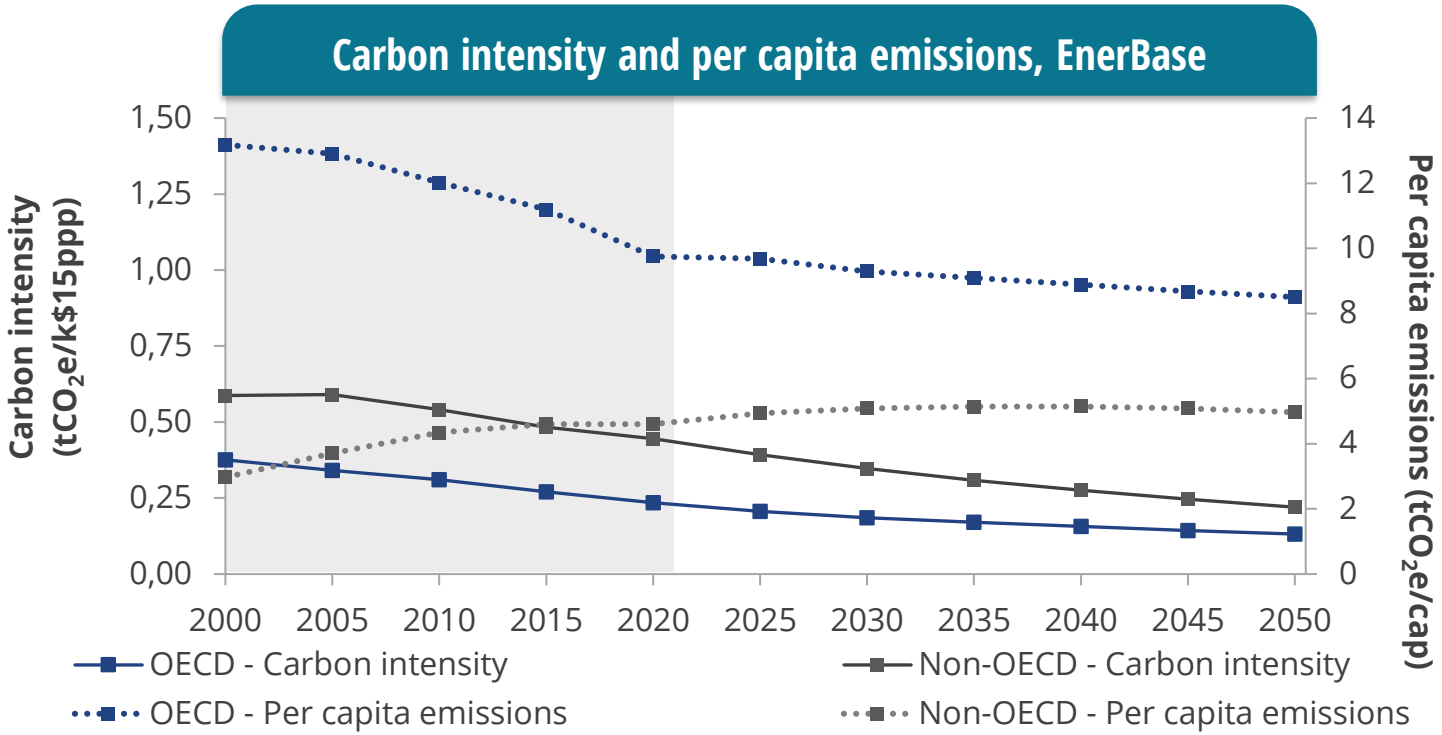
- Fossil fuel consumption increases in absolute terms (+21% over 2021-2050)

Emissions from non-OECD countries continue to increase steadily



- GHG emissions increase globally by 0.6%/year between 2021 and 2050, driven by growth in developing countries
- Developed countries fail to significantly curb their emissions

Carbon intensity decreases globally



- In the absence of specific policy support, efforts to decorrelate GHG emissions from economic and demographic growth are very limited
- Carbon intensity slightly decreases following recent historic trends while emissions per capita roughly stabilise in OECD countries, and moderately increase in non-OECD countries

4 EnerBlue

What impacts from new NDCs achievement?

Enerdata

EnerBlue: Scenario Definition

- EnerBlue describes a world in which **the Nationally Determined Contributions (NDCs) are achieved,** and longer-term trends are pursued up until 2050. These commitments correspond to the pledges as firstly defined after the Paris Agreement and updated in successive COPs up to the end of 2021.

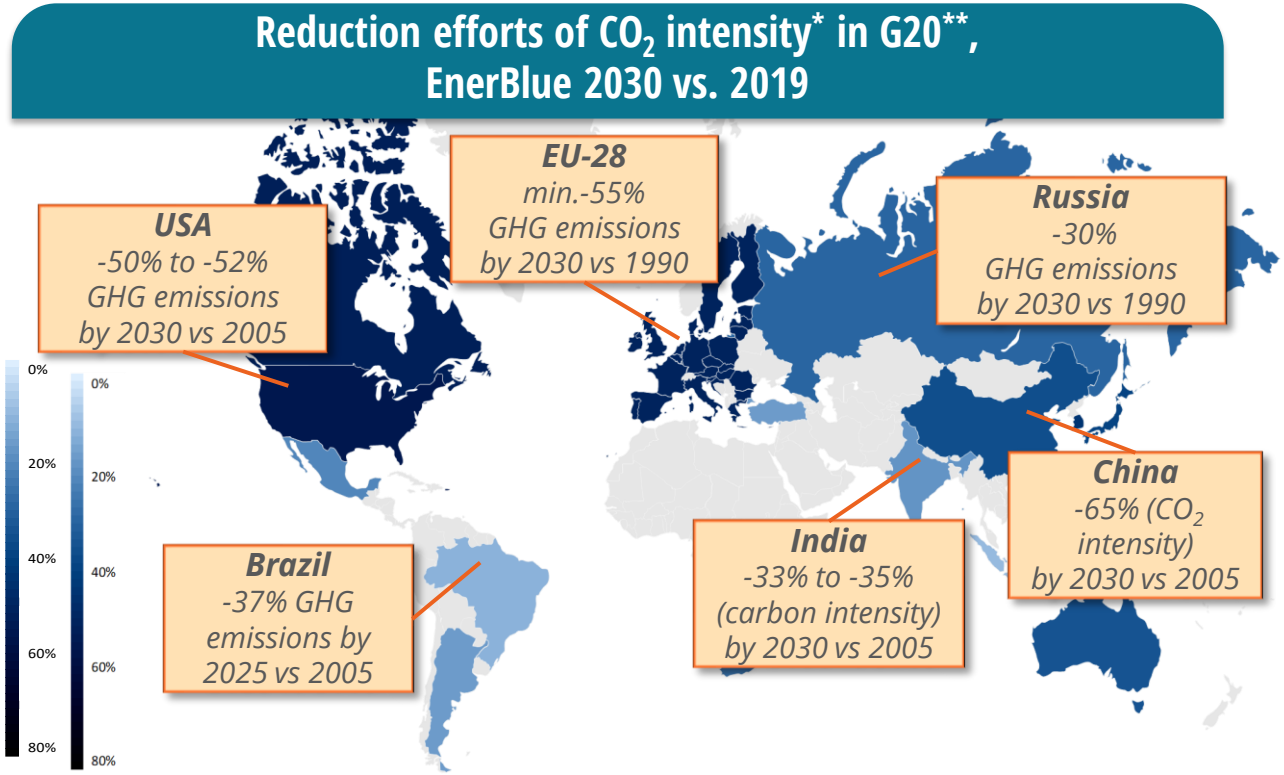
- International fossil **fuel prices remain overall stable** or experience a very slight increase, reflecting lower demand

- While sustained growth in emerging economies is a powerful driver of global energy consumption, **NDCs play a key role in controlling the pace of demand growth and integrating carbon-free technologies** into the global energy mix

- At global level, **GHG emissions peak around 2030** in non-OCDE countries and fall afterwards, while largely decreasing in OCDE countries.

- *EnerBlue leads to a temperature rise between 2°C and 2.5°C.*

New targets revised upwards in countries' NDCs

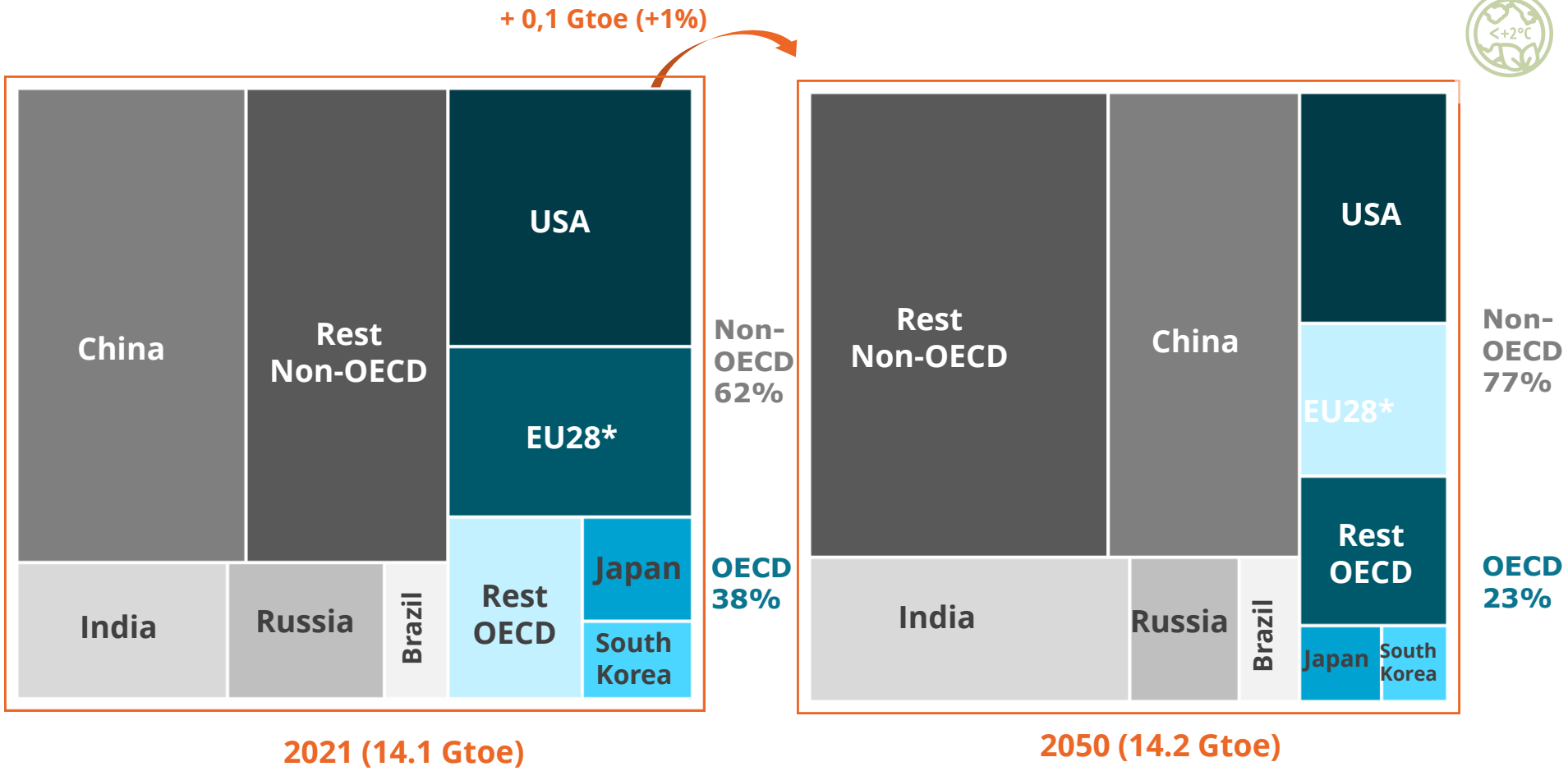


- No harmonised definitions of NDCs targets, with different scopes or reference years
- Large range of efforts by country through conditional vs unconditional targets, which leads to uncertainty in ambition levels

Source: UNFCCC, submitted NDCs, EnerFuture EnerBlue scenario

* CO_2 intensity of GDP: ratio of CO_2 emissions to GDP, excl. LULUCF
** G20 countries represent ~84% of global CO_2 emissions (2019)

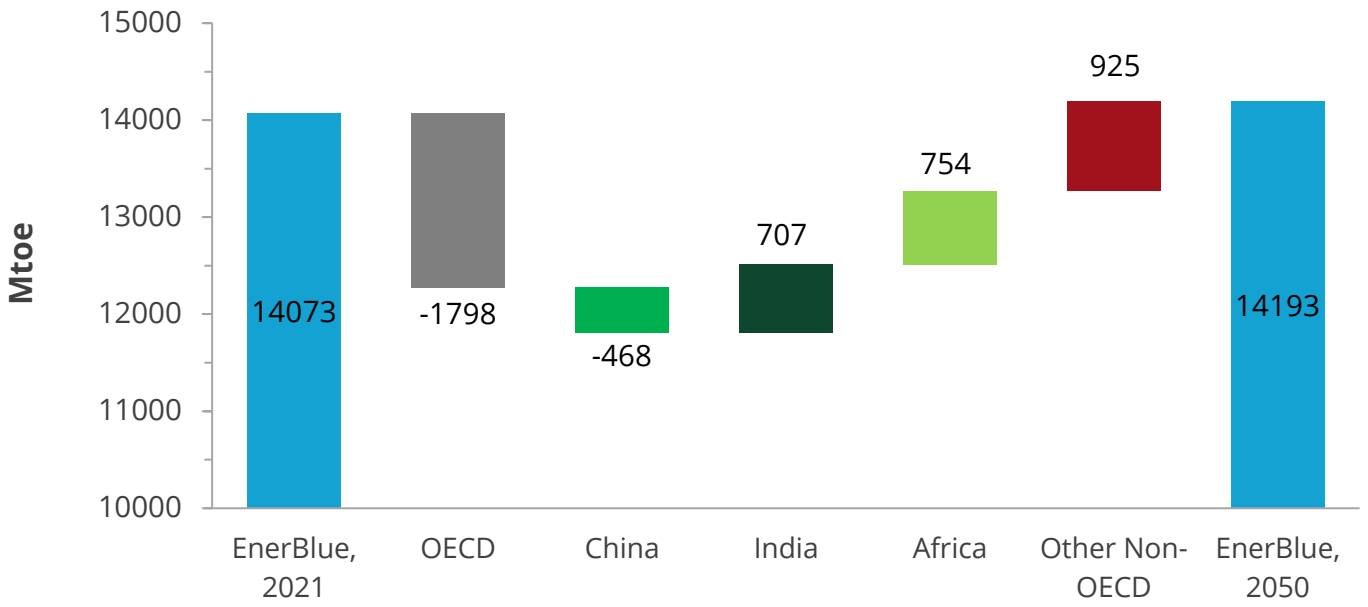
Non-OECD countries drive the increase in energy consumption, whereas OECD demand slightly decreases



** excluding non-OECD countries*

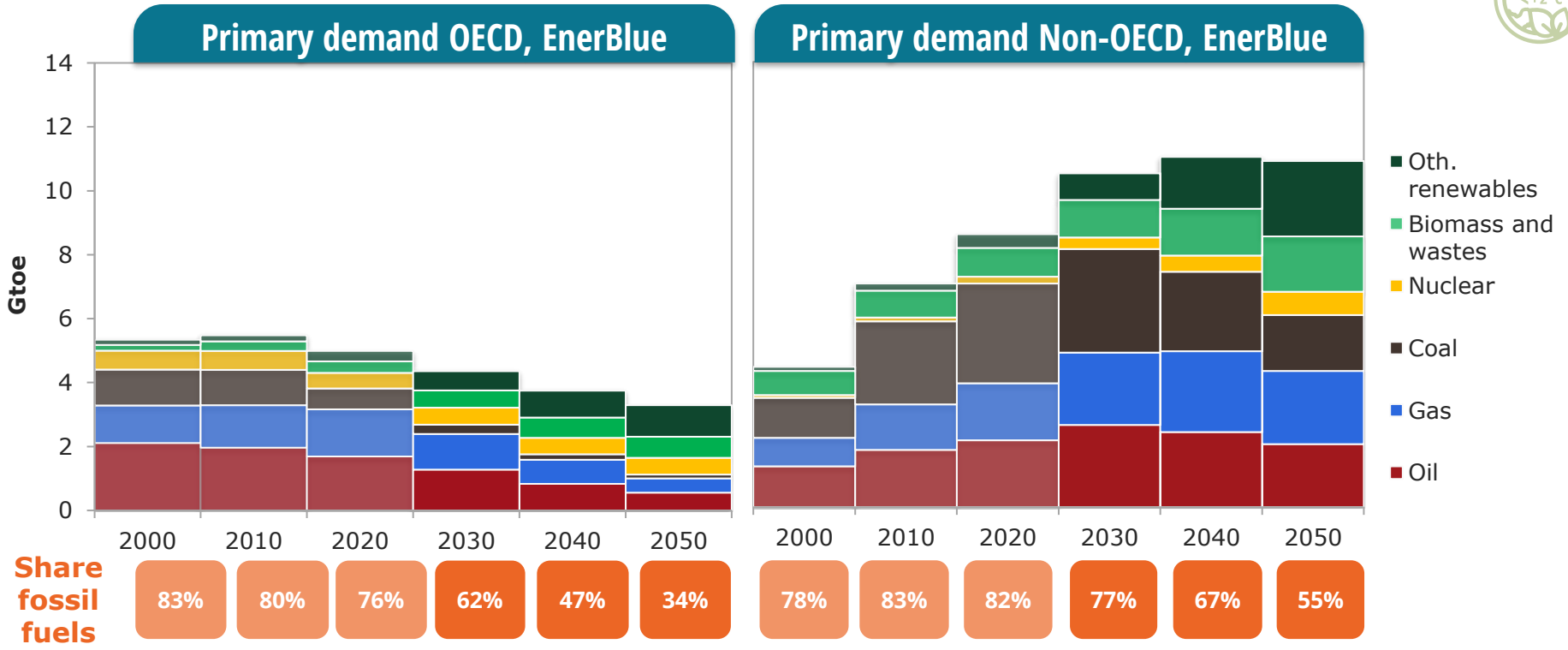
As primary consumption decreases in OECD countries and China, Africa and India drive the global demand increase

Regional contribution in primary consumption, 2019 vs 2050, EnerBlue



- African and India alone are expected to account for more than 60% of the increase in non-OECD primary energy consumption

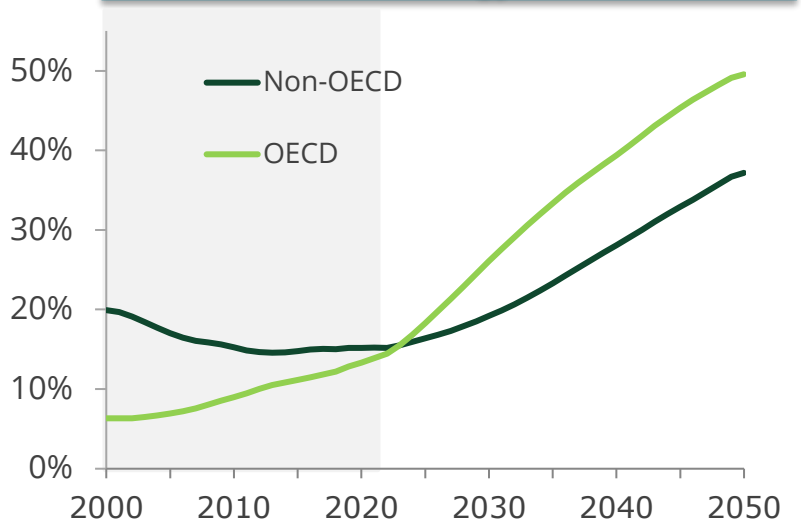
Progressive shift from fossil fuels to renewables both in the OECD and in non-OECD countries



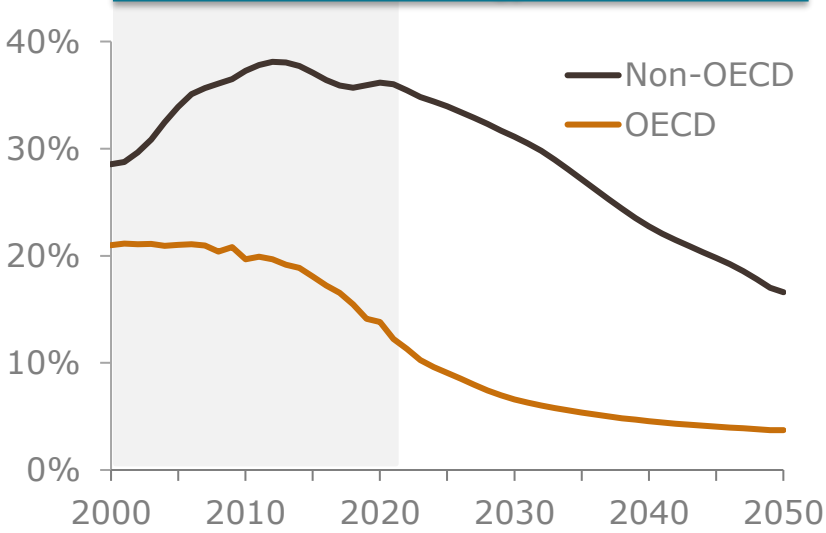
- However, in absolute values the fossil fuels demand increases by 9% in non-OECD countries between 2021 and 2030
- The switch from oil and coal to gas in OECD countries is rapidly curbed by renewables.

How renewables and coal compare in the next 30 years

Share of RES in energy mix, EnerBlue

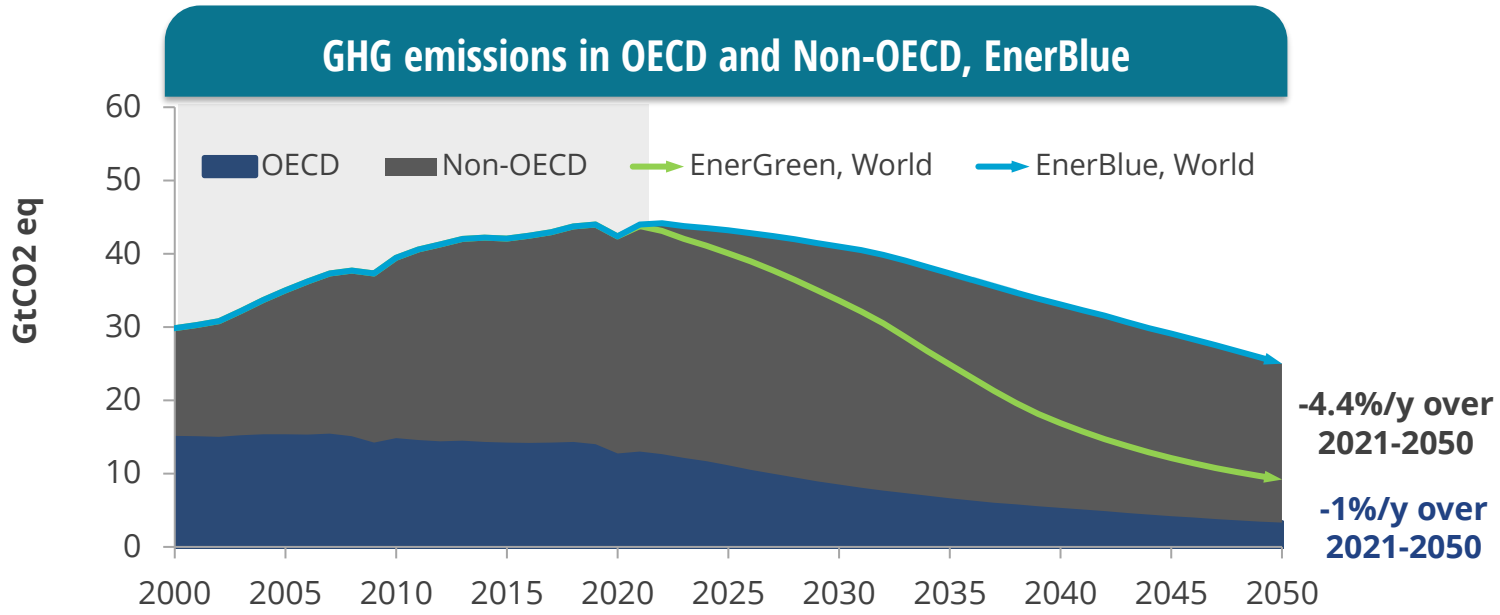


Share of coal in energy mix, EnerBlue



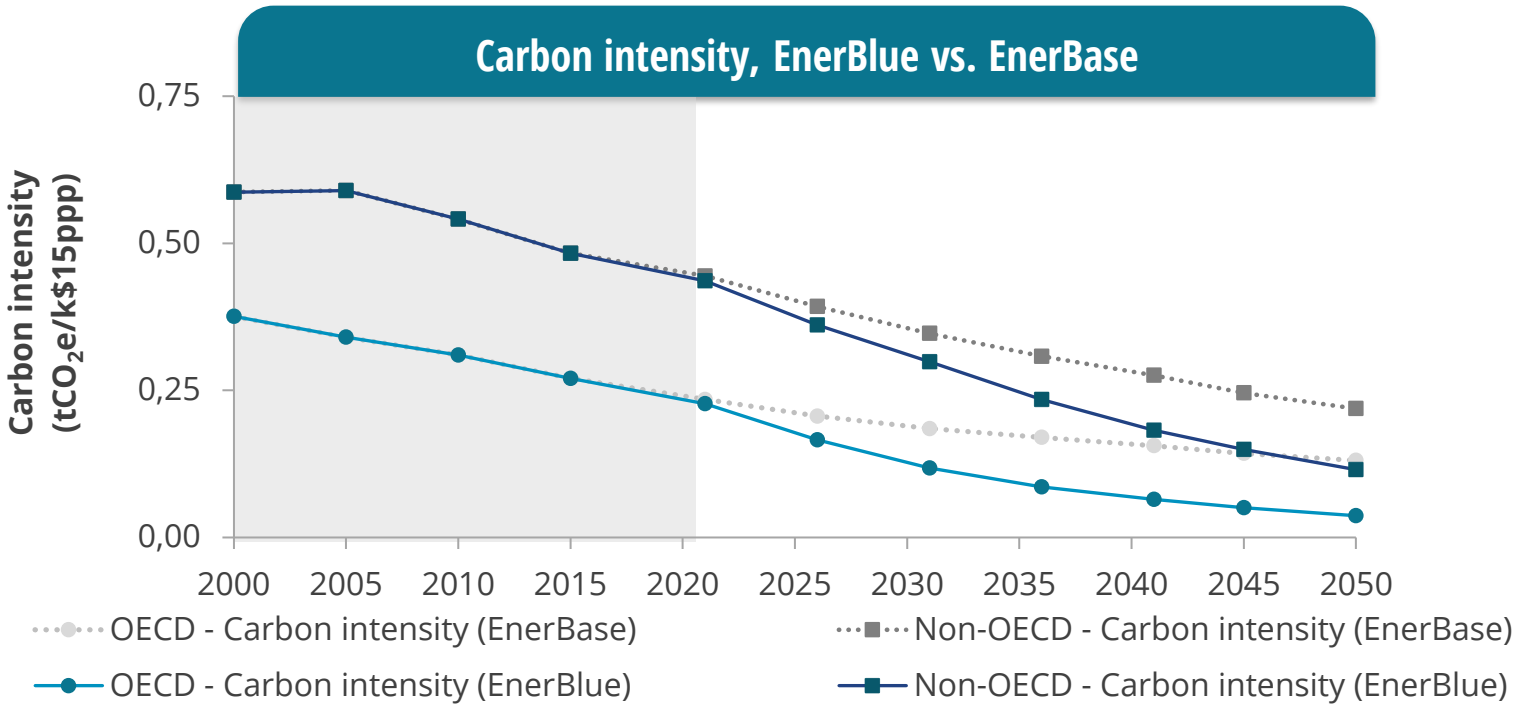
- RES grow in both OECD and Non-OECD regions, with a take-off in OCDE countries around 2025.
- Progressive decline of the share of coal in non-OECD, but remains substantial by 2050 (16%), while downward trend continues in OECD and stabilizes at 4%.

Emissions decrease globally by 2050 in EnerBlue



- NDC-based policies implemented in EnerBlue allow to balance the economic-driven growth in developing countries, while emission reductions in OECD countries are much more significant than in EnerBase
- Climate mitigation efforts are still far from being enough to reach the Paris agreements goals, as suggested by the EnerGreen global emission trajectory

Substantial energy efficiency improvements are required



- Carbon intensity decreases globally at a much higher pace than in EnerBase, similarly across OECD and non-OECD countries (-5.9 and 4.3%/year on average between 2021 and 2050, vs. -1.9% and -2.3%/y respectively in OECD and non-OECD in EnerBase)

5

EnerGreen

Which challenges to stay below 2°C temperature rise?

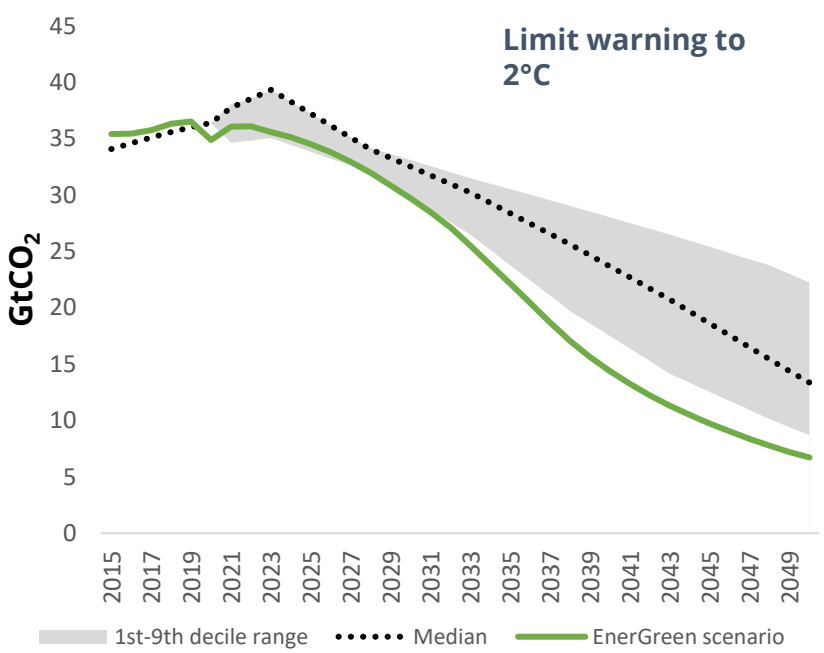
Enerdata

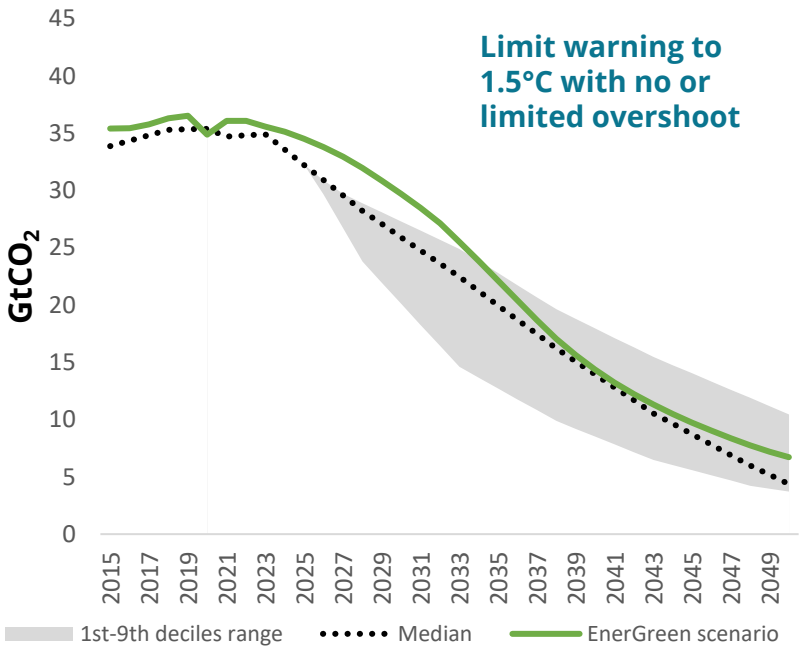
EnerGreen: Scenario Definition

- EnerGreen is a scenario exploring the implications of more **stringent energy and climate policies to limit climate change**
- In this context, **fossil fuel market prices are driven down by lower demand**, but **carbon pricing** more than balances this effect for end-user prices
- With countries regularly revising upwards their commitments and emissions goals, **significant improvements are made in energy savings**, through both sufficiency and efficiency. In parallel, decarbonation processes are in place with a **strong deployment of renewables**
- The scenario leads to an **important decrease in global emissions**, with a regional distribution of the effort based on a customized methodology
- Non-OECD countries **drastically reduce their carbon intensity**, while a lot of OECD countries reach **carbon neutrality**
- *EnerGreen leads to a temperature rise below 2 °C*

EnerGreen is in line with a limitation of global temperature increase below 2°C

CO_2 emissions (energy + industry) in EnerGreen compared to +1.5°C and +2°C scenarios



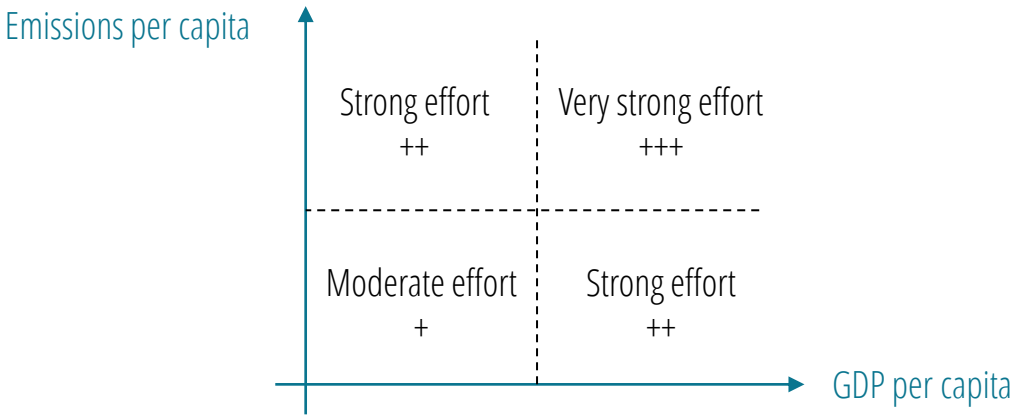


Source: IIASA AR6 scenario database

- Emissions trajectories in EnerGreen are lower than equivalent trajectories of scenarios deemed compatible with a +2°C increase in global temperatures
- However, EnerGreen emissions pathway is not aligned with +1.5°C scenarios

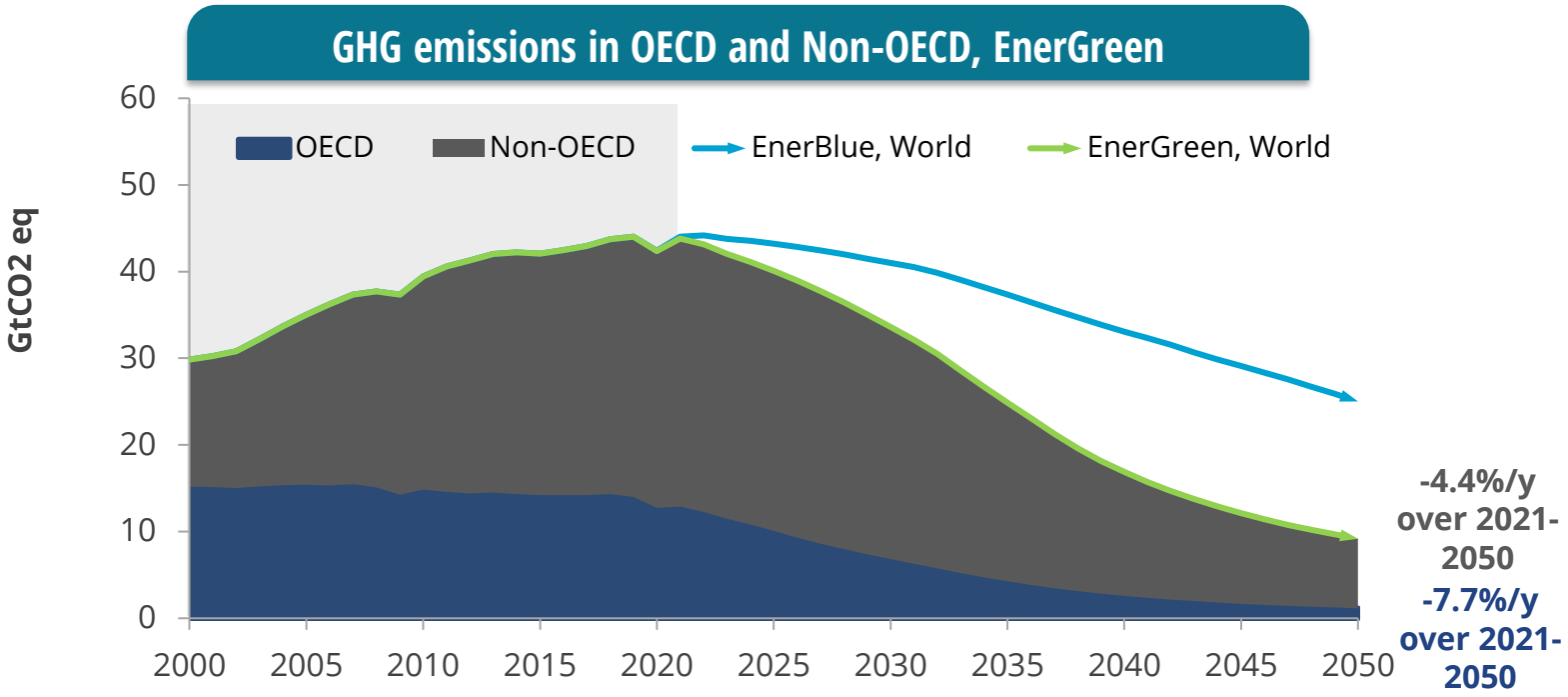
EnerGreen: Methodology for 2°C Compatible Country Pathways

- Approach based on soft-landing and capacity-responsibility indicator
  - Emissions follow a **soft-landing** trajectory, i.e.
    - ✓ As smooth as possible
    - ✓ Characterised by a peak, followed by a plateau and a decrease
    - ✓ Abatements start in the short term and reach a highest around 2030-40
  - Mitigation efforts are determined by a **capacity-responsibility indicator** (based on GDP per capita and emissions per capita)



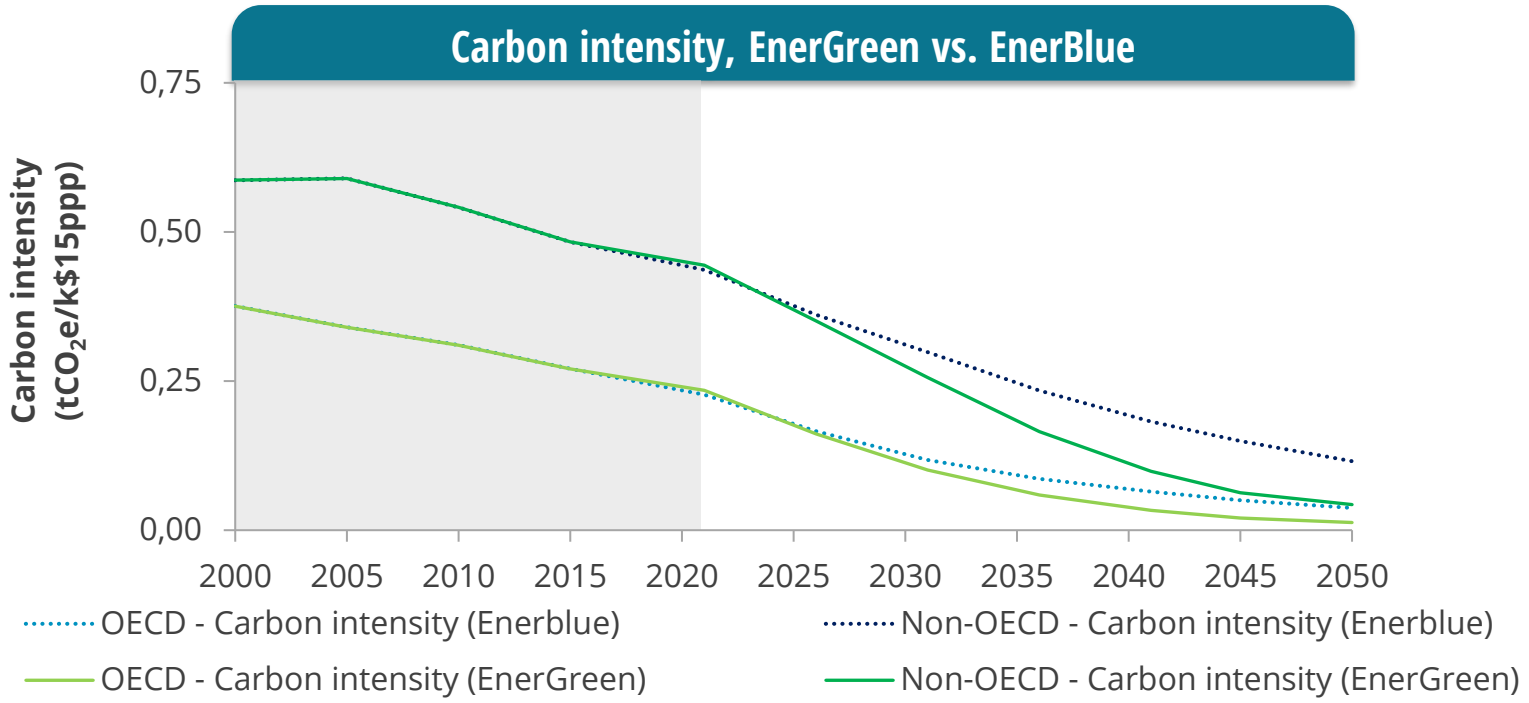
- Reference: *National soft-landing CO_2 trajectories under global carbon budgets*, Criqui P., Ilasca C., Prados E., 2014

Carbon emissions are significantly reduced in EnerGreen in both OECD and non-OECD countries



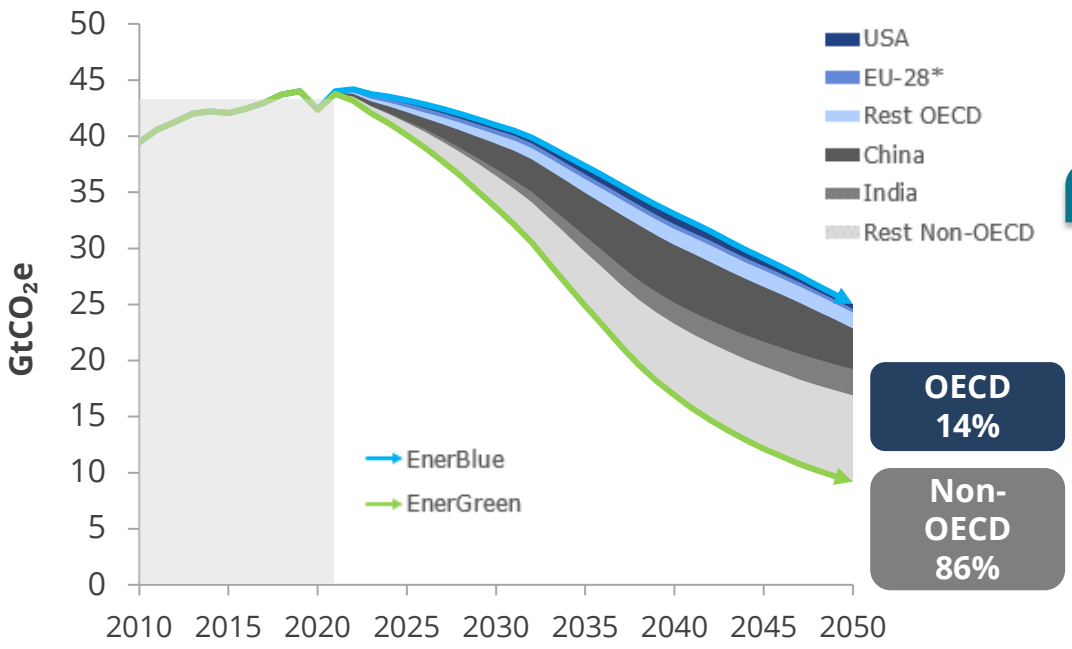
- Global emissions in EnerGreen drop very sharply, with a **significantly increased early action** (-18% in 2030 compared to EnerBlue)

Carbon intensities are significantly reduced in EnerGreen in both OECD and non-OECD countries



- EnerGreen suggests higher relative efforts for non-OECD countries, in order to converge to some extent towards carbon intensity levels of OECD members

About 80% of additional emission reductions are carried out by non-OECD countries



OECD 14%

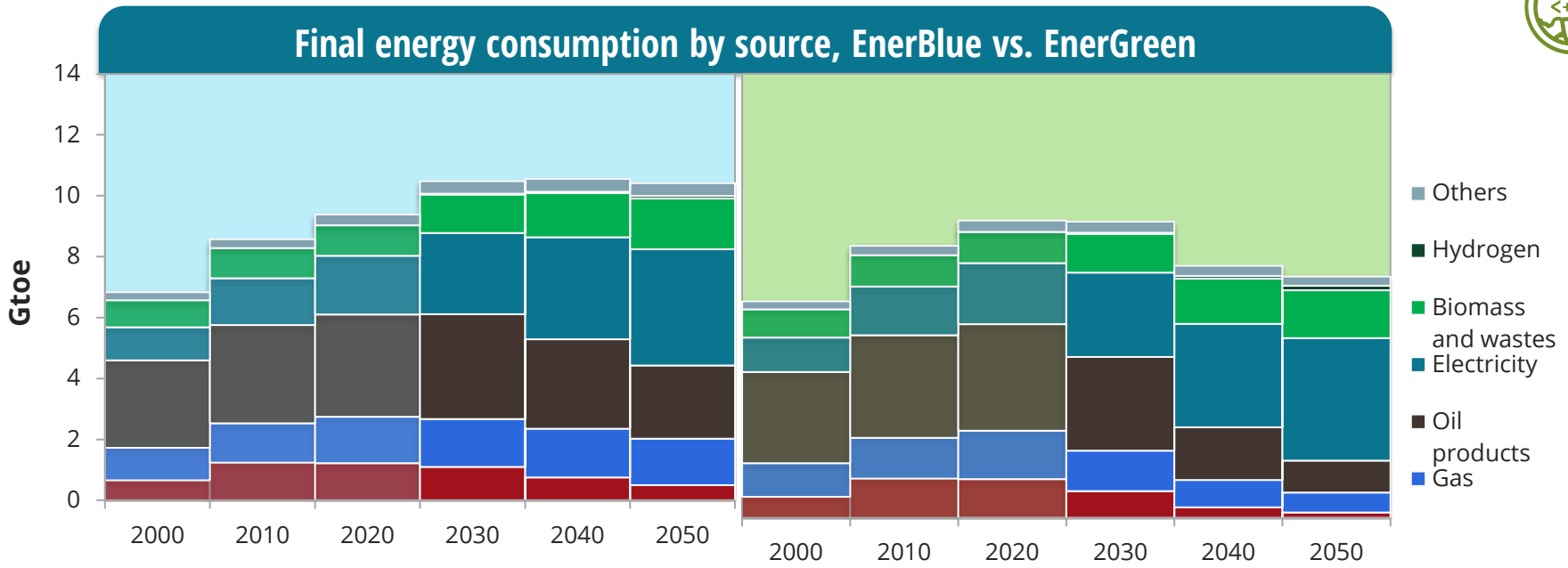
Non-OECD 86%

% reduction, cum. 2021-2050		
USA	**54 $GtCO_2e$**	**5%**
EU-28*	**29 $GtCO_2e$**	**3%**
Rest OECD	**41 $GtCO_2e$**	**10%**
China	**157 $GtCO_2e$**	**29%**
India	**46 $GtCO_2e$**	**12%**
Rest Non-OECD	**140 $GtCO_2e$**	**41%**

* OECD members only

- The **core of the emission reductions** required to reach an emissions pathway that is compatible with a 2°C temperature increase lies with **developing countries**, with e.g. China alone accounting for 29% of the required abatement

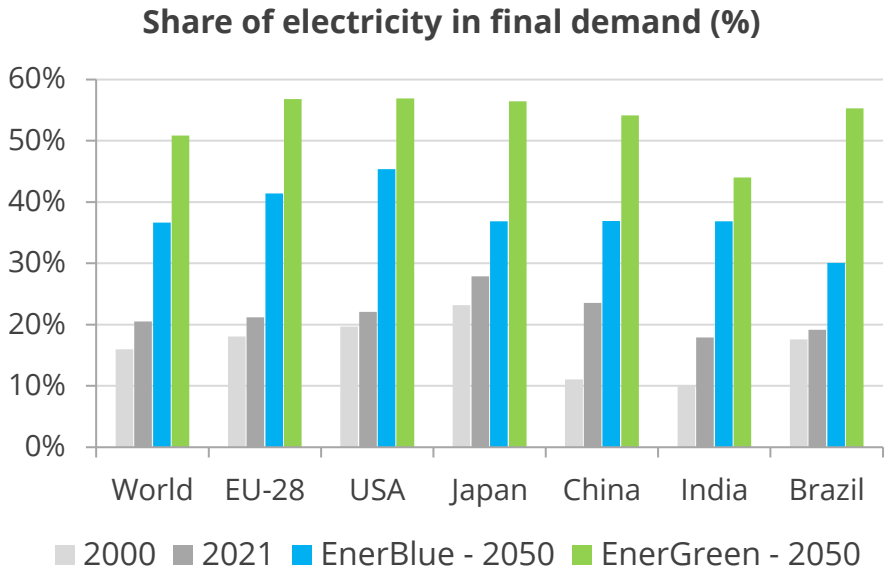
Combined energy efficiency and decarbonisation efforts lead to lower final demand and high share of clean energy vectors



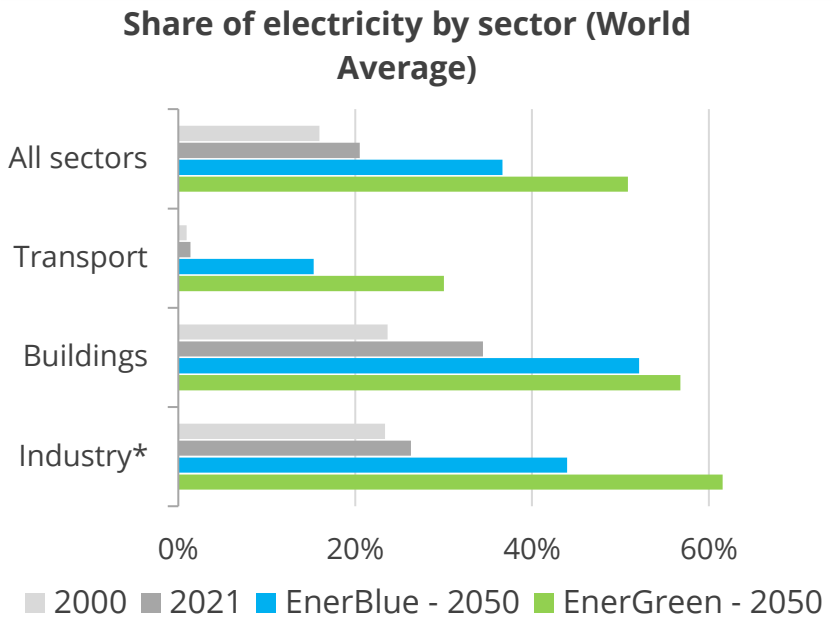
- Global final consumption is significantly curbed in EnerGreen (27% below EnerBlue in 2050), and **decarbonised sources** account for up to **70% of the total** in EnerGreen, mainly due to electricity and bioenergy
- **Hydrogen** plays a **marginal** – yet not negligible - role overall in energy transition as per EnerGreen (about 2% of final consumption in 2050)

Electrification appears as a main pillar of energy transition and decarbonation

Share of electricity in final demand, %



Share of electricity by sector, World, %

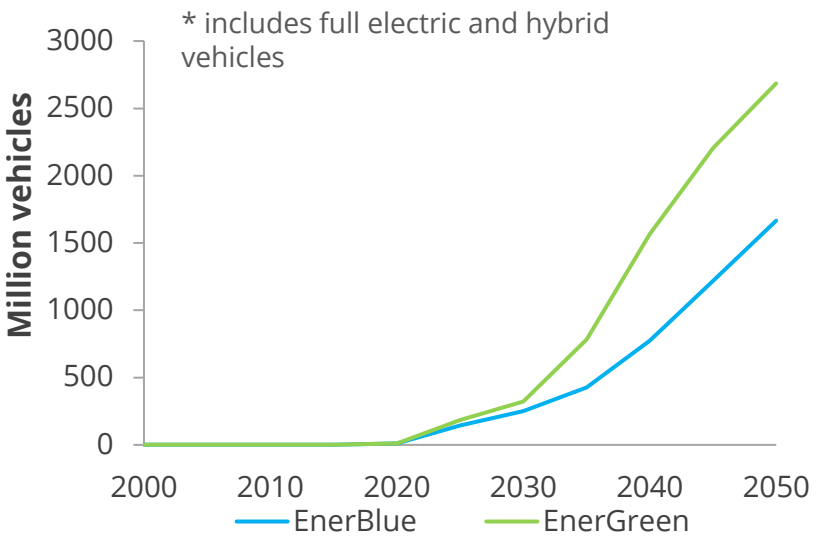


** excluding non-energy uses*

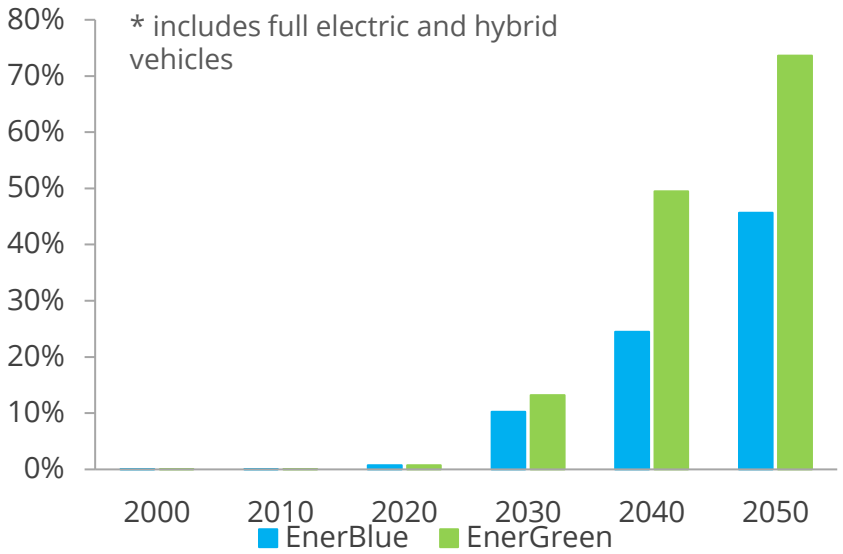
- The **share of electricity in final demand** increases across all sectors and regions in all three scenarios, **reaching 51%** (+14pp vs EnerBlue) in 2050 in EnerGreen globally, from the current 21%
- The buildings sector remains the main consumer of electricity followed by industry, while **transport** shows the **highest relative growth** in terms of electricity consumption

In 2050, electric vehicles account for almost 80% of the car fleet

Number of electric cars* in total car fleet



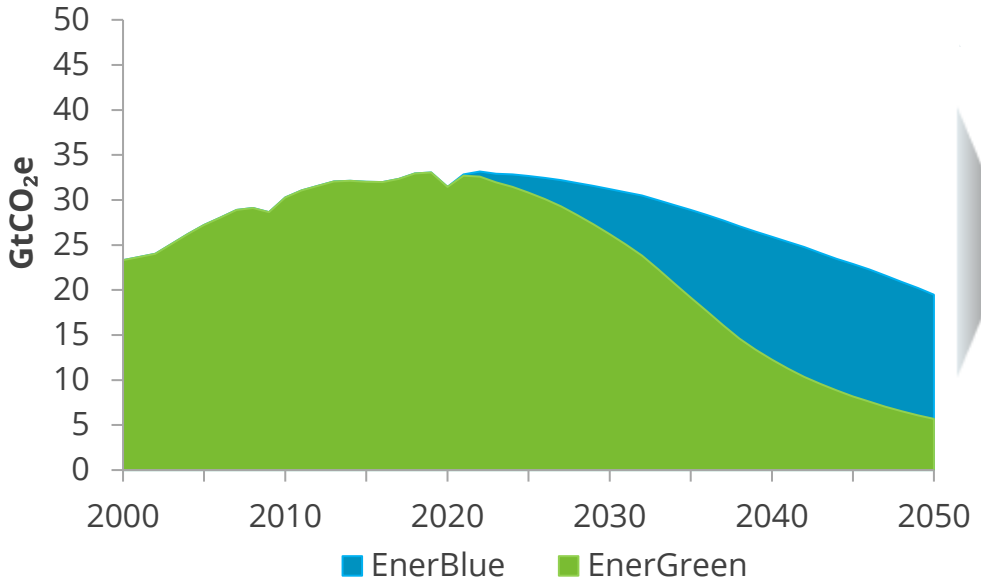
Share of electric cars* in total car fleet



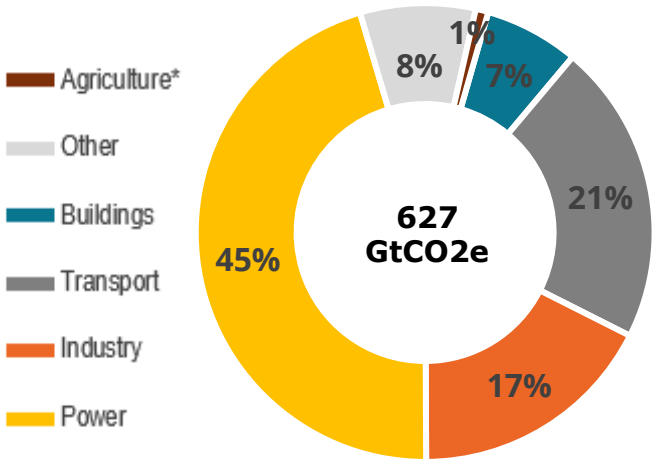
- In 2050, the share of electric vehicles reaches 74% of the car fleet in 2050 (2.7 bn EVs) in EnerGreen and 46% in EnerBlue
- This uptake represents a total of **200 Mbl of avoided oil consumption** in EnerGreen compared to EnerBlue

Early action is required in the electricity generation sector, presenting the lowest abatement costs

GHG emissions, World



Cumulative reduction options, 2021-2050, World

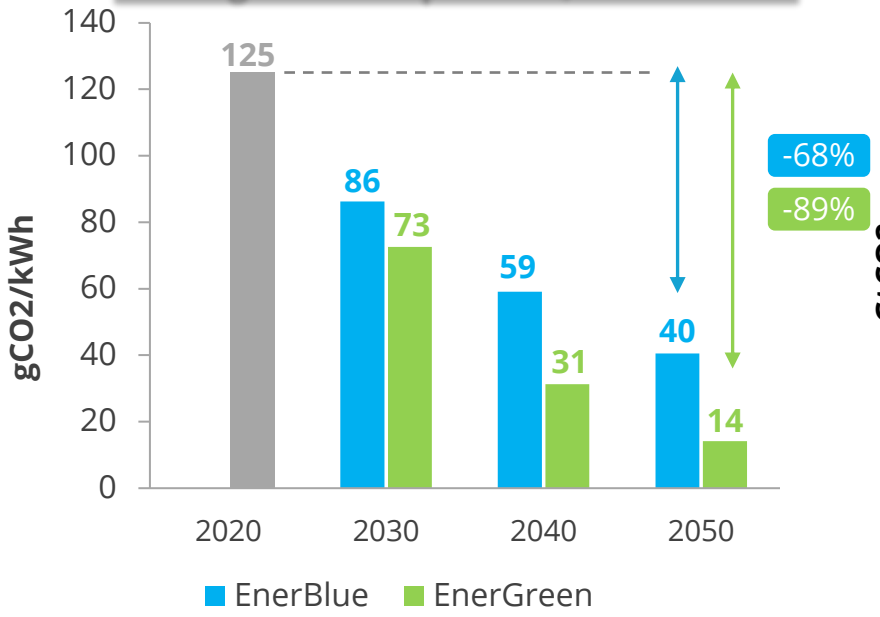


* Fuel combustion only

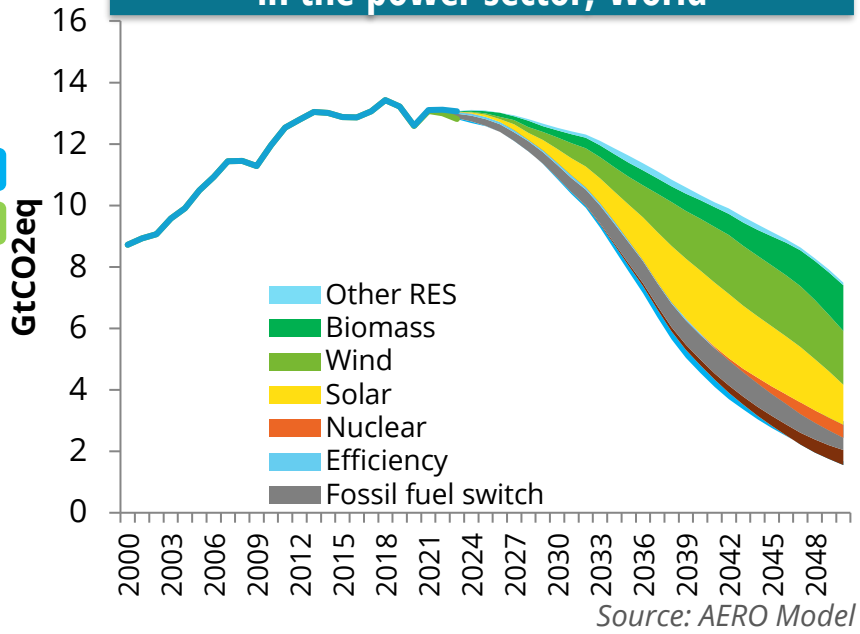
- Power generation could contribute to 45% of the emissions reductions required over 2021-2050 to reach the below +2°C target

Each kWh of electricity generated will release about 90% less CO_2 emissions in 2050 vs 2020

CO_2 emissions of electricity generation per kWh, World



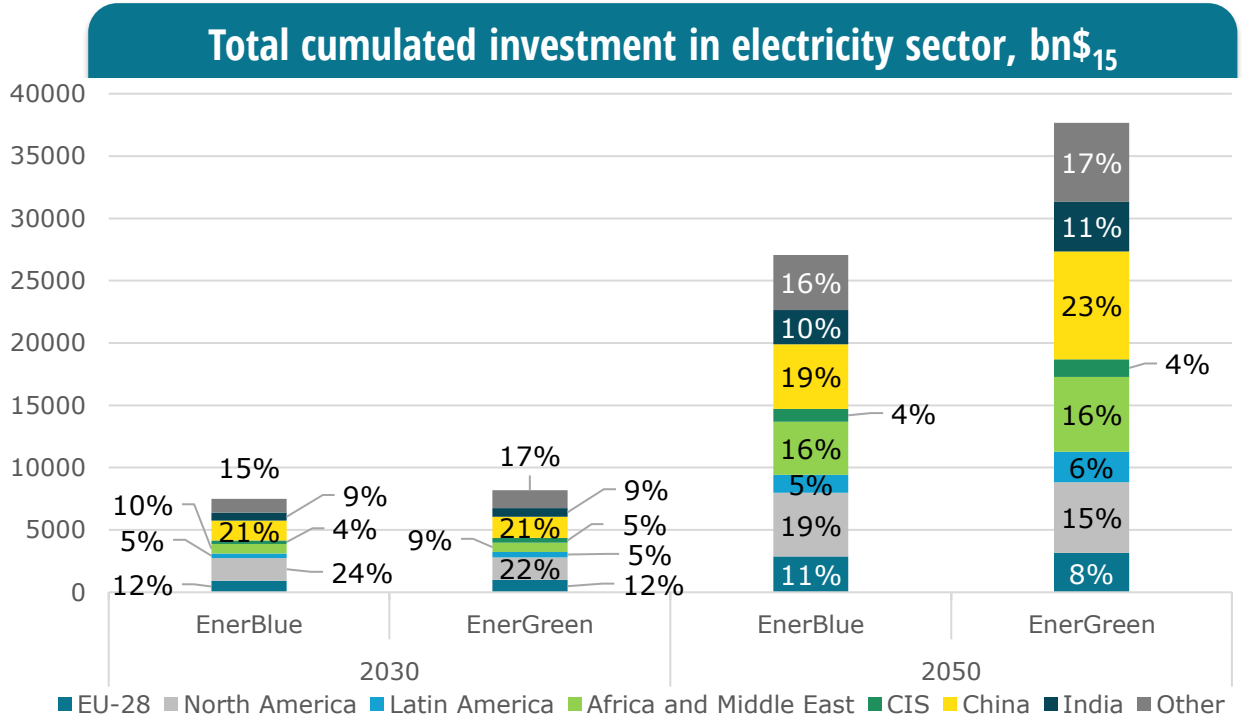
Emission reduction options in the power sector, World



Source: AERO Model

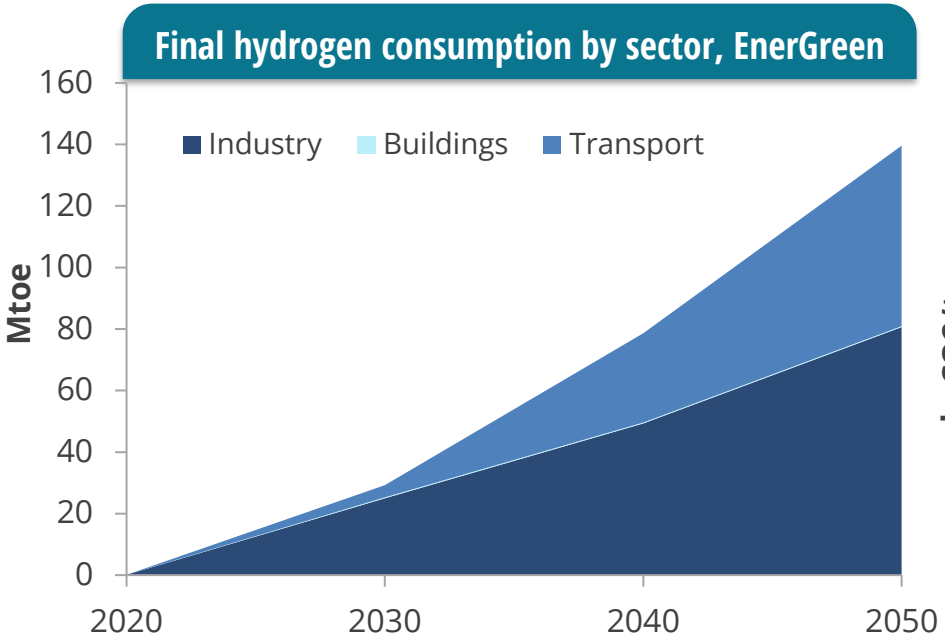
- The main decarbonation driver in power generation is the deployment of renewables, while CCS and nuclear appear as a competitive option with substantial potential only after 2040.
- Wind, solar and biomass are the main drivers of abatement globally between EnerGreen and EnerBlue

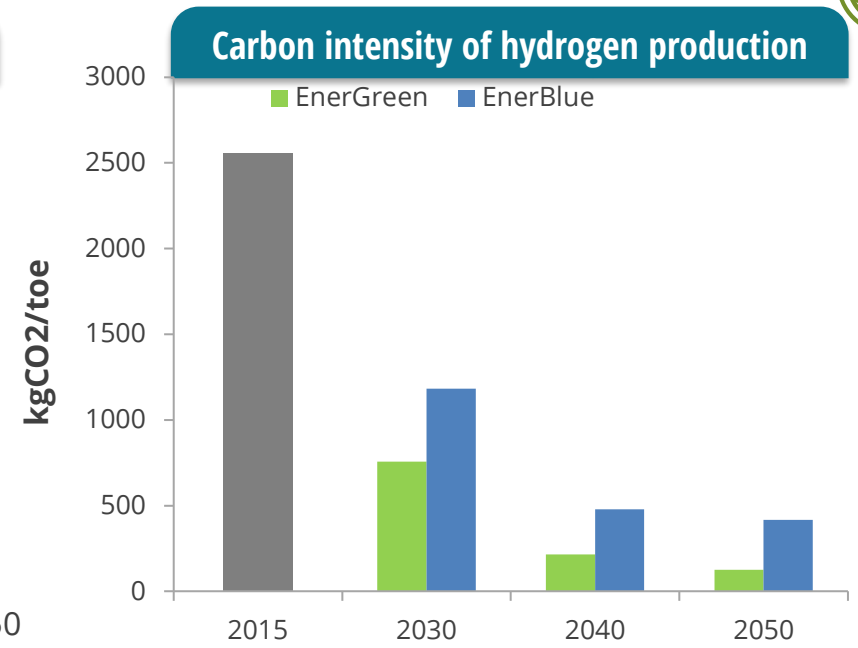
In the future, China will continue to be by far the first investor in power generation assets



- In China, the 2020-2050 cumulated investment in the electricity sector corresponds to $\$_{2015}$4,069bn in EnerBlue and $\$_{2015}$8,660bn in EnerGreen (roughly ¼ of the global cumulated investment)
- Over 2020-2050, the cumulated investment in the electricity sector represents between 1.06% (Africa, Middle East) and 0.38% (EU-28) of GDP (EnerGreen scenario), with 0.62% for China

The role of hydrogen in global energy consumption remains limited, despite a relatively significant uptake in transport





- Though limited overall (2% of global energy consumption), hydrogen accounts for up to **4% of energy consumption** in the **transport** sector globally in 2050 in EnerGreen
- In the meantime, to fully exploit the potential of hydrogen as a decarbonisation lever, production massively switches towards cleaner production methods, mainly electrolysers
- In EnerGreen, carbon intensity is **reduced by 70% in 2050** compared to EnerBlue

6 Conclusions

EnerFuture Scenarios Takeaways

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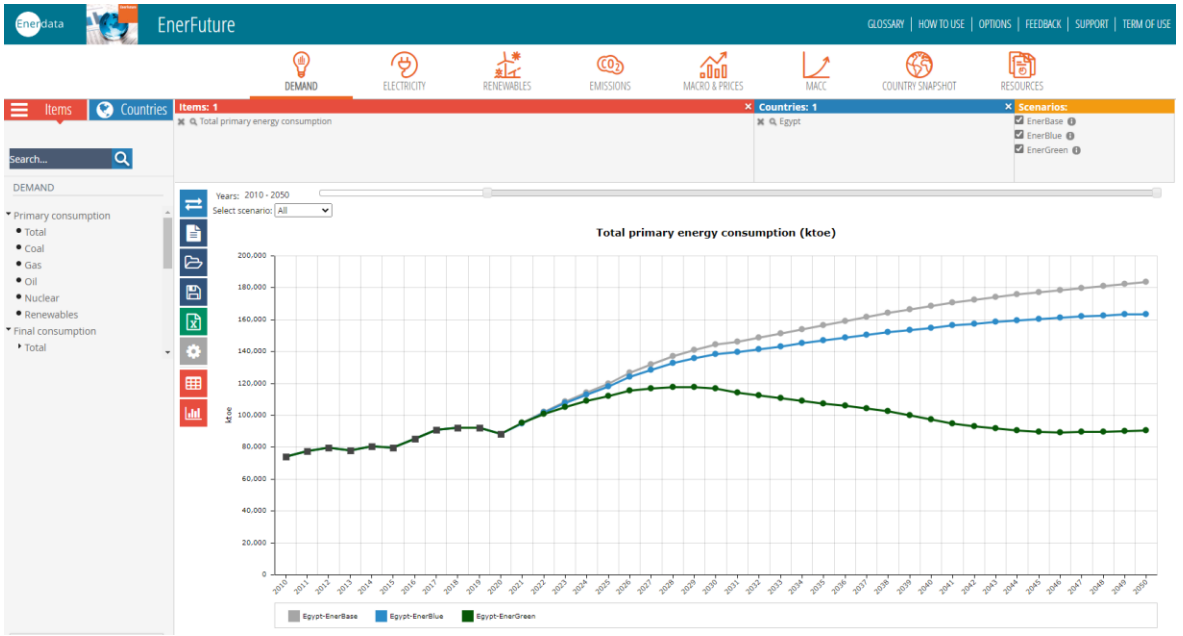
EnerFuture Scenarios: Wrap-Up

EnerBase	EnerBlue	EnerGreen
CLIMATE OBJECTIVES		
▪ Climate change mitigation efforts limited to existing trends ▪ NDCs objectives not reached ▪ *>3°C temperature increase*	▪ Climate ambition in line with newest NDC targets (end of 2021) ▪ Progressive policy enforcement ▪ *~2-2.5°C temperature increase*	▪ Strong global efforts towards climate change mitigation ▪ Ambitious GHG emissions budgets ▪ *<2°C temperature increase*
KEY OUTCOMES		
▪ Demand continues to grow: +34% over 2021-2050 ▪ Fossil fuels still account for 73% of primary mix by 2050 ▪ RES power production increases by 2.6 over 2021-2050, but remains just above 40% of the mix in 2050 ▪ CO_2 emissions grow by +18% over 2021-2050, reaching over 43 $GtCO_2$	▪ Demand grows by 1% over 2021-50 (+21.4% in non-OECD) ▪ Energy mix transformation: less fossil (50% in 2050), RES share 41% by 2050 ▪ Final energy intensity of GDP is cut in half over 2021-2050 ▪ CO_2 emissions decrease to around 21 $GtCO_2$ by 2050 (-41% vs. 2021), thanks to RES and energy efficiency	▪ Global demand decreases by 25% between 2021 and 2050 ▪ Fossil fuels share around 25% by 2050, coal production declines by 87% ▪ RES and nuclear represent 90% of power generation in 2050 ▪ CO_2 emissions reach around 6 $GtCO_2$ in 2050; very strong reduction efforts in non-OECD

EnerFuture online service: benefit from instantaneous access to POLES-Enerdata model outputs

- Annual projections to 2050 for 65 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 2022

Global Energy Scenarios Through 2050

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About Enerdata

Enerdata is an energy intelligence and consulting company established in 1991.

Our experts will help you tackle key energy and climate issues and make sound strategic and business decisions.

We provide research, solutions, consulting and training to key energy players worldwide.

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7 Annex

Additional EnerFuture Material

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Annex 1

Methodology

The POLES-Enerdata Model

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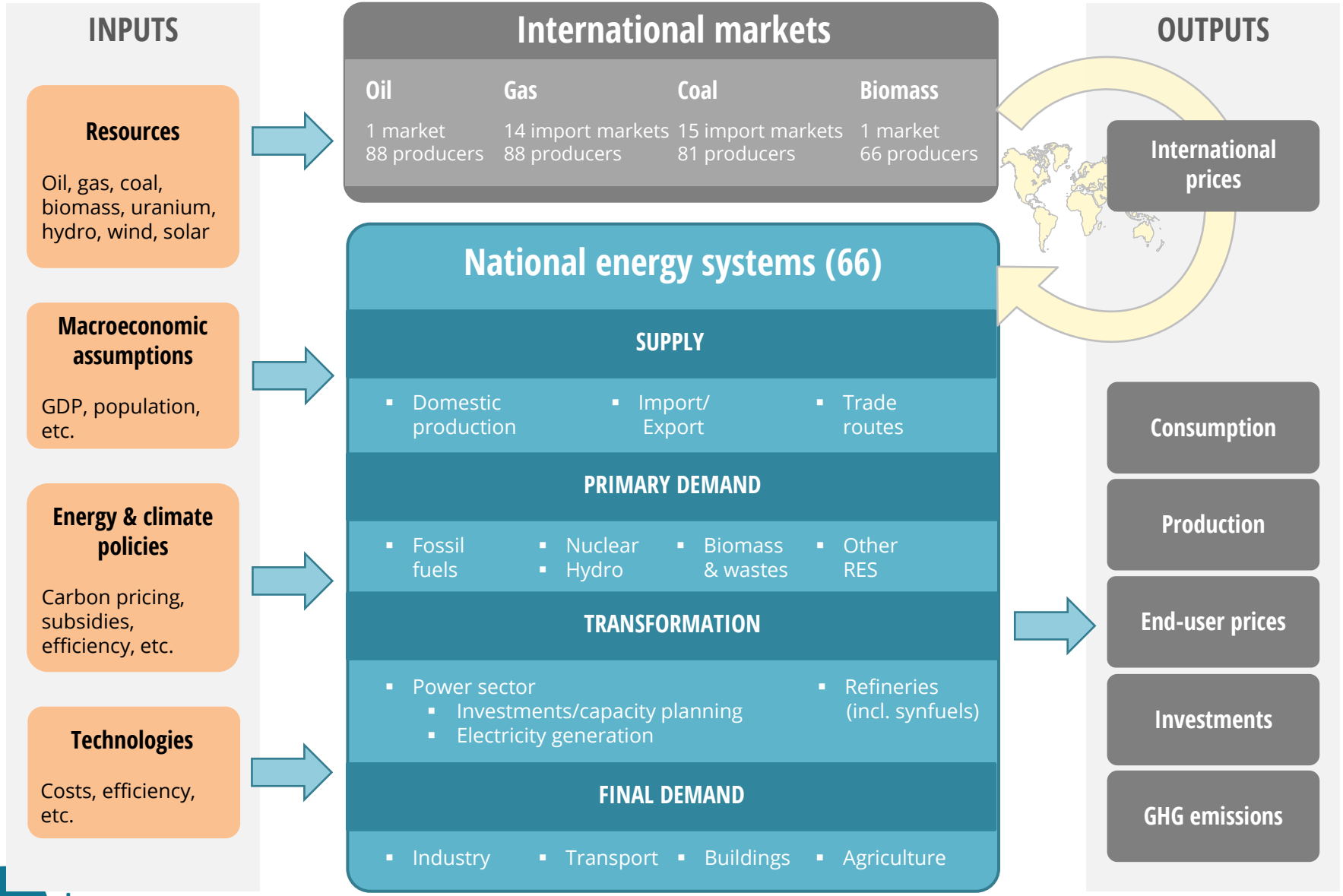
POLES-Enerdata: Origins and Objectives

- The objective of **POLES** (**Prospective Outlook on Long-term Energy Systems**) is to analyse and forecast 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: 66 Countries and Regions Covered

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: Issues and Topics Covered

Energy Demand

- 66 countries/regions
- 15 detailed sub-sectors industry, buildings & transportation, incl. detailed description of large Energy Intensive Industries : steel, aluminium…
- All key energies: oil, gas, coal, power, biomass, solar, wind
- End consumer prices
- Detailed demand technology description (buildings, transport)
- Demand function based on activity levels, prices effects, autonomous technological change

Energy supply

- Oil, gas, coal, and renewables
- Resources, discoveries and reserves for 88 producing countries
- Production strategies (countries)
- Unconventional oil and gas
- International and regional prices: oil, gas, coal, biomass
- Development potential for renewables
- Oil, gas, coal, and biofuels, imports & exports

Transformation

- 30 different power generation technologies
- Simulation of future power generation mix by country
- Power capacity planning
- Electricity load forecasting
- Power price analysis
- Technology availability scenarios: Nuclear revival or phase-out, CCS, wind & intermittency…
- Impact of support schemes for renewables (feed-in tariffs…)
- Hydrogen

POLES-Enerdata: Overview of Modules

- Resources
- Population and GDP
- Policies
- Technology costs

Assumptions and Inputs

- Consumption by sector and energy type
- Energy efficiency

Demand

- Capacity and production planning
- Investment, fix and variable costs

Power Generation

- International fossil fuel prices
- End-user prices

Energy prices

- Oil, gas, coal and renewables
- Resources, production, trade

Fossil Fuel Supply

- Assessment of carbon taxation policies
- ETS and non-ETS

Carbon Markets

- Energy and emissions balances
- Energy prices
- MACCs

Outputs

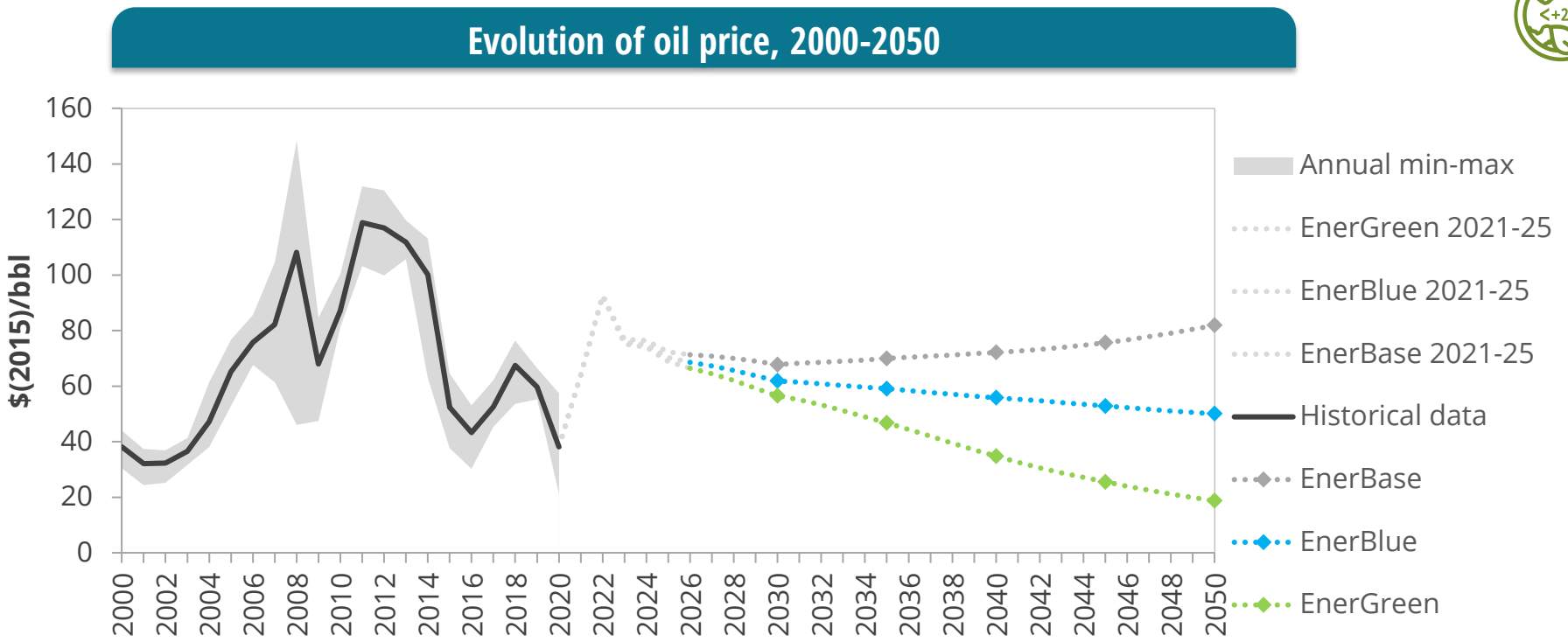
Annex 2

Energy Supply

Focus on Long-Term Trends

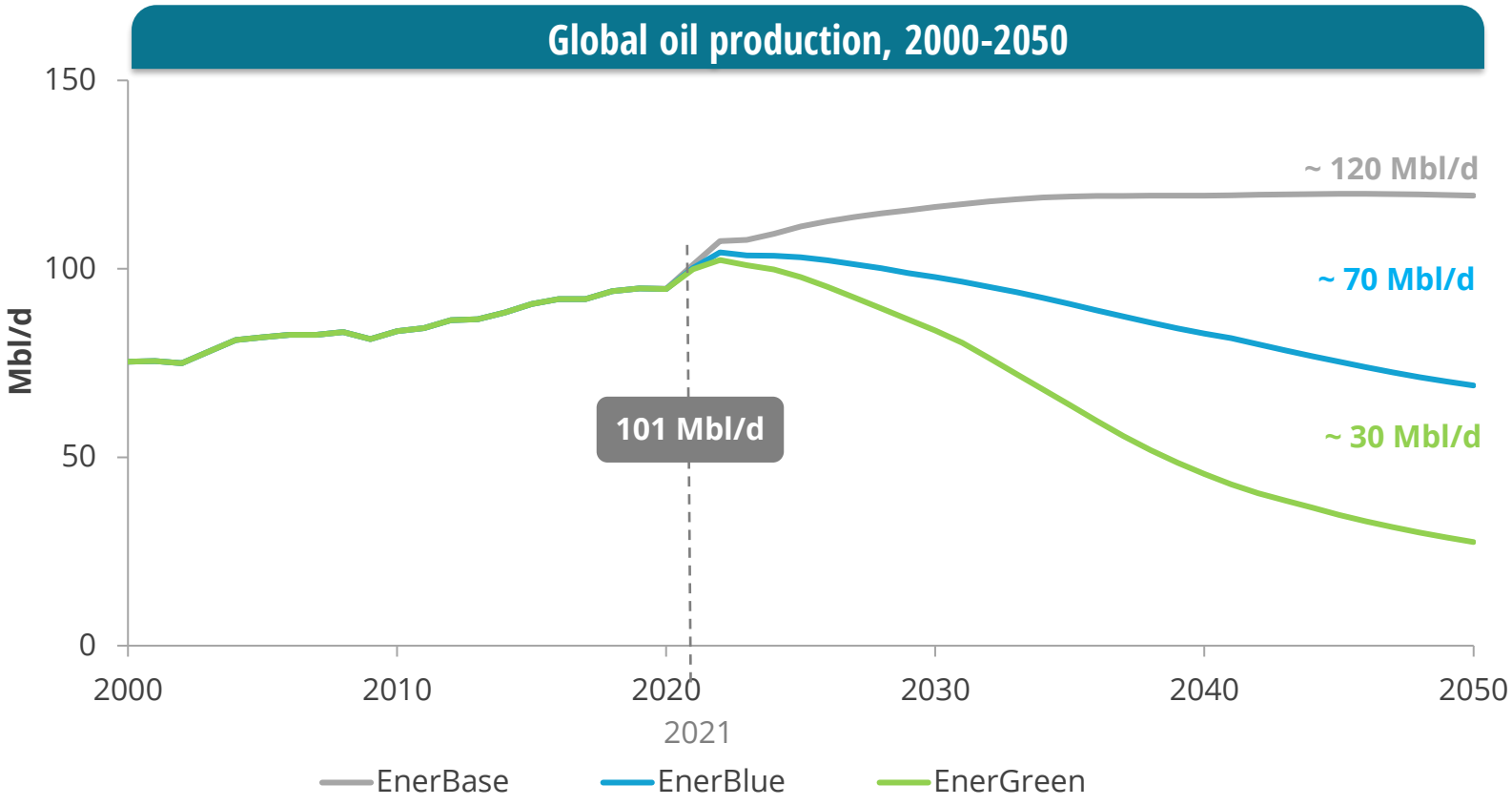
Enerdata

Based on supply-demand fundamentals, long-term oil prices are strongly depending on climate ambition



- Without global cooperation on climate policies, the geopolitical context and risks could lead oil to high prices, as well as high risks of volatility and security of supply issues
- In EnerBlue and EnerGreen, increased commitment towards GHG abatements leads to less demand and geopolitical risks, and therefore to lower oil prices, in a US$18-50/bbl range

Compared to EnerBlue, higher prices in EnerBase limit oil demand, leading to similar global production levels



- Enforced climate mitigation efforts in EnerGreen lead to significantly lower oil production