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GLOBAL ENERGY TRANSFORMATION

A ROADMAP TO 2050

April 2018

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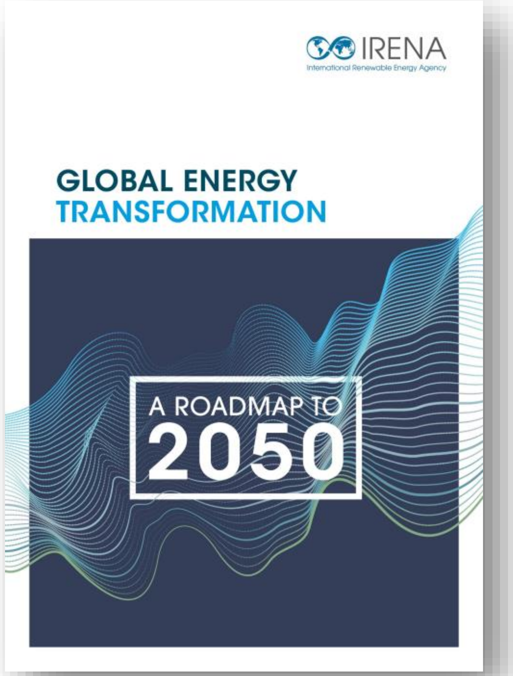
This presentation has been prepared based on the report:

IRENA (2018), *Global Energy Transformation: A roadmap to 2050*, International Renewable Energy Agency, Abu Dhabi.



This report is available for download from http://www.irena.org/publications.

Energy-related CO_2 emissions: Bridging the gap

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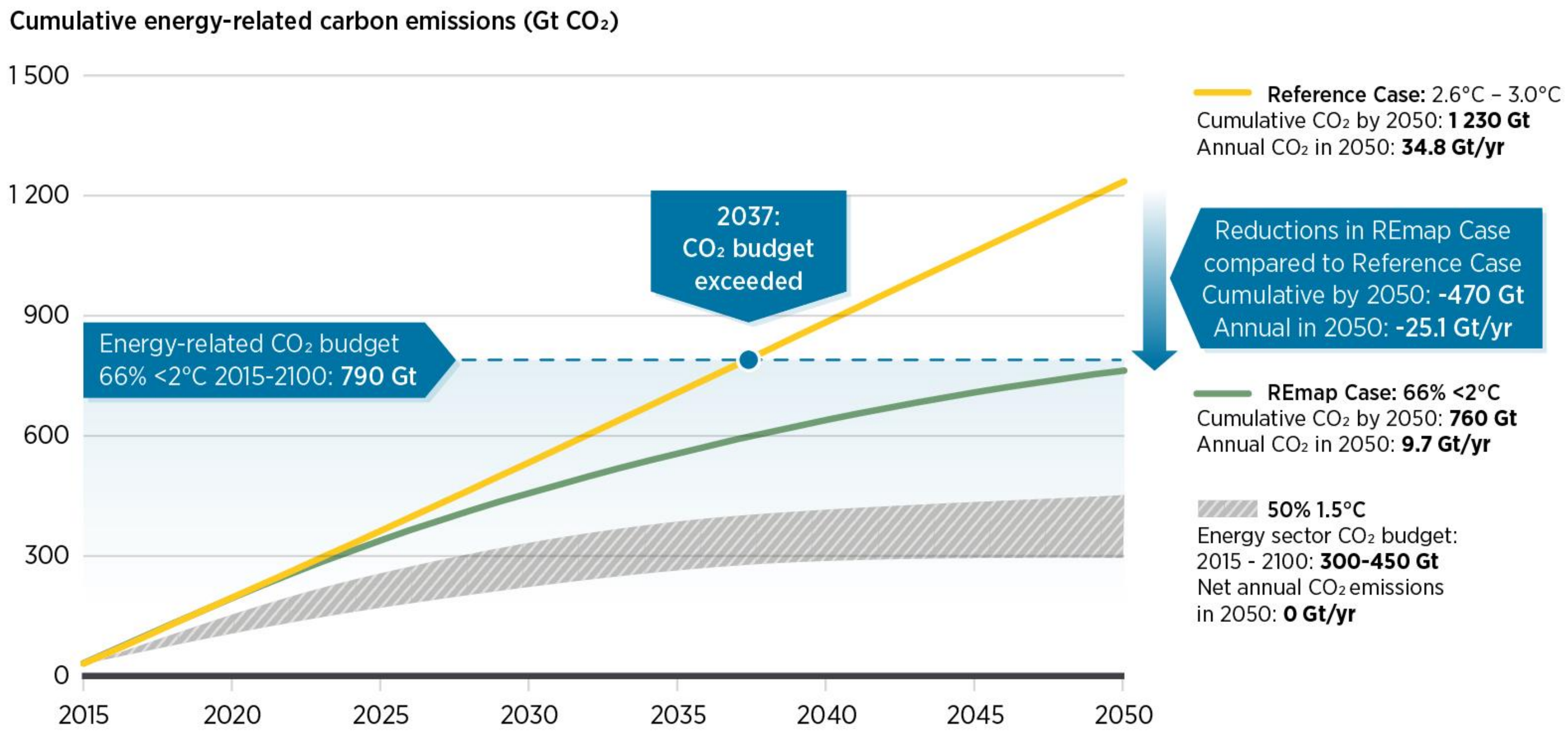
- The reduction of energy-related CO_2 emissions is at the heart of the energy transition.
- Government plans also still fall short of emission reduction needs.
- According to the **Reference Case, energy-related CO_2 emissions will increase slightly year on year to 2040**, before dipping slightly by 2050 to remain roughly at today's level.
  - » The Reference Case reflects current and planned policies including NDCs.
- IRENA's analysis concludes that **renewable energy and energy efficiency,** coupled with deep electrification of end-uses, **can provide over 90% of the reduction in energy-related CO_2 emissions**

Energy-related CO_2 emissions: Bridging the gap with IRENA's REmap Case

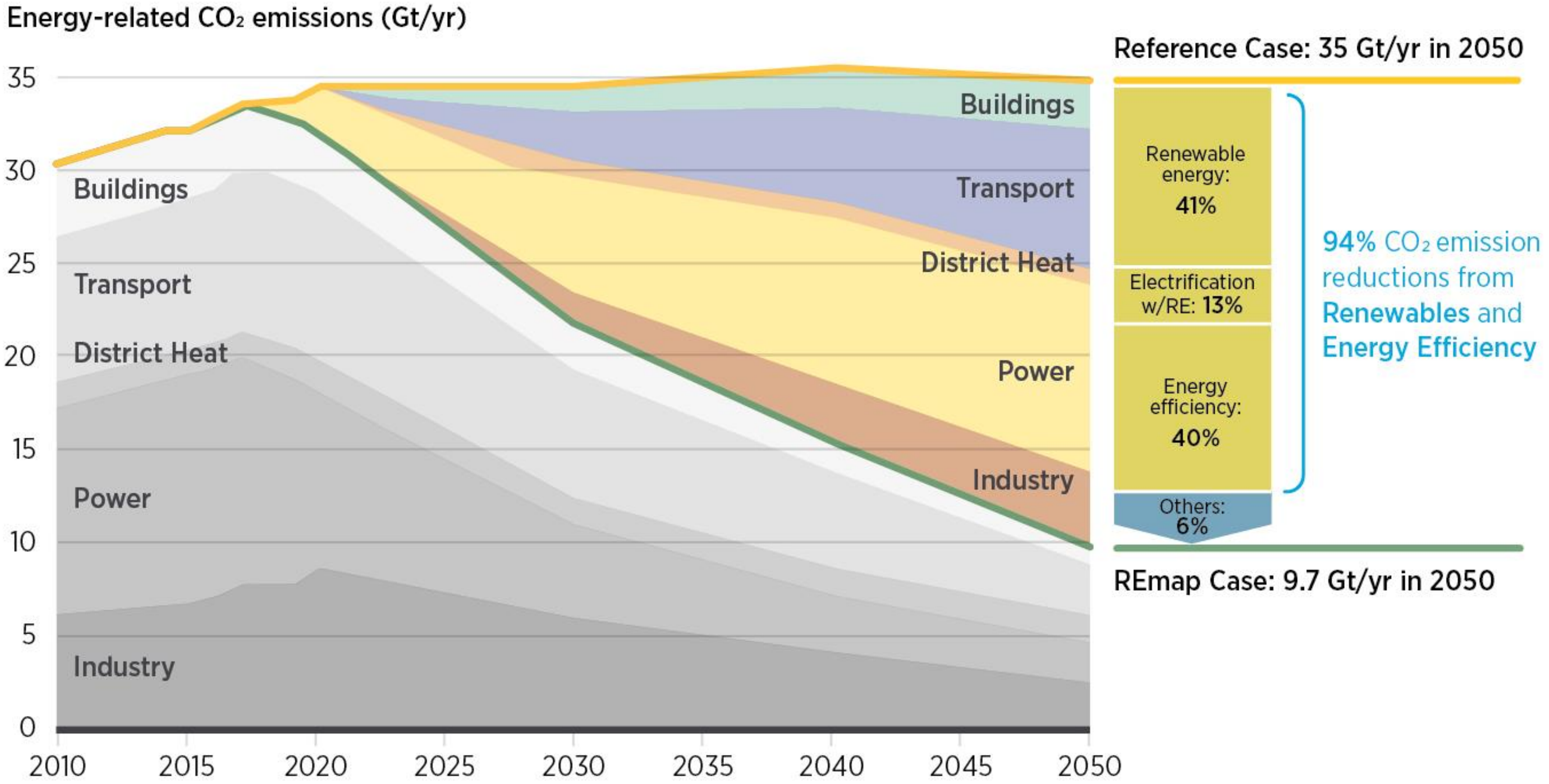
Cumulative energy-related CO_2 emissions and emissions gap



Based on current policies (set out in the Reference Case), in under 20 years, cumulative energy-related emissions will exceed the carbon budget required to hold temperature increases below 2°C. Emission reductions of 470 Gt will be needed by 2050 to reduce warming to 2°C

Renewable energy and energy efficiency can provide over 90% of the reduction in energy-related CO_2

Annual energy-related CO_2 emissions and reductions, 2015-2050



Annual energy-related emissions are expected to remain flat (under current policies in the Reference Case) but must be reduced by over 70% to bring temperature rise to below the 2°C goal. Renewable energy and energy efficiency measures provide over 90% of the reduction required

Key messages (I)

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- The global energy system has to be transformed.
  - » An energy supply system based largely on renewable energy would create a world that is both more prosperous and exposed to fewer long-term risks.
- The starting objective of the analysis is to **limit the global temperature** rise to **below 2°C** in the present century, with **66% probability.**
- In 2017 the deployment of renewables reached record levels, both in terms of power generation and capacity addition.
  - » Overall the share of renewables in total final energy consumption grew by an estimated 0.25%, to around **19% of TFEC**, a new record. The share of renewable power is estimated to have increased to 25%.
  - » Growth in renewable energy must nevertheless accelerate six-fold.

Key messages (II)

- A sustainable energy future is technically and economically feasible.
  - » Although addressing climate change remains a key driver, the energy transition brings a much wider range of benefits than simply carbon emissions reduction.

- There is universal agreement that **energy efficiency and renewable energy are the two main pillars to reduce energy-related carbon emissions** – a key driver of climate change.

- The majority of the technologies needed are available today, and their deployment can be accelerated immediately.
  - » Technological and business model innovation remain critical to a successful and cost-effective energy transition.

Key messages (III)

- The global **energy transition makes socio-economic sense.**
  - The cumulative gain over the Reference Case through increased GDP from 2018 until 2050 would amount to USD 52 trillion.
  - By 2050, the energy transition provides increases of 15% in welfare, 1% in GDP, and 0.14% in employment over the Reference Case.

- Understanding the **socioeconomic footprint** of the energy transition is essential to optimize the outcome.
  - The **energy transition cannot be considered in isolation from the socio-economic system** in which it is deployed.
  - **Gaining insight into the footprint drivers** allows improving the transition outcome by reinforcing the adequate evolution of the transition and the socioeconomic system, fostering synergies among them.

- Maximising the socioeconomic benefits of the energy transition requires **increasing the transition ambition**, internalising **climate externalities** (carbon taxes, fossil fuel subsidies phase-out), and stimulating the diversification and reinforcement of **deep domestic supply chains.**

Key messages (IV)

- Socio-economic structures and the financial system should be aligned with broader sustainability and transition requirements.
  - » Investments need to be urgently reallocated towards low-carbon solutions.
  - » Economic flows should be aligned with transition needs, reallocating resources with priorities and incentivizing direct social involvement.
- Enable a **fair and just transition.**
  - » Collaborative process involving the whole of society are required for transition success.
  - » Costs and benefits of the energy transition should be shared fairly.
  - » Just transition: create the structures that allows those individuals and regions trapped into the fossil fuel dynamics to participate from the transition benefits.

Status of the energy transition: a mixed picture (I)

- The energy transition is underpinned by the **rapid decline of renewable energy costs.**
  - » Auction results and continued technical innovations suggest that costs will fall further in the future.
  - » Costs of solar PV and wind continue to fall: Solar PV costs are expected to halve again by 2020 (relative to 2015-2016)
- Additions to renewable **power capacity** are exceeding fossil fuel generation additions by a widening margin.
- The integration of **renewable electricity** in power systems also broke records in 2017.

Status of the energy transition: a mixed picture (II)

- **Progress in end-use sectors** (transport, industry and buildings) **is lagging**.

- Electrification **enables the rapid and cost-effective decarbonisation of road transport**.
  - » In 2017, a record of 1.2 million new electric vehicles were sold globally (around 1.5% of all car sales).

- The **building** sector, which consumes more electricity than other end-use sectors, has large potential to contribute to the transition but has observed limited progress to date.

- The most challenging sector is **industry** due to the high energy demand in energy intensive industries, the high carbon content of certain products, and the high emissions of certain processes.

A PATHWAY FOR THE TRANSFORMATION OF THE GLOBAL ENERGY SYSTEM

A pathway for the transformation of the global energy system

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- The acceleration envisaged in the REmap Case would significantly transform the global energy system.
  - » The energy intensity of the global economy would need to fall by about two-thirds by 2050.
  - » By 2050, fossil fuel use for energy would fall to one-third of today's levels.
  - » The total share of renewable energy must rise from around 15% of TPES in 2015 to around 66% in 2050.
  - » The share of electricity rises to 40% of TFEC, and 85% of electricity generation is from renewable sources.
  - » Modern bioenergy can play a vital role in the energy transition if scaled up significantly.
- Due to the vast synergies between renewable energy and energy efficiency, under the REmap Case, primary energy supply (TPES) would fall slightly below 2015 levels, despite significant population and economic growth.

The global share of renewable energy in energy supply would need to increase to two-thirds

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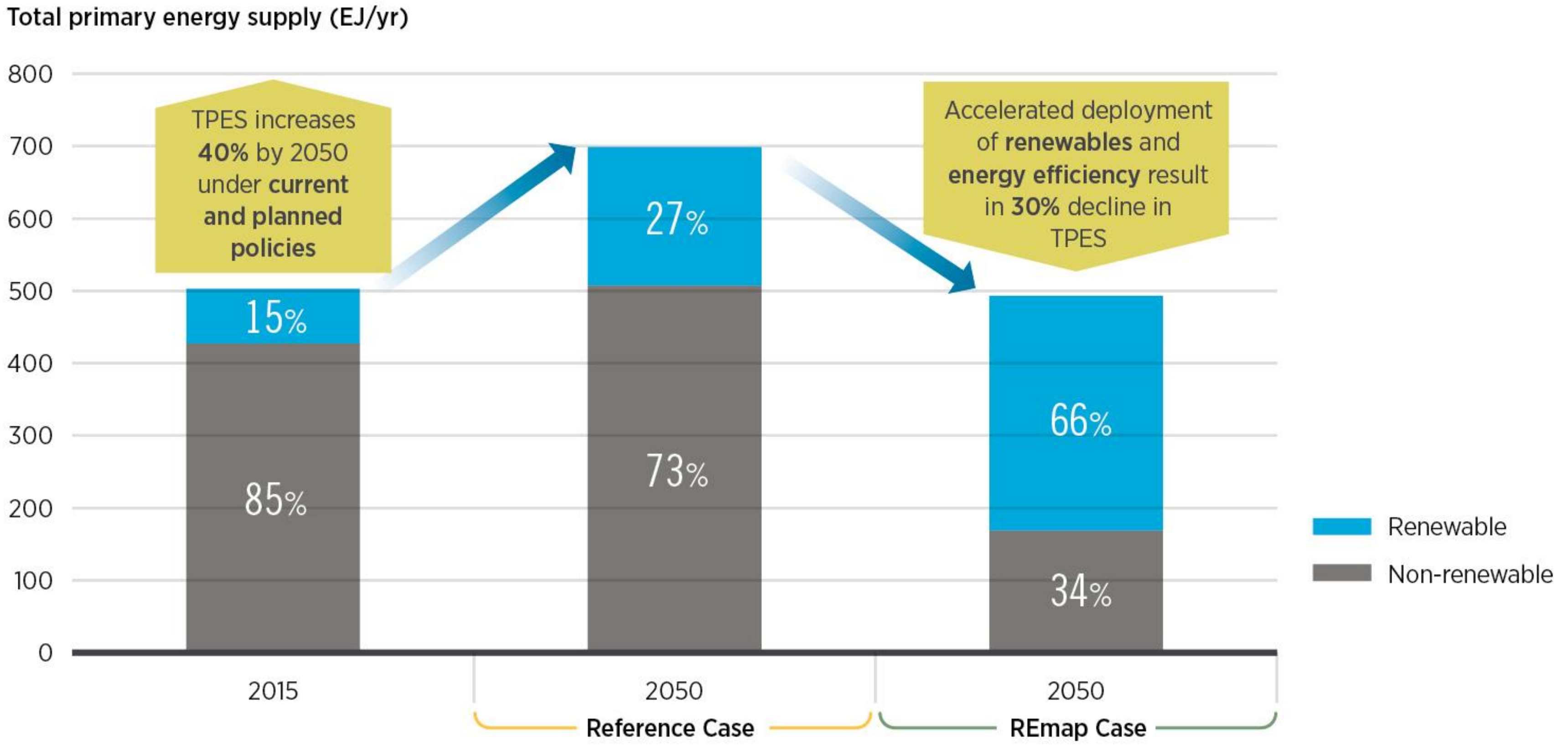
TPES and the share of renewable and non-renewable energy under the Reference and REmap cases



Under current and planned policies (the Reference Case) TPES is expected to increase almost 40% by 2050. To achieve a pathway to energy transition (the REmap Case), energy efficiency would need to reduce TPES slightly below 2015 levels, and renewable energy would need to provide two-thirds of the energy supply.

Growth in the renewable energy share needs to increase at least six-fold to 1.4 percentage points per year

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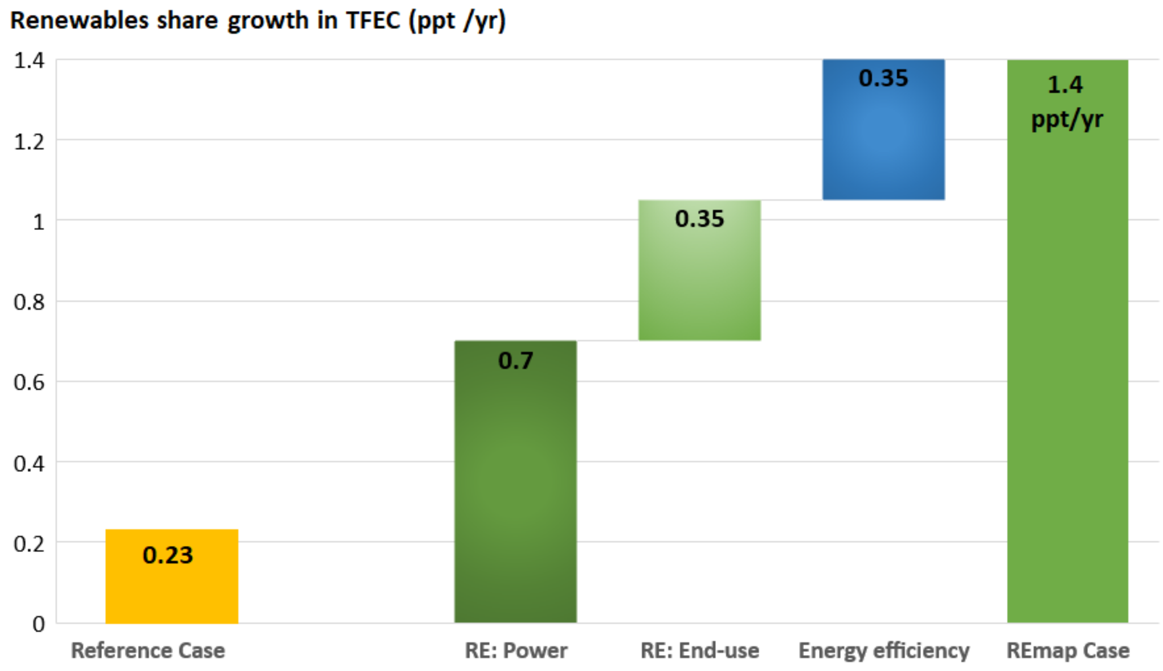
- From **2010 to 2015**, **growth** in the renewable energy share averaged **0.17 percentage points per year**.

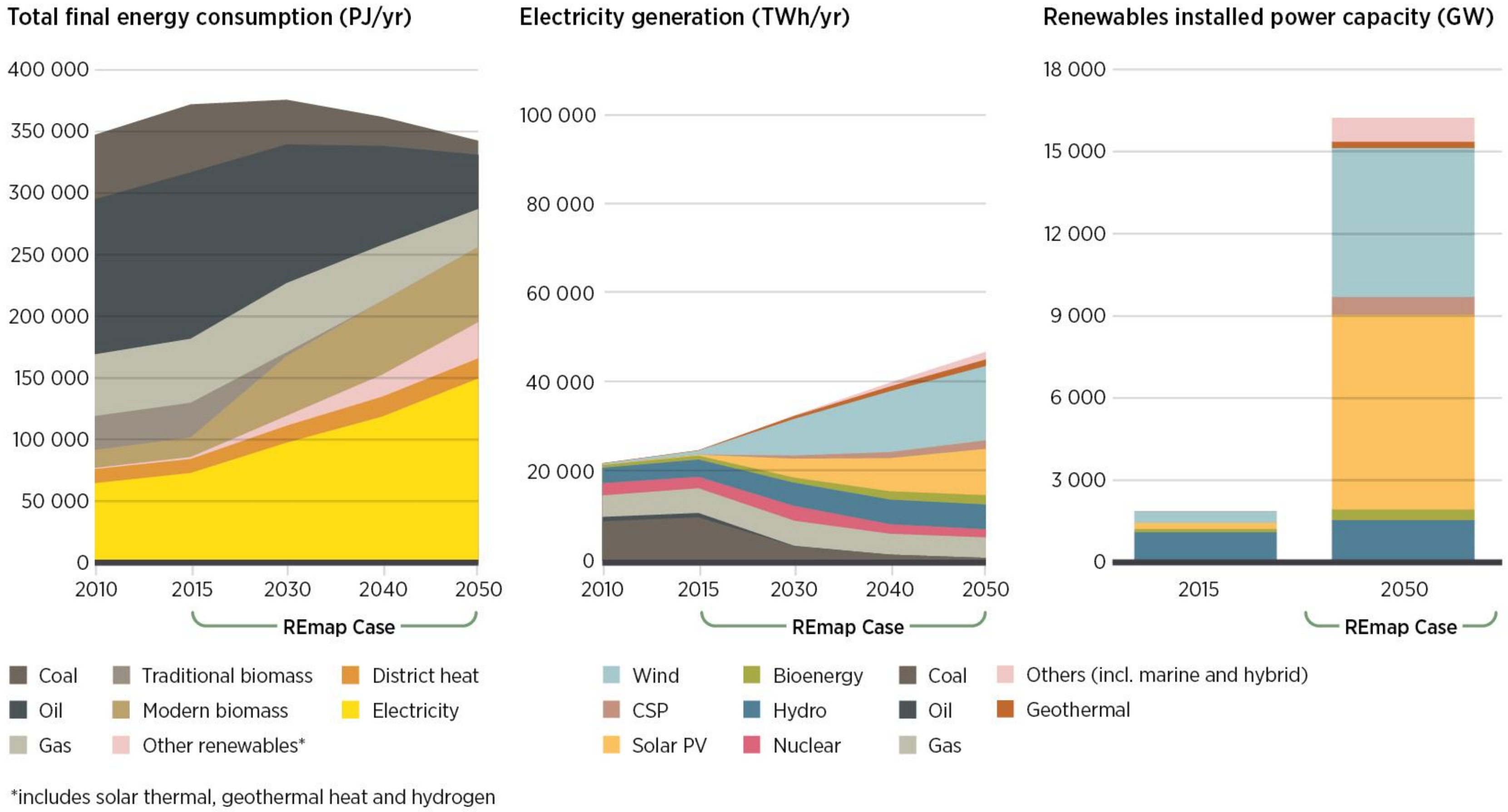
Average annual renewable percentage point increase in TFEC, 2010-50



Three-quarters of the increase in renewable share growth in the REmap Case is attributable to renewable energy, but an additional one-quarter of the growth reflects a lowering of overall energy demand via broad-scale deployment of energy efficiency measures.

Rising importance of electricity derived from renewable energy

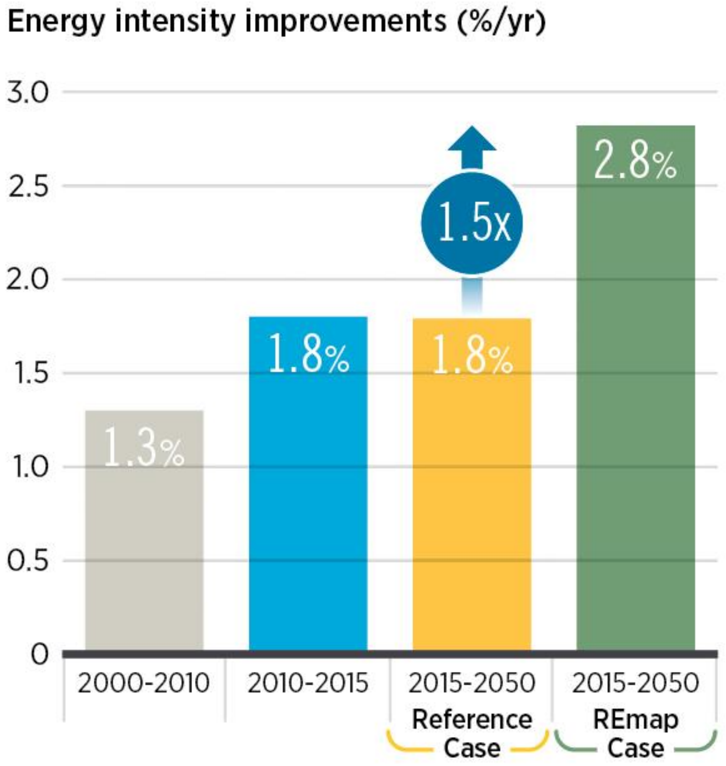
Share of electricity in total final energy consumption, electricity generation mix, and renewable capacity developments for the REmap Case, 2015-2050

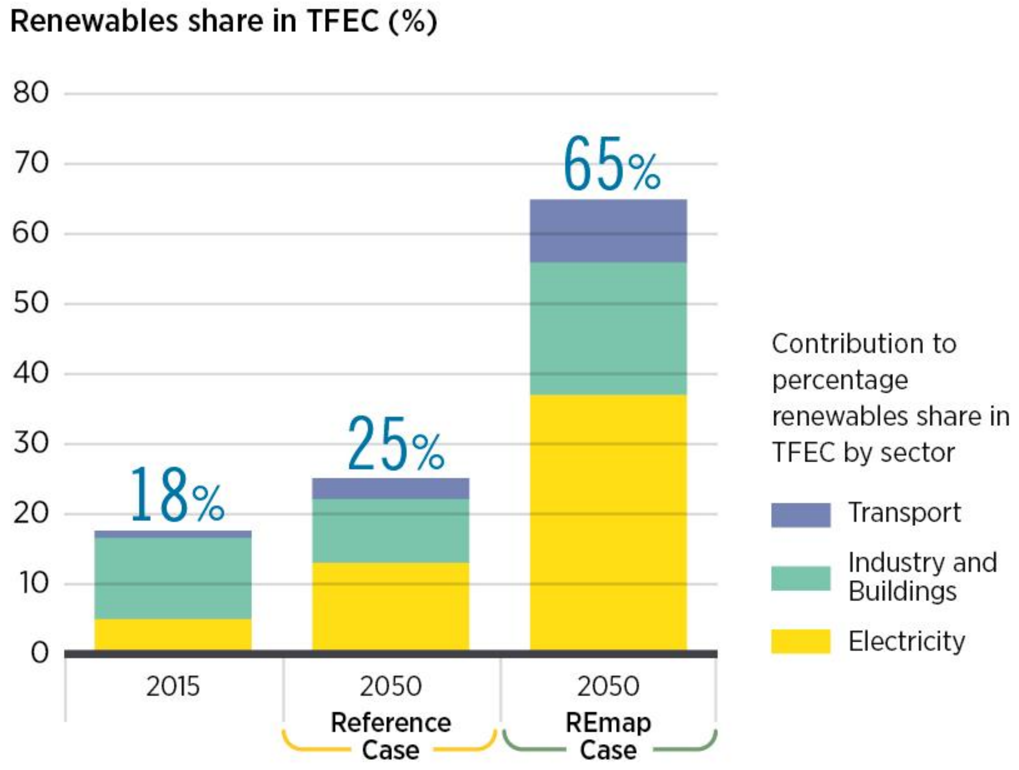


The share of electricity in total final energy consumption needs to double between 2015 and 2050.

Significant improvements in energy intensity are needed and the share of renewable energy must rise

Energy intensity improvement rate and renewable energy share in TFEC, Reference and REmap cases



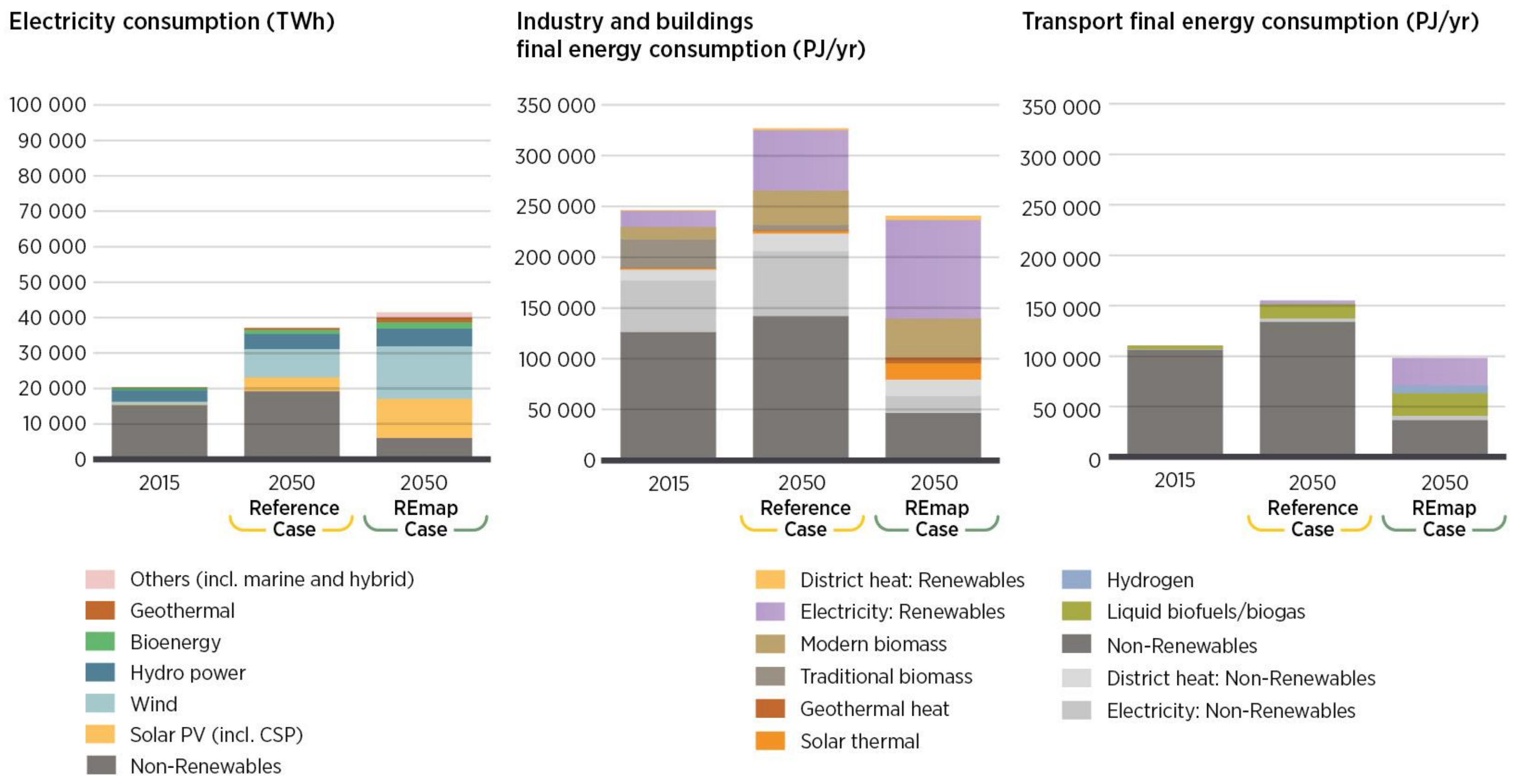


Source: Historical energy intensity improvement values from (SE4ALL, 2016), projections based on IRENA analysis

Both renewable energy and energy efficiency are at the heart of the energy transition and climate goals. By 2050 action in both areas must be scaled up considerably.

Renewable energy should be scaled up to meet power, heat and transport needs

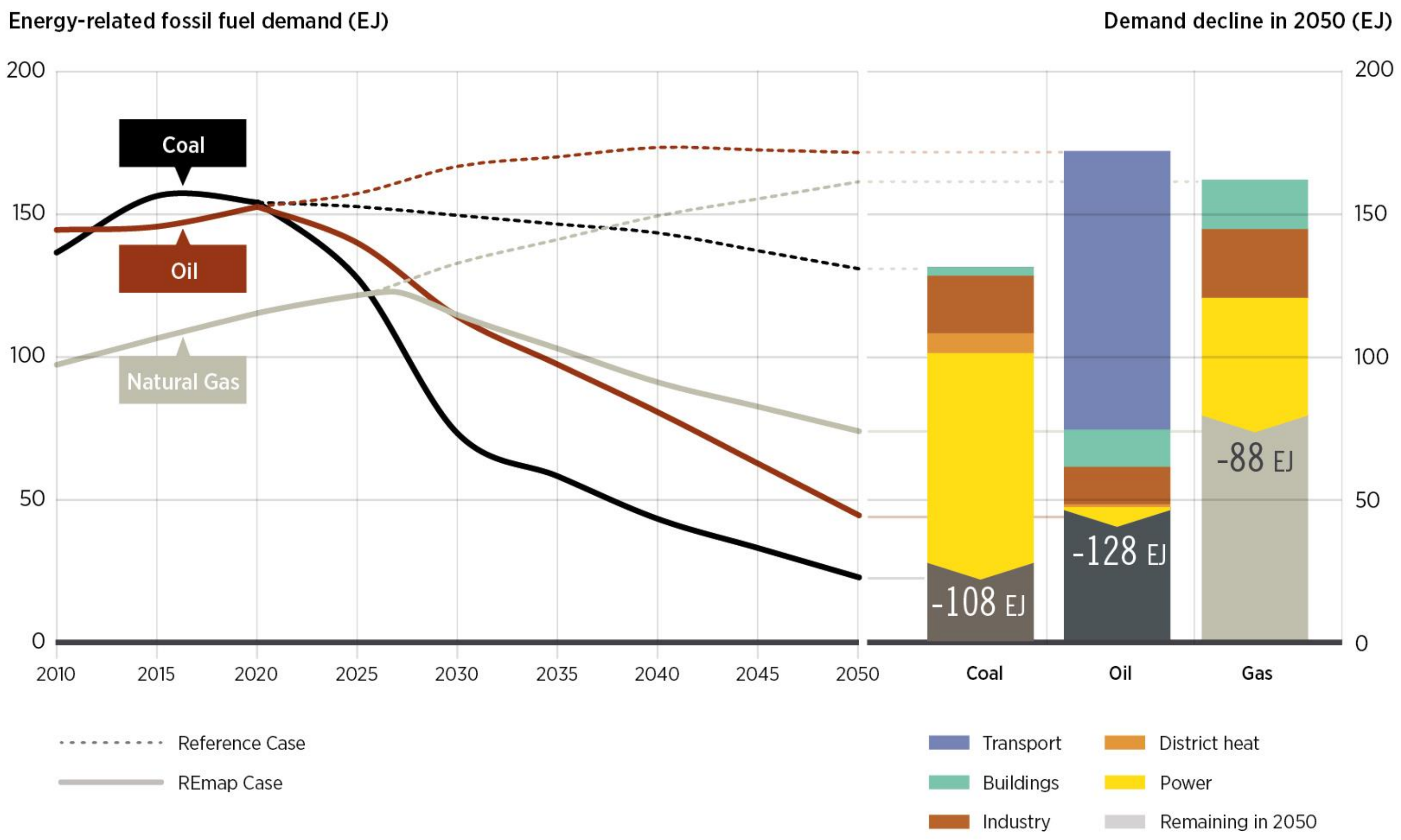
Use of renewable and fossil energy in electricity generation, buildings and industry, and transport



The share of electricity rises to 40% of TFEC in the REmap Case, and 85% of electricity generation is from renewable sources.

The importance of fossil fuels is declining

Fossil fuel use (left), 2015-2050; decline in fossil fuel use by sector - REmap Case relative to Reference Case



Under the REmap Case, both oil and coal demand decline significantly and continuously, and natural gas demand peaks around 2027. In 2050, natural gas is the largest source of fossil fuel.

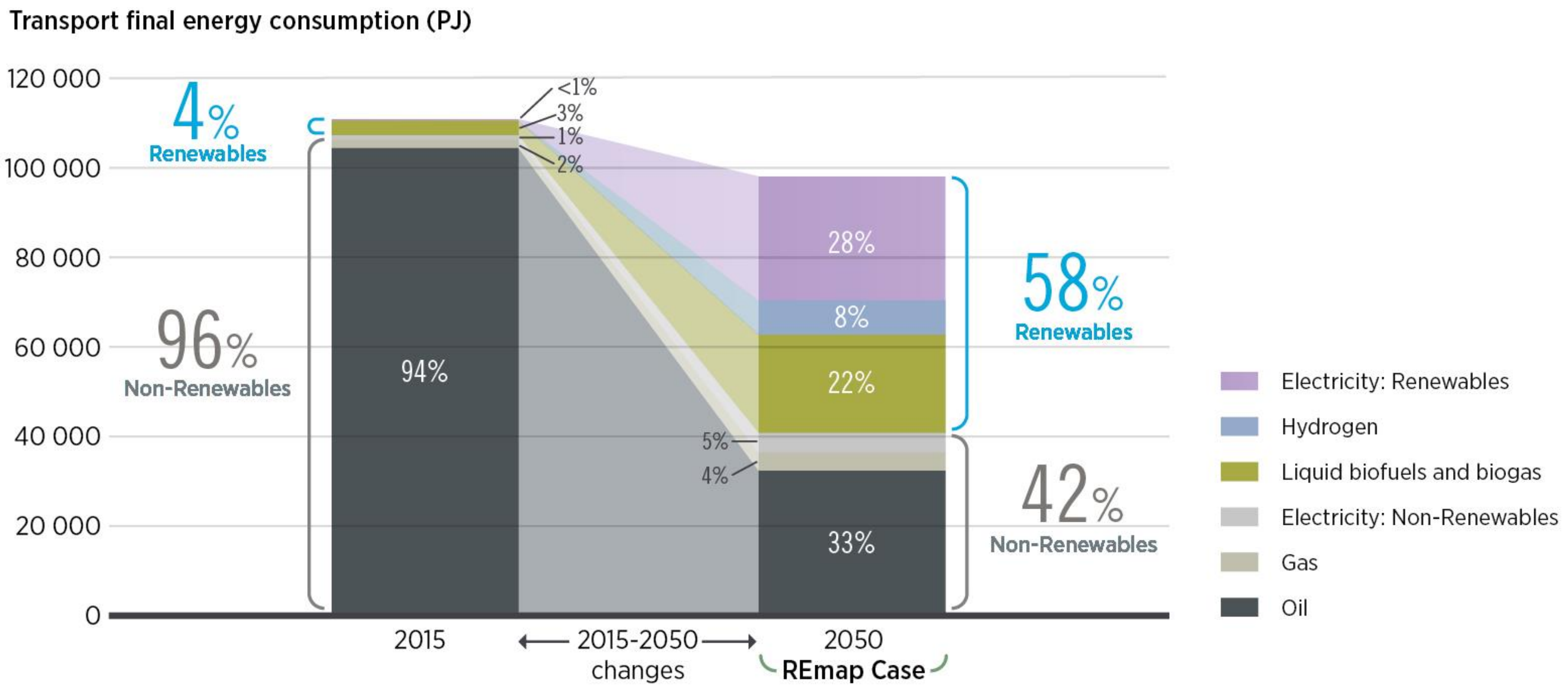
ANALYSIS AND INSIGHTS IN KEY SECTORS

Analysis and insights in key sectors: Transport

- The **transport sector currently lags** behind and is dominated by fossil fuels.
- Under the REmap Case, **electrification** of passenger transport expands significantly as well as the use of biofuels.
- **New energy sources, in combination with information and communication technologies** (ICT), are changing the entire transport industry.
- The REmap Case explores the use of **hydrogen as a transport fuel** which can be used for example, in vehicles powered by fuel cells.
- Nearly **USD 14 trillion of total investment** would be required under the REmap Case in the transport sector by 2050.

Transforming energy demand in the Transport sector

A breakdown of final energy consumption in the transport sector by source



The transport sector is dominated by fossil fuels and needs to undergo a profound transformation.

Energy use indicators in Transport

TRANSPORT

Indicators for energy use in the Transport sector

ACTIVITY

2015		REmap Case 2050
22 921 billion passenger-km/yr	Passenger cars	43 076 billion passenger-km/yr
16 945 billion passenger-km/yr	Buses, 2/3 wheelers, rail	27 493 billion passenger-km/yr
6 643 billion passenger-km/yr	Aviation	21 666 billion passenger-km/yr
92 481 billion tonne-km/yr	Freight	216 500 billion tonne-km/yr

RENEWABLE ENERGY AND ELECTRIFICATION SHARES

2015	REmap Case 2050
4% Renewable share in energy use in transport	58% Renewable share in energy use in transport
1% Electricity share in final energy use in transport	33% Electricity share in final energy use in transport

ENERGY INDICATORS

ELECTRIC MOBILITY

2015		REmap Case 2050
1.24 million vehicles	Passenger vehicles	965 million vehicles
0.02 million vehicles	Buses and light duty vehicles	57 million vehicles
200 million vehicles	2/3 wheelers	2 160 million vehicles

BATTERY STORAGE available to grid from EVs*

2015		REmap Case 2050
0.5 GWh	Storage	12 380 GWh

BIOFUELS

2015		REmap Case 2050
129 billion liters	Liquid biofuels	902 billion liters
0.4 billion m³	Other biofuels Biomethane	23 billion m³

* Considering 50% grid connected EVs and 25% grid connected 2/3 wheelers

ENERGY RELATED CO_2 EMISSIONS

2015	REmap Case 2050
7.7 Gt CO_2/yr	3.1 Gt CO_2/yr

Avoided CO_2 emissions in 2050 compared to Reference Case: 7.6 Gt CO_2/yr

INVESTMENT

Total investments for decarbonisation between 2015 and 2050: 14.2 USD trillion

Analysis and insights in key sectors: Buildings

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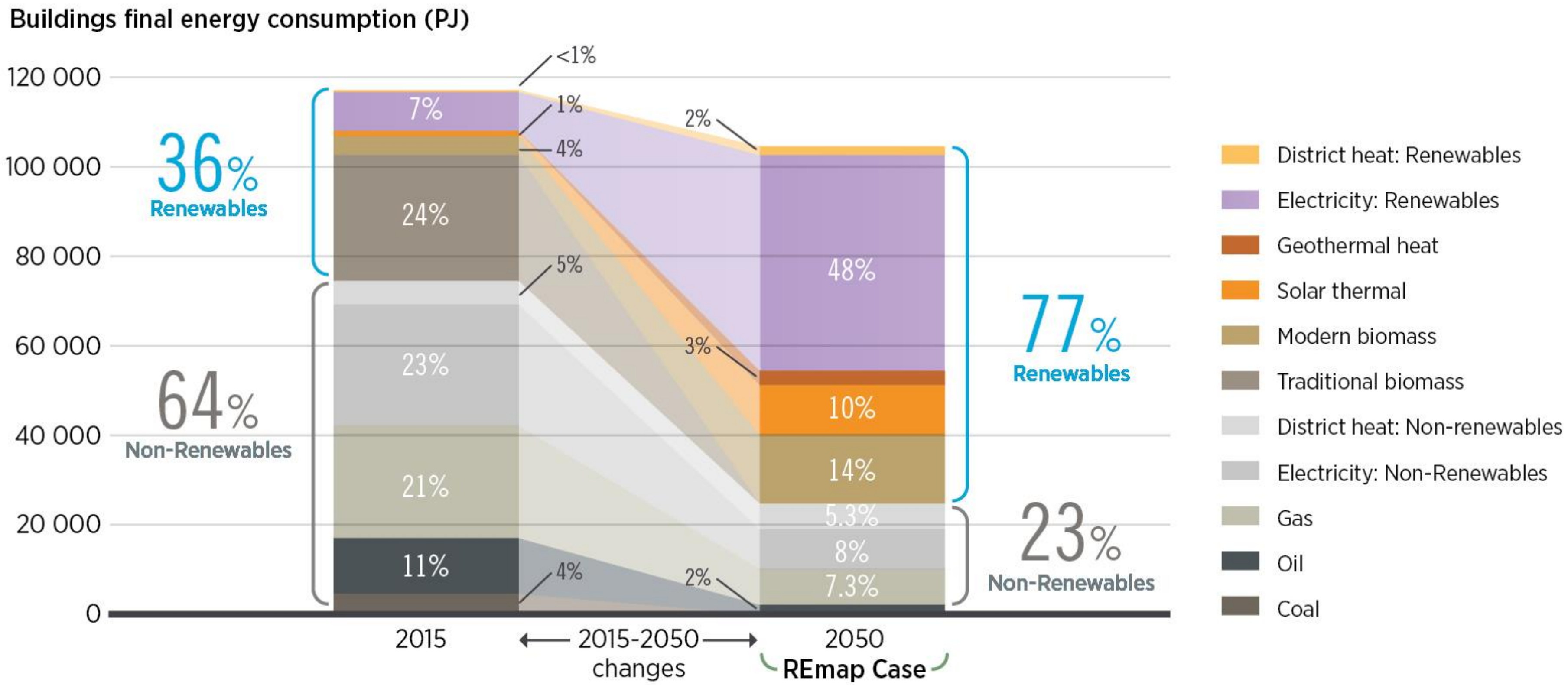
- Electricity **demand** in the building sector is projected to increase by **70% by 2050**.
- A significant increase in the share of **modern renewables** (excluding traditional uses of biomass) for heat and other direct-use must take place.
- Use of **heat pumps** in buildings can be expanded. They achieve energy efficiencies 3 to 5 times higher than boilers and can be powered by renewable electricity.
- The **shift in cooking** technologies from fuel to electricity will also promote renewables, due to the high share of renewable power in electricity supply.
- **Bioenergy** will remain the **largest renewable fuel source in buildings**.
- Under the REmap Case, these measures require a cumulative **investment** of **USD 38 trillion** by 2050, with **USD 1.6 trillion for renewables** deployment in buildings.

The use of electricity in Buildings increases while the use of fossil fuels declines

Breakdown of final energy consumption in the building sector by source



Modern renewable energy in the building sector needs to increase significantly. Up to three-quarters of energy consumption in buildings could be supplied by renewables. Electricity will supply almost 56% of the sector's energy demand.

Energy use indicators in Buildings

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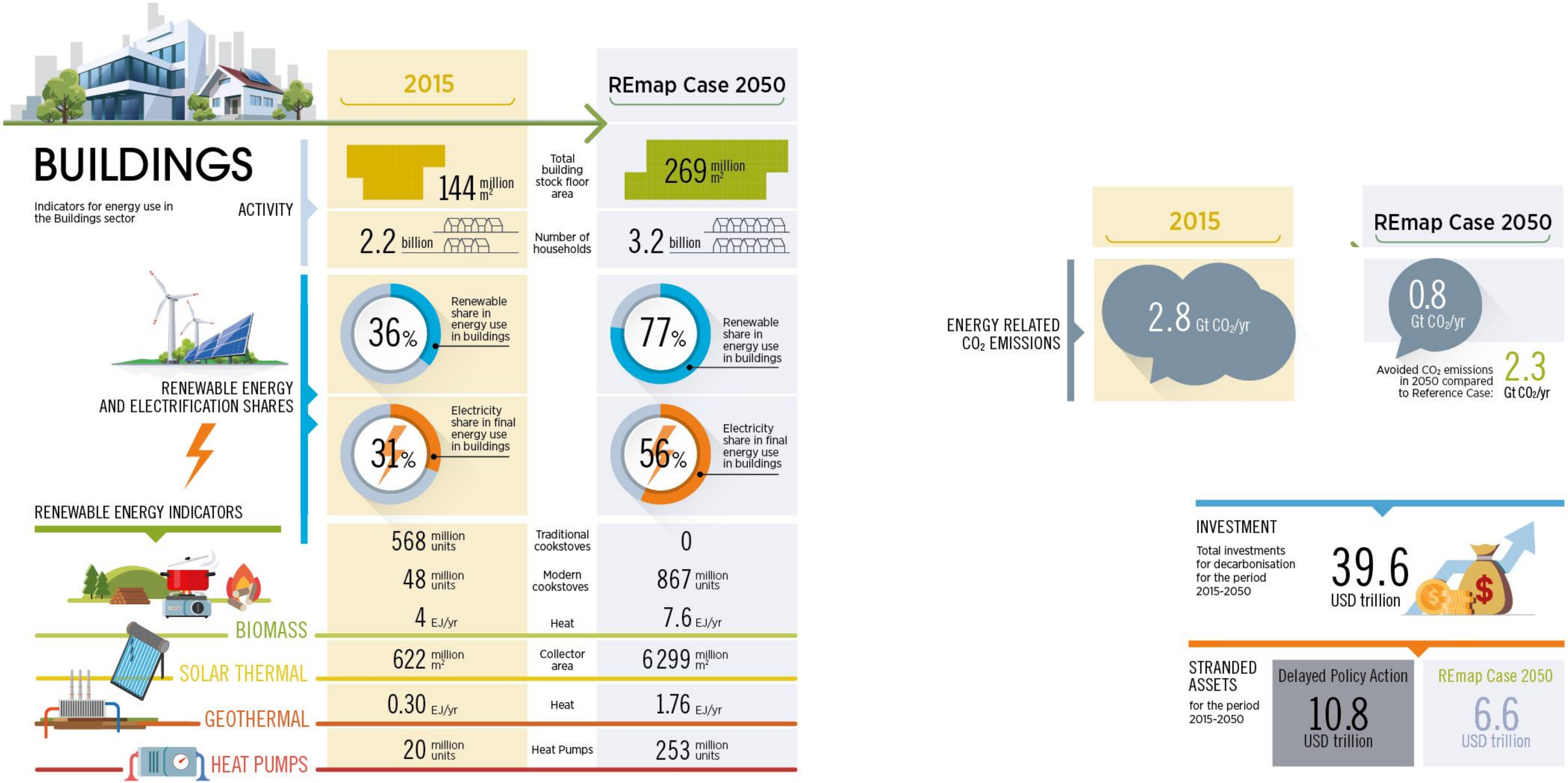
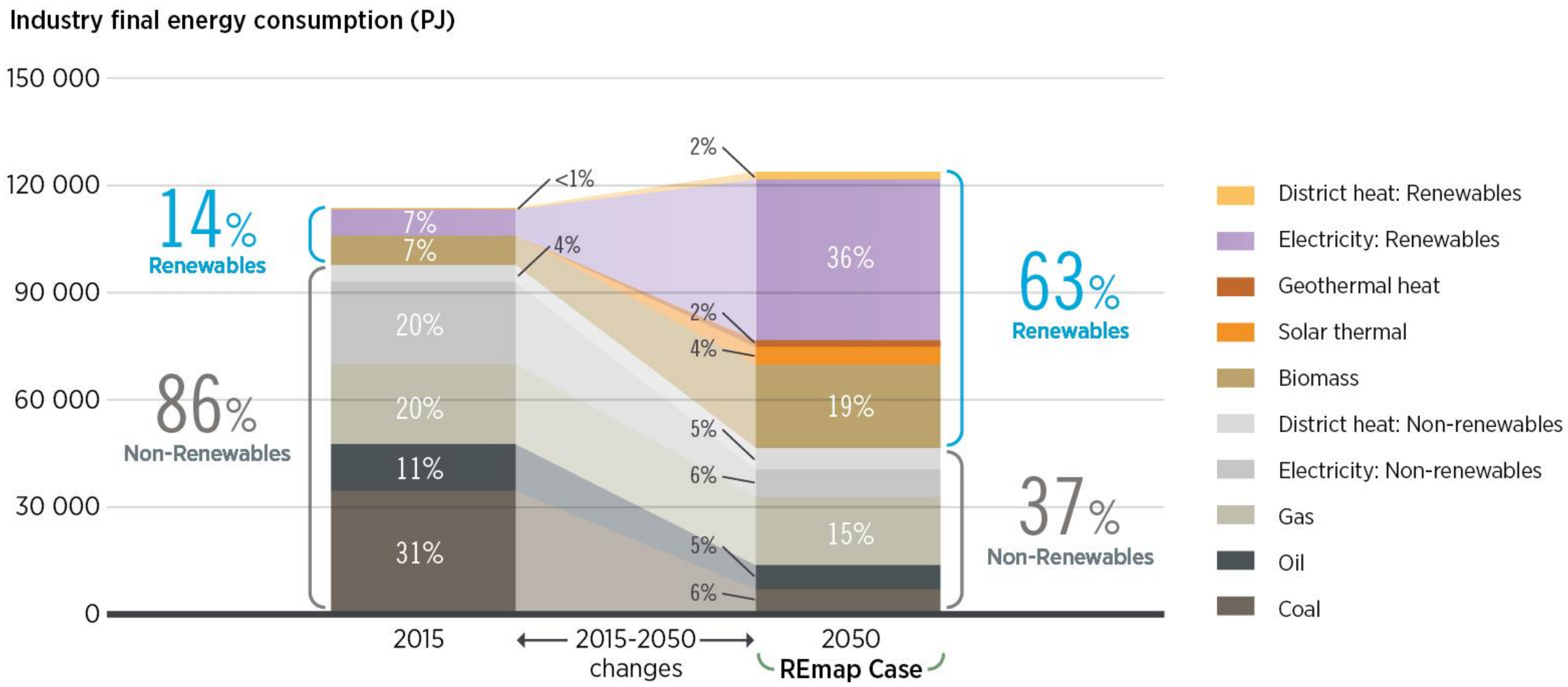


Analysis and insights in key sectors: Industry

- To date, the **industry sector has been the biggest laggard** in the energy transition. In 2015 renewables provided only around 7% of direct energy use.
- In terms of emissions, the **industrial sector is the second-largest emitter of energy-related CO_2**. It is responsible for a third of emissions worldwide.
- Under the REmap Case, industry must increase the **share of renewable energy to 48%** in direct-uses and fuels by 2050.
- In percentage terms, the largest growth will be in use of **solar thermal heat** for low-temperature processes.
- **Hydrogen** will also play an important role in the sector; the use of hydrogen derived from renewables grows to 7 EJ by 2050.
- There is large potential to improve **energy efficiency. Industrial energy consumption could be reduced by about a quarter** with the best available technologies.

The Industry sector shows a diverse energy mix with sizeable bioenergy demand

Breakdown of final energy consumption in the industry sector by source



By 2050 renewable energy use in industry needs to grow by more than four times. Biomass and renewable electrification will have a prominent role.

Energy use indicators in Industry

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INDUSTRY

Indicators for energy use in the Industry sector

	2015		REmap Case 2050
ACTIVITY	2 872 Mt/yr	Iron and steel	3 608 Mt/yr
	7 237 Mt/yr	Cement	8 889 Mt/yr
	612 Mt/yr	Chemical and petro-chemical	1 079 Mt/yr
	167 Mt/yr	Aluminium	269 Mt/yr
	688 Mt/yr	Pulp and paper	822 Mt/yr
RENEWABLE ENERGY AND ELECTRIFICATION SHARES	14% Renewable share in energy use in industry		63% Renewable share in energy use in industry
	27% Electricity share in final energy use in industry		42% Electricity share in final energy use in industry

RENEWABLE ENERGY INDICATORS

	2015		REmap Case 2050
BIOMASS	8 EJ/yr	Biomass heat	20.2 EJ/yr
	0.8 EJ/yr	Biomass feedstocks	10.5 EJ/yr
SOLAR THERMAL	0.1 GWth	Concentrated solar thermal	134 GWth
	1 million m²	Collector area	3 450 million m²
GEOTHERMAL	0.02 EJ/yr	Heat	4.11 EJ/yr
HEAT PUMPS	0.2 million units	Heat Pumps	80 million units

	2015	REmap Case 2050
ENERGY RELATED CO_2 EMISSIONS*	9.5 Gt CO_2/yr	5.1 Gt CO_2/yr

Avoided CO_2 emissions in 2050 compared to Reference Case: 6.7 Gt CO_2/yr

INVESTMENT

Total investments for decarbonisation for the period 2015-2050: 5.0 USD trillion

* Includes process emissions

STRANDED ASSETS for the period 2015-2050

Delayed Policy Action	REmap Case 2050
0.75 USD trillion	0.23 USD trillion

Key insights: Bioenergy for heating

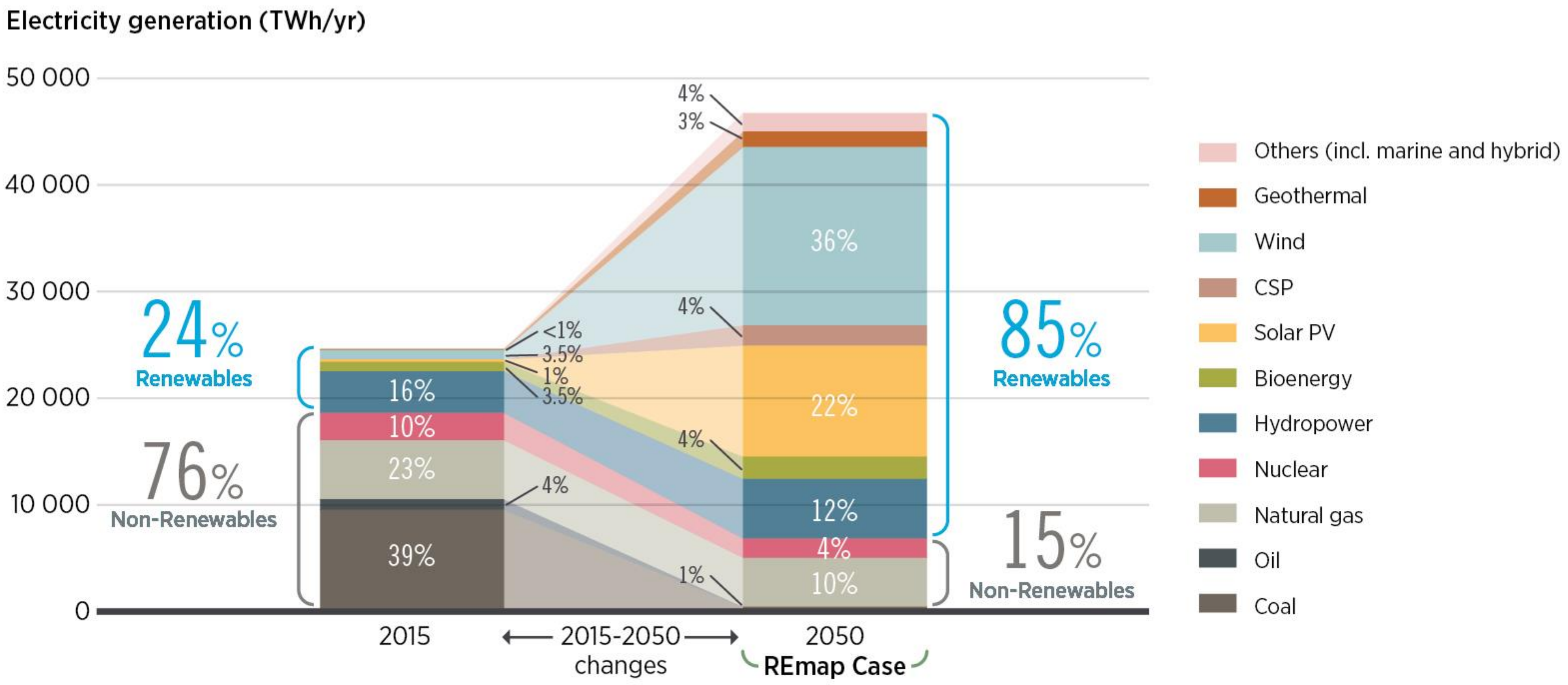
- **Bioenergy** will account for around **one-third of total global final renewable energy use** in the REmap Case **in 2050**.
- In **industry** the challenge lies in the sub-sectors of heavy industry and manufacturing.
  - » Solutions include the use of **biomass residues**, **waste for industry**, and the role of **biomass feedstocks for petrochemicals**.
  - » Achieving this supply of bioenergy in industry would necessitate **scaling up the use of residues**, better **collection**, and more **efficient supply chains**.
- Bioenergy will remain the largest source of fuel use in **buildings**, providing around **30% of heating and cooking demand in 2050,** around three-fold today's levels.
- Bioenergy in **transport** will require a careful approach that considers the **sustainability of supply** and does not infringe on land used for growing food.

Analysis and insights in key sectors: Power

- Under the REmap Case, **electricity consumption in end-use sectors would double by 2050** (relative to 2015 levels) to over 42 000 TWh, **while the carbon intensity of the power sector would decline by 85%.**
- **No new coal plants** should be commissioned and 95% of coal plants in operation today should be phased out.
- **Investment in new renewable power capacity** should increase to **USD 500 billion per year** over the period to 2050.
- In **total**, investment in decarbonisation of the **power system** will need to reach an average of nearly **USD 1 trillion per year** to 2050.
- Gross power generation will almost double with **renewable energy** providing **85% of electricity**.

In the Power sector, solar and wind energy are on the path to dominance

Breakdown of electricity generation by source



Gross power generation will almost double with renewable energy providing 85% of electricity.

Energy use indicators in Power

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POWER

Indicators for energy use in the Power sector

	2015		REmap Case 2050
Electricity demand	20 204 TWh/yr		41 508 TWh/yr
RENEWABLE ENERGY SHARE IN TOTAL ELECTRICITY GENERATION	24% Renewable share		85% Renewable share

RENEWABLE ENERGY INDICATORS

	2015		REmap Case 2050
HYDROPOWER	1 248 GW		1 828 GW
	155 GW	of which pumped hydro	325 GW
WIND	411 GW		5 445 GW
	399 GW	Onshore	4 923 GW
	12 GW	Offshore	521 GW
SOLAR PV	223 GW		7 122 GW
CSP	5 GW		633 GW
BIOENERGY	119 GW		384 GW
GEOTHERMAL	10 GW		227 GW
OTHERS (incl. marine, hybrid)	0.3 GW		881 GW

ENERGY RELATED CO_2 EMISSIONS

2015	REmap Case 2050
12.4 Gt CO_2/yr	1.9 Gt CO_2/yr

Avoided CO_2 emissions in 2050 compared to Reference Case: 8.8 Gt CO_2/yr

INVESTMENT

Total investments for decarbonisation for the period 2015-2050

POWER GENERATION	POWER SYSTEM FLEXIBITLITY AND GRID*
24.6 USD trillion	18 USD trillion

* This includes investments needed for transmission and distribution grid expansion, increased generation flexibility, electricity storage.

STRANDED ASSETS

for the period 2015-2050

Delayed Policy Action	REmap Case 2050
1.4 USD trillion	1 USD trillion

Key insights: Integration of renewable energy in the Power sector

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- Under the REmap Case, the global share of wind and solar increases to 38% by 2030 and to 62% by 2050.

- With the increasing share of renewable energy in electricity, power systems will require technological solutions and infrastructure that enable a smooth operation of the power system including :

  » **Transmission and distribution** grids expansion, including ultra-high voltage AC/DC transmission lines to connect sites with large renewable resources to load centres.

  » Increased **generation flexibility** through dispatchable generation capacity.

  » Electricity **storage** to provide energy and other services to the grid.

- Mini-grids, are another solution enabling to develop higher shares of renewable power, for off-grid applications and remote locations.

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COSTS, INVESTMENTS AND REDUCED EXTERNALITIES OF THE ENERGY TRANSITION

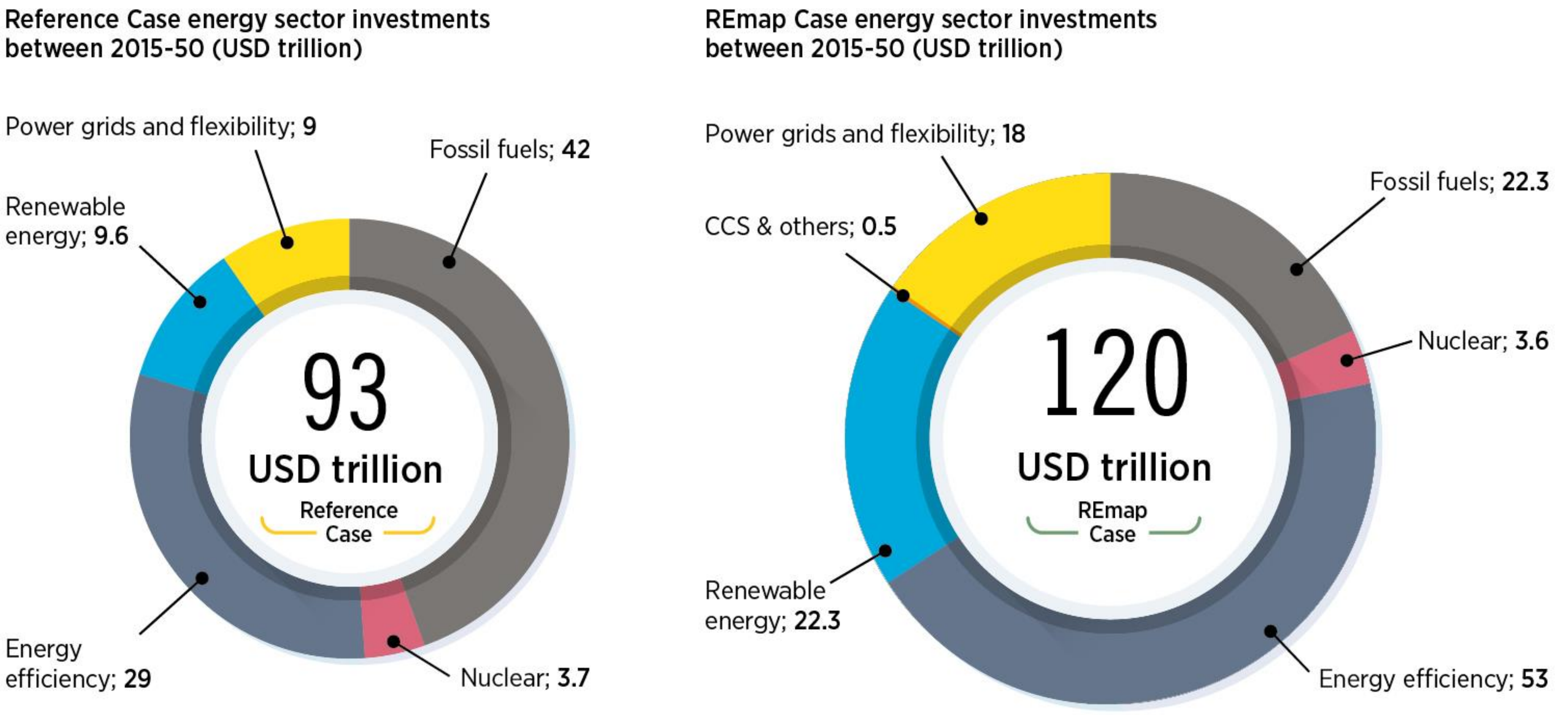
The energy transition is technically feasible and economically beneficial

- **The energy transition is technically feasible and economically beneficial**, but will require substantial additional investment in low-carbon technologies compared to current and planned policies.
  - » Under the REmap Case, cumulative **investment of USD 120 trillion** must be made between 2015 and 2050 in **low-carbon technologies,** equivalent to **2% of the period average global GDP per year, USD 27 trillion more** than the Reference Case.
  - » Investments in decarbonisation solutions will include renewable energy, energy efficiency and other technologies (e.g. carbon capture and storage - CCS - in industry).

- However, **cost savings significantly outweigh the cost increases**. Cost savings would be made from **air pollution** decline, lowering **health costs**, and decrease in **environmental damage** related to CO_2.

Investment will need to shift to renewable energy and energy efficiency

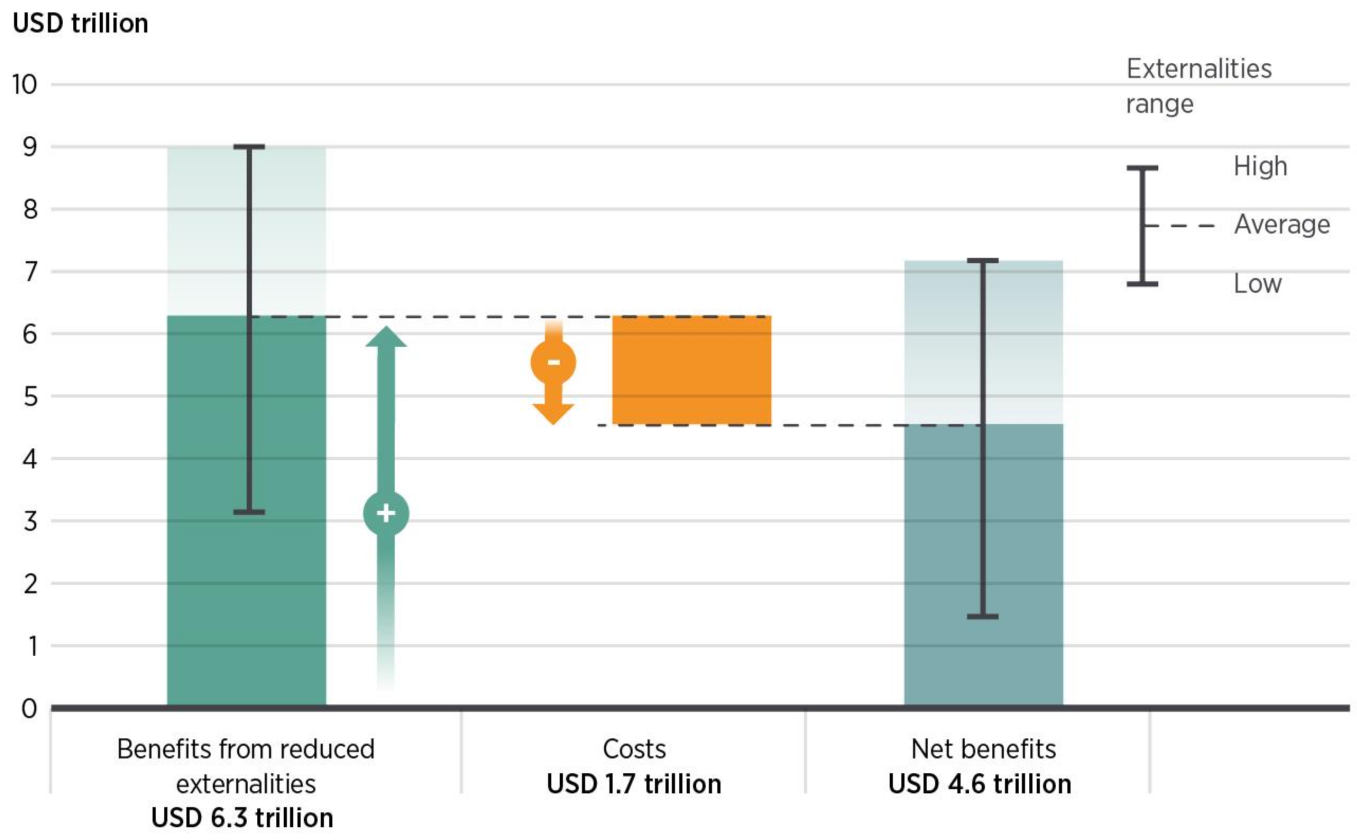
Cumulative investment - Reference and REmap cases, 2015-2050



Under the REmap Case, cumulative investment of USD 120 trillion must be made between 2015 and 2050 in low-carbon technologies, averaging around 2% of the period average global GDP per year. This is USD 27 trillion more than the Reference Case.

Reduced negative externalities far outweigh the costs needed to achieve a global energy transformation

Annual costs of the energy transition set against reduced externalities (air pollution and CO_2 damages) - REmap Case compared to the Reference Case in 2050



Under the REmap Case, annual health and CO_2 benefits associated with the energy transition outweigh incremental costs by a factor of 2 to 5 in 2050.

Further considerations on the costs and benefits of the energy transition

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- Energy **subsidies** and **externalities** cause many misconceptions about the costs of the energy transition.
  - » In 2016, **subsidies to fossil fuels exceeded those to renewables** by a factor of two (not counting externalities) to thirty-eight (including externalities).

- To reduce the risk of **stranded assets**, action has to be taken quickly and investments must be channeled into low-carbon energy technologies
  - » The slow progress of emission mitigation to date means that the adoption of an emissions mitigation path in the REmap Case will still result in **stranded assets worth more than USD 11 trillion**.

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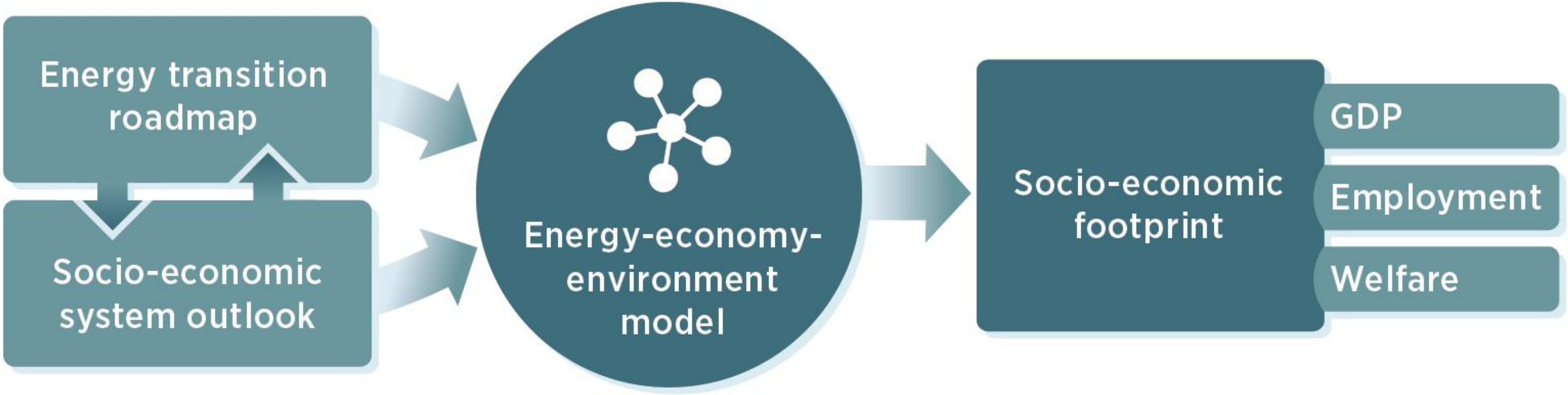
SOCIO-ECONOMIC BENEFITS OF THE ENERGY TRANSITION

Measuring the Socio-economics of the energy transition

- The **energy transition cannot be considered in isolation from the socioeconomic system** in which it is deployed.
  - » There are strong, deep and bidirectional interactions between the energy transition and the socio-economic system.
  - » Planning the energy transition and the socio-economic system evolution with these interactions in mind can foster synergies and improve the transition outcome.
  - » Failing to properly manage these interactions can lead to strong transition barriers.

- The close interplay between the energy sector and the socio-economic system produces a **socio-economic footprint** associated to each energy transition roadmap, impacting GDP, employment and human welfare.

Socio-economic footprint of the energy transition



The close interplay between the energy sector and the economy alters the socio-economic footprint and generates a number of benefits in terms of GDP, employment and human welfare.

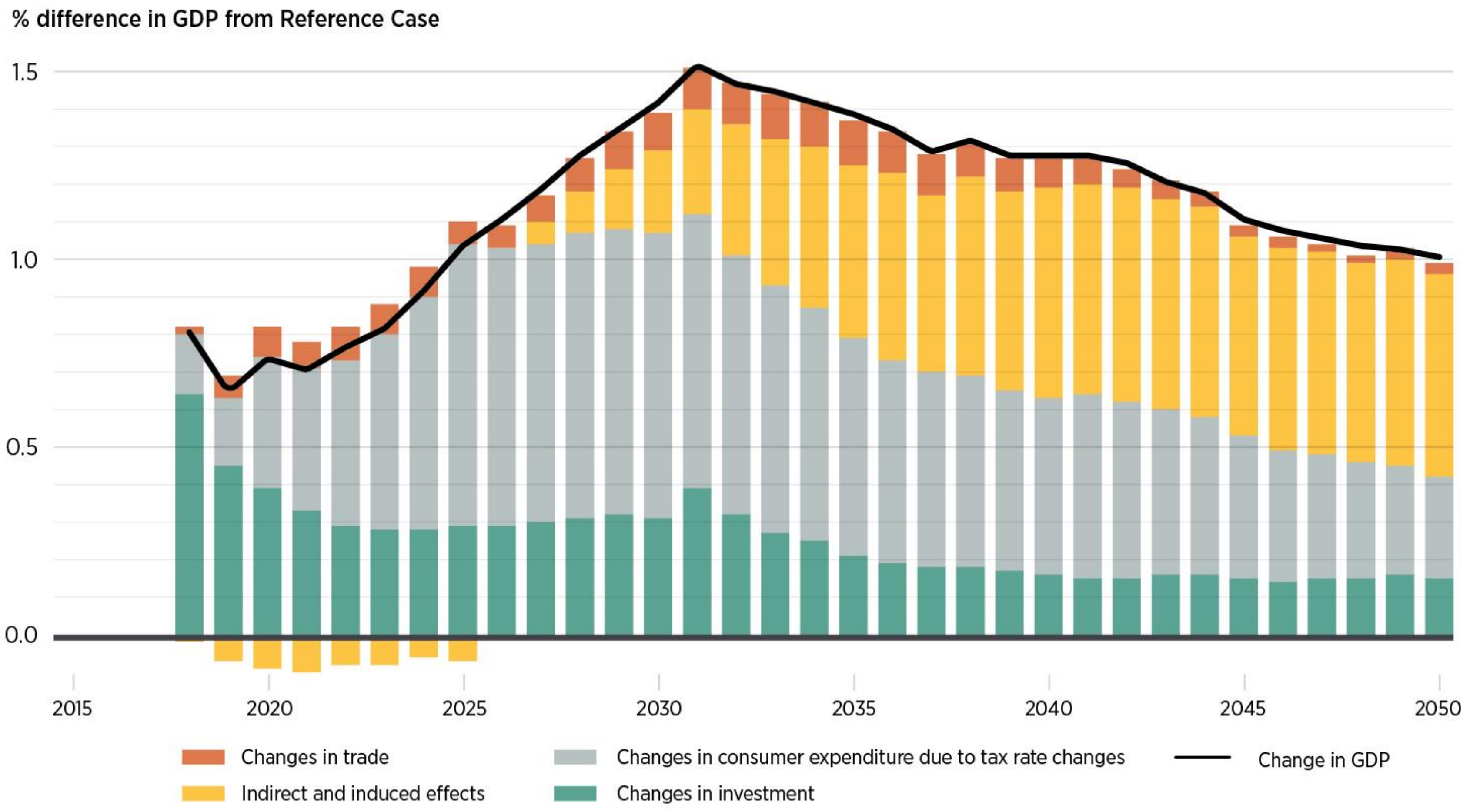
Global GDP

- The Remap energy transition has a consistently positive effect on global GDP between 2018 and 2050,compared to the Reference Case.
  - » The gain over the Reference Case is greatest around 2030, peaking at 1.5%, and then gradually narrows to 1.0% in 2050.
  - » The cumulative gain through increased GDP from 2018 till 2050 will amount to USD 52 trillion, almost twice the cumulative REmap additional investment.

- The energy transition additional investment stimulus dynamically ripples through the global economy, amplifying its positive impact, if appropriate structures are in place:
  - » Tax effects: requires carbon taxes to be deployed and fossil fuel subsidies to be phased out.
  - » Indirect and induced effects: requires strong and deep domestic supply changes to be in place.

The energy transition results in GDP growth higher than the Reference Case between 2018 and 2050

Relative difference of global GDP between the REmap Case and the Reference Case



Investment

+0.31% compared to the Reference case in 2030

+0.15% compared to the Reference case in 2050

Trade

+0.10% compared to the Reference case in 2030

+0.03% compared to the Reference case in 2050

Tax rate

+0.76% compared to the Reference case in 2030

+0.27% compared to the Reference case in 2050

Indirect and induced

+0.22% compared to the Reference case in 2030

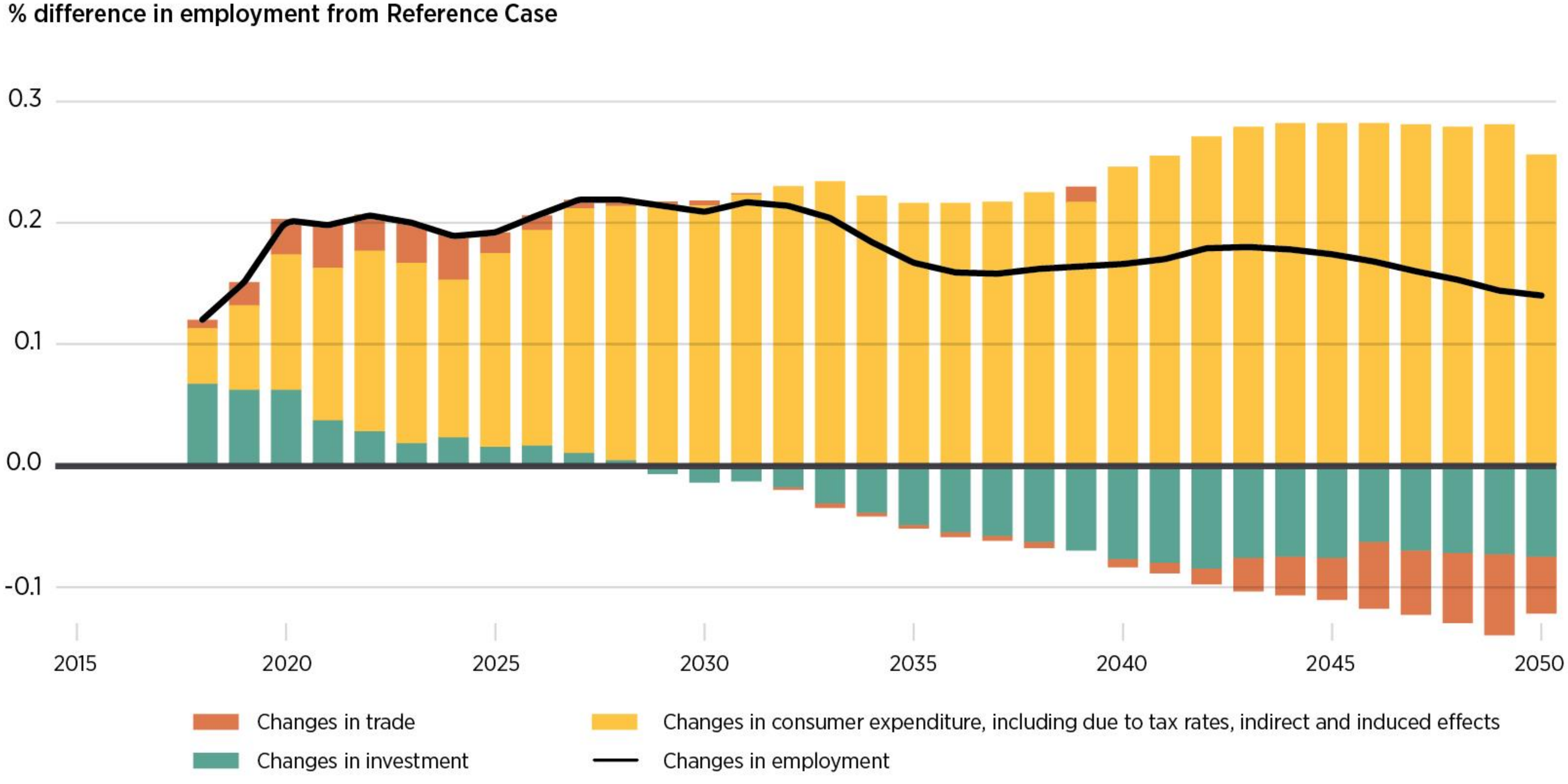
+0.54% compared to the Reference case in 2050

Global economy-wide Employment

- The energy transition boosts overall employment in the economy, when compared to the Reference Case.
  - In 2050, the aggregate gain in employment is around 0.14% higher under the REmap Case, compared to the Reference Case which witnesses 0.42%/yr compound annual growth rate during the transition period.
- The changes in consumer expenditure drive the positive employment results. This includes indirect supply chain employment associated to renewables and energy efficiency deployment.
- The investment driver provides a negative drag on employment in the second half of the transition, due to foregone fossil fuel employment and crowding out. This includes only direct employment from renewables and energy efficiency.
- The trade driver provides a negative drag on employment in the second half of the transition.

The energy transition results in employment growth higher than the Reference Case between 2018 and 2050

Relative differences in global employment - REmap Case and Reference Case, disaggregated by three main drivers



Investment

-0.01% compared to the Reference case in 2030

-0.07% compared to the Reference case in 2050

Trade

0.00% compared to the Reference case in 2030

-0.05% compared to the Reference case in 2050

Indirect and induced

+0.22% compared to the Reference case in 2030

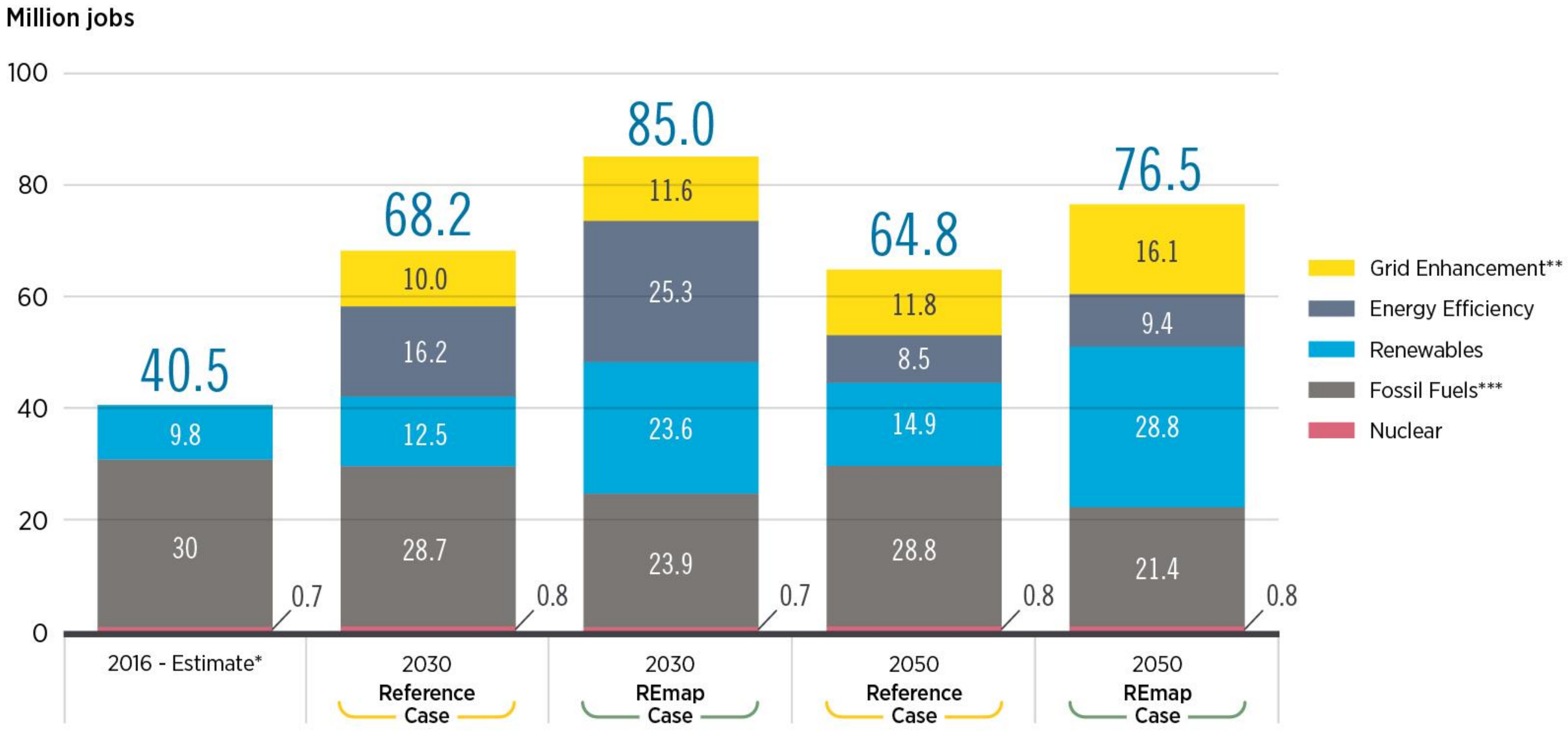
+0.26% compared to the Reference case in 2050

Employment in the energy sector

- Taking into account overall direct and indirect jobs, the energy transition boosts employment within the energy sector, with a net gain of 11.6 million jobs in 2050, a balance of two opposing trends:
  - a loss of 7.4 million direct and indirect jobs in fossil fuels;
  - a simultaneous gain of 19.0 million jobs in renewable energy, energy efficiency, and grid enhancement.
- With adequate re-training and other transition assistance, a proportion of this the lost fossil fuel workforce can be absorbed by renewables and energy efficiency, helping to meet the demand for skills.
- However, energy related jobs are not likely to be created and lost in the same areas and at the same time: Proactive just transition policies are needed
  - Job creation in other parts of the economy provides labour reallocation opportunities.

The energy transition would generate over 11 million additional energy sector jobs by 2050

Employment in the overall energy sector, 2016, 2030 and 2050



* Estimates for jobs in energy efficiency and grid enhancement are not available for 2016.

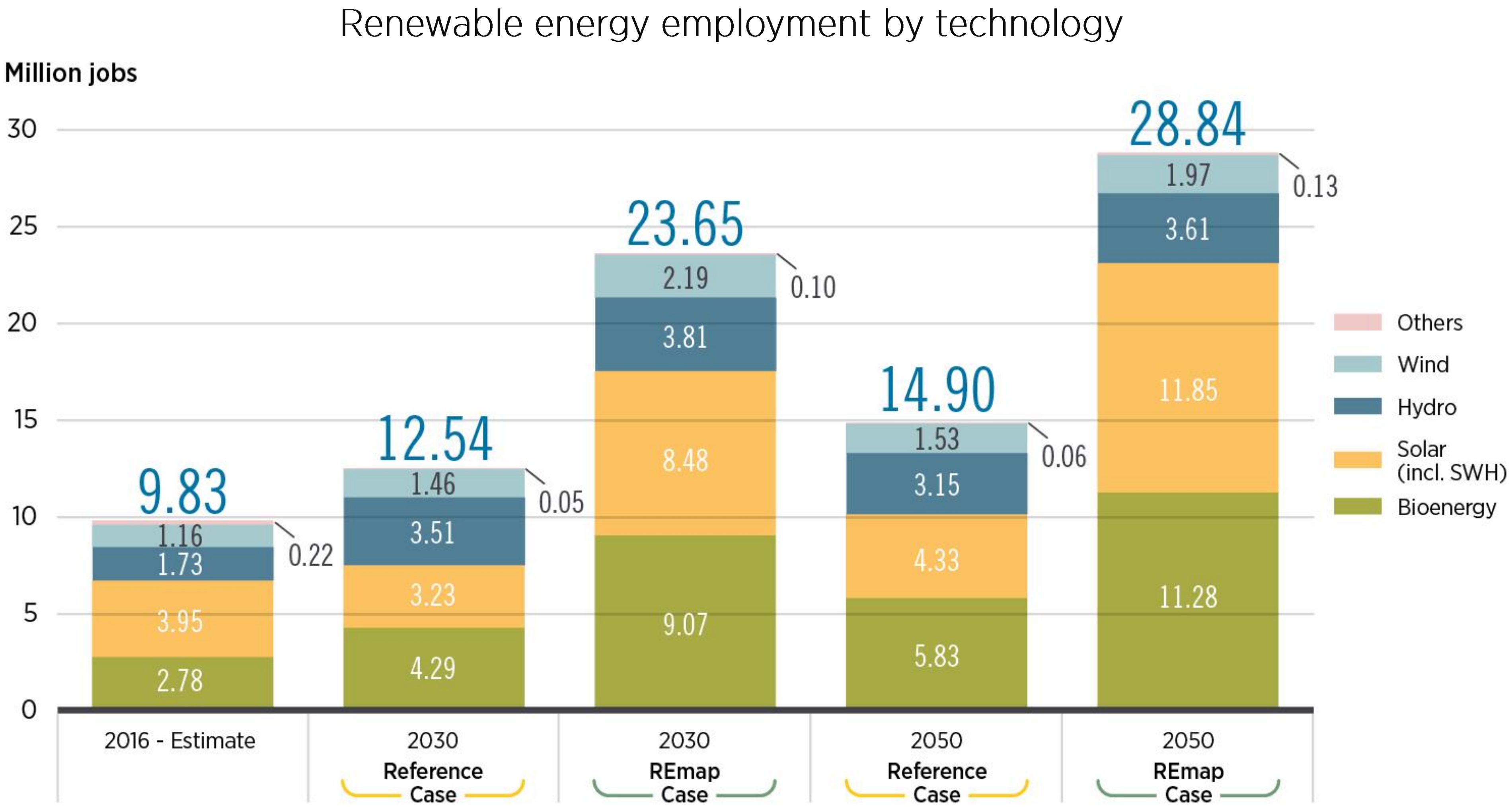
** The jobs in grid enhancement make reference to the jobs for T&D grids and Energy Flexibility, created in the development, operation and maintenance of infrastructure to enable the integration of RES into the grid.

*** Includes all jobs in the fossil fuel industry including in their extraction, processing and consumption.

Employment in Renewables

- Under REmap total direct and indirect employment in RE is expected to boost:
  - By **2030**: almost two and a half times current values, reaching around **24 million jobs**, almost twice the renewable energy jobs in the Reference Case.
  - By **2050**: almost triple from current values, reaching around **29 million jobs**, more than doubling the renewable energy jobs in the Reference Case.

Renewable Energy employment



The energy transition would generate 14 million additional jobs in renewable energy by 2050.

Human Welfare

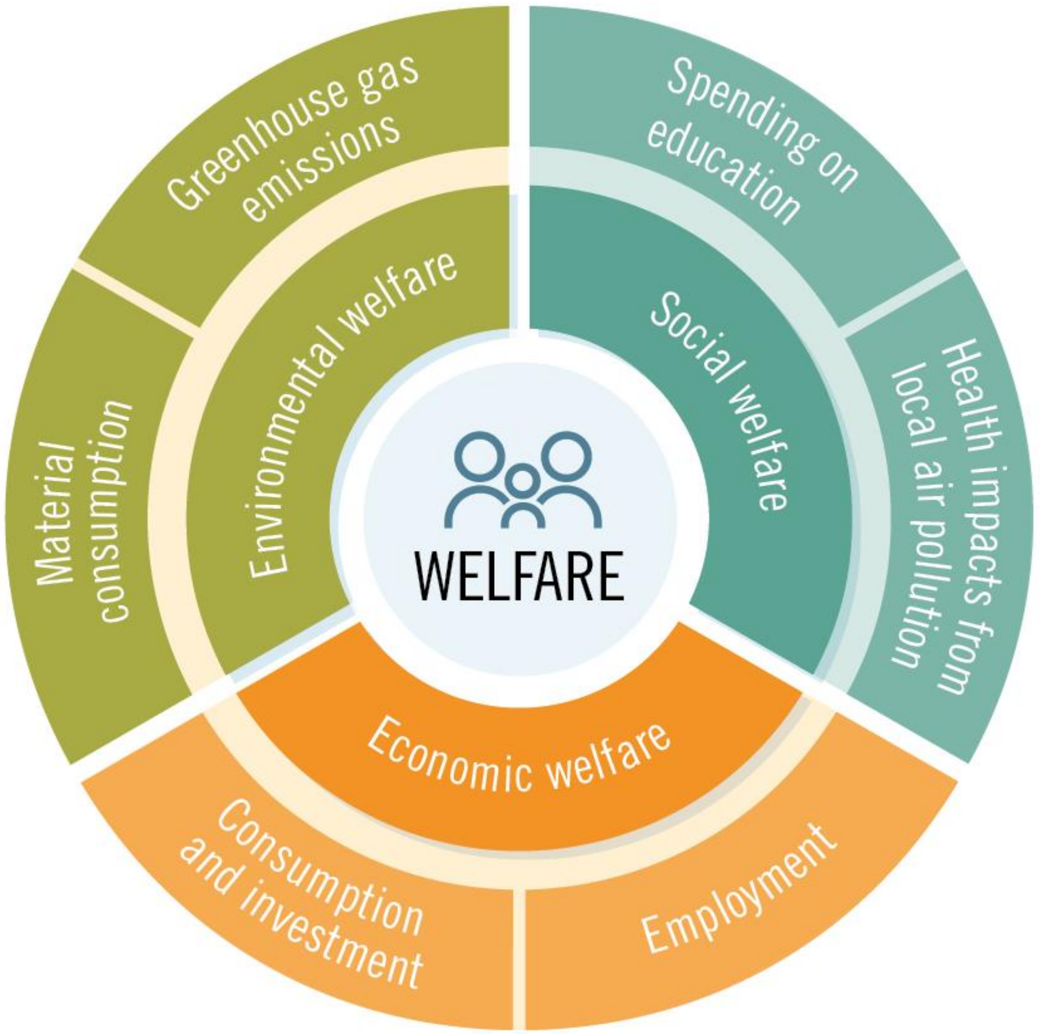
- Human welfare has many other dimensions than what traditional economy performance indicators like GDP measure. The welfare indicator considers the economy, social and environmental dimensions.

- The main reason for undertaking the transition is improving human welfare over what the Reference Case would provide.

- The energy transition generates broader socio-economic benefits, in addition to higher GDP and employment, improving other welfare components such as health, education and climate change.

- The REmap Case provides an overall welfare improvement over the Reference Case of 15% in the year 2050.

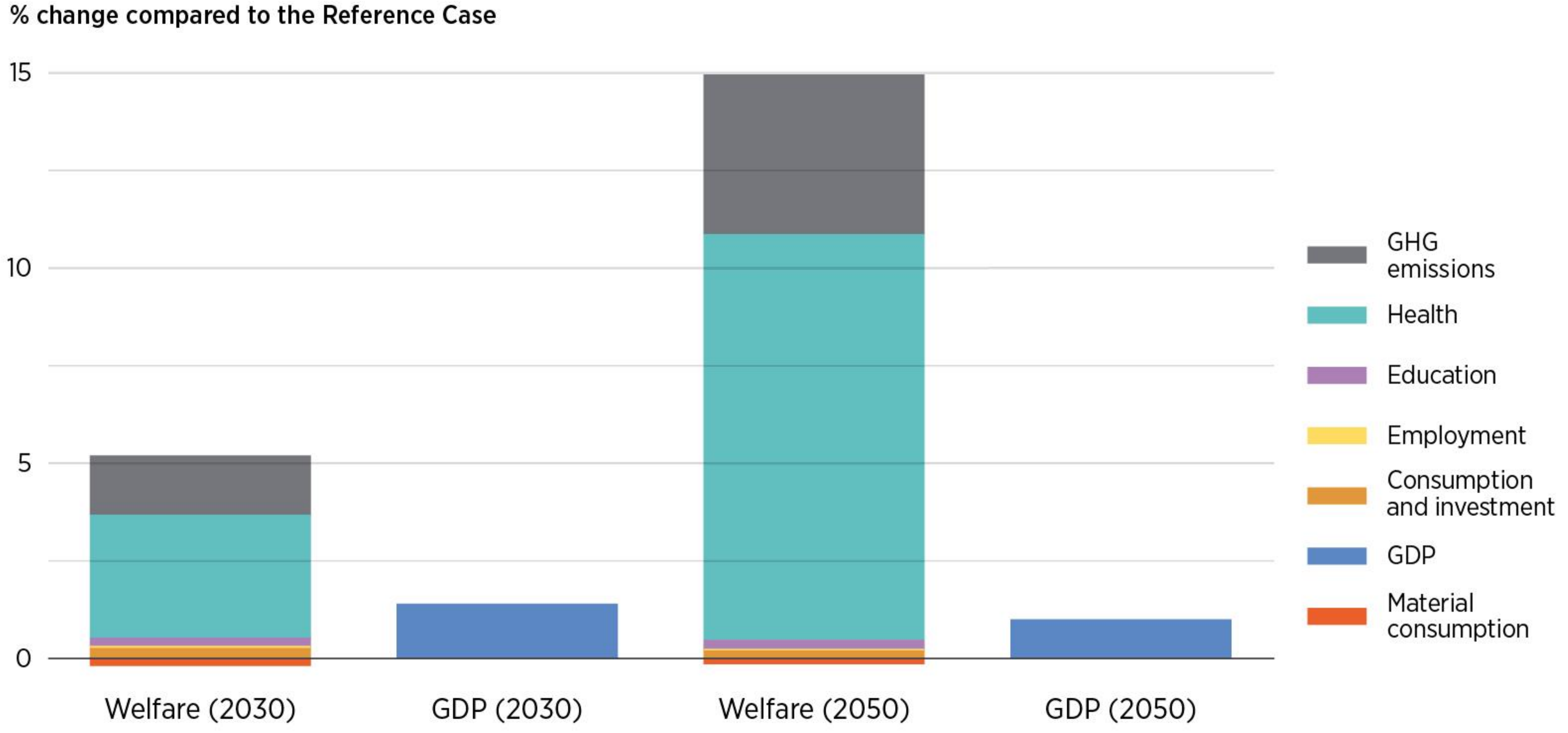
The Welfare indicator: Measuring beyond GDP



- The **economic** dimension includes total employment, consumption and investment.
- The **social** dimension is a proxy for human capital, considers total (public and private) expenditure in education, and health impacts from air pollution.
- The **environmental** dimension focuses on GHG emissions and the depletion of natural resources through consumption of materials.

The energy transition generates significant increases in global welfare

Global welfare indicators and GDP - the REmap Case compared to the Reference Case, 2030-2050



Human Welfare indicator dominated by health and GHG emissions, which is where the REmap energy transition roadmap makes the highest difference with the Reference Case.

Regional distribution of socio-economics benefits (I)

- In absolute terms all regions experience positive GDP growth during the transition, but in relative terms to the Reference Case that is not the case.

- At regional level the outcome of the REmap energy transition depends on the combination of its regional ambition and the regional socioeconomic structure.

- Regions with socioeconomic systems dependent of oil exports or weak domestic supply chains, can see GDP and employment reductions relative to the Reference Case, though still they will experiment a significant welfare improvement.

- The capability of a region to reap the long lasting indirect and induced transition benefits depends on how much its domestic supply chains contribute to the energy transition deployment and to the induced economic activity.

Regional distribution of socio-economics benefits (II)

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- Significantly different regional socioeconomic footprints are obtained from the REmap energy transition, with clear winners and losers, and increasing inequalities that could eventually develop in transition barriers.

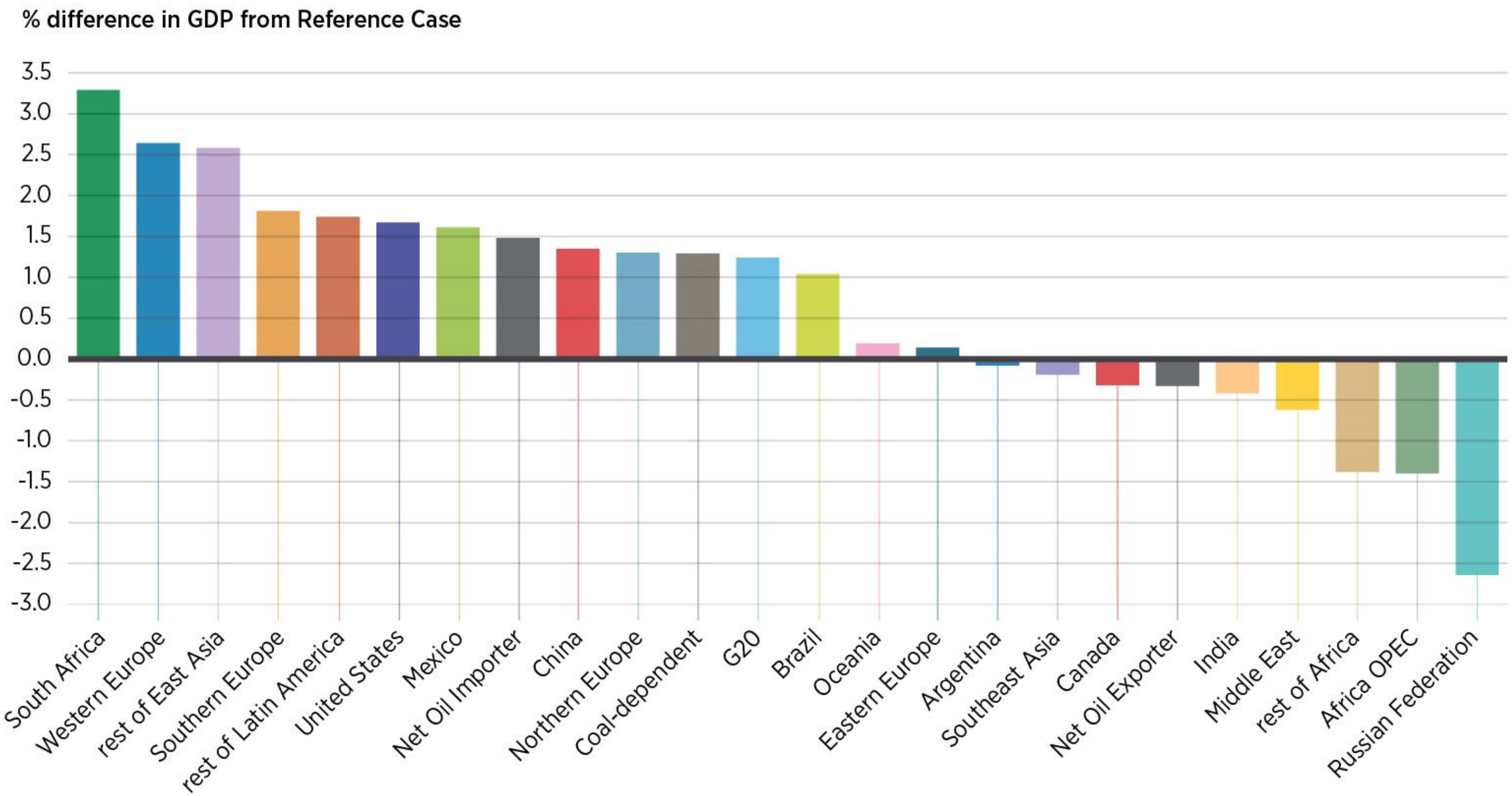
- Negative impacts on low-income countries must be addressed for the transition to be successful. Increasing the energy transition ambition and prioritising climate finance to steer the transition in these countries, reinforcing domestic supply chains to reap indirect and induced effects from the transition, and redirecting global economic flows with fairness criteria (i.e. regional redistribution of carbon tax incomes), can all contribute to address these issues.

Regional distribution of socio-economics benefits (III)

- Improving the regional transition outcome requires:
  - » Addressing fossil fuel export dependency and the entailment of the domestic supply chains with the fossil fuel industry, through a diversification of the economy. Just transition considerations need to be factored in: big parts of the society from these countries is currently held hostage by the fossil fuel industry that has benefited the growth of the economy elsewhere.
  - » Increasing the regional ambition from the energy transition. Comparatively increasing the transition ambition in low-income countries is closely related to fair transition considerations, since these countries have the lowest historic responsibility on the current climate crisis because of using fraction of the historic carbon budget well below their fair share.
  - » Strengthening domestic supply chains in order to reap all the socioeconomic benefits from its transition, instead of having other countries benefiting from it.

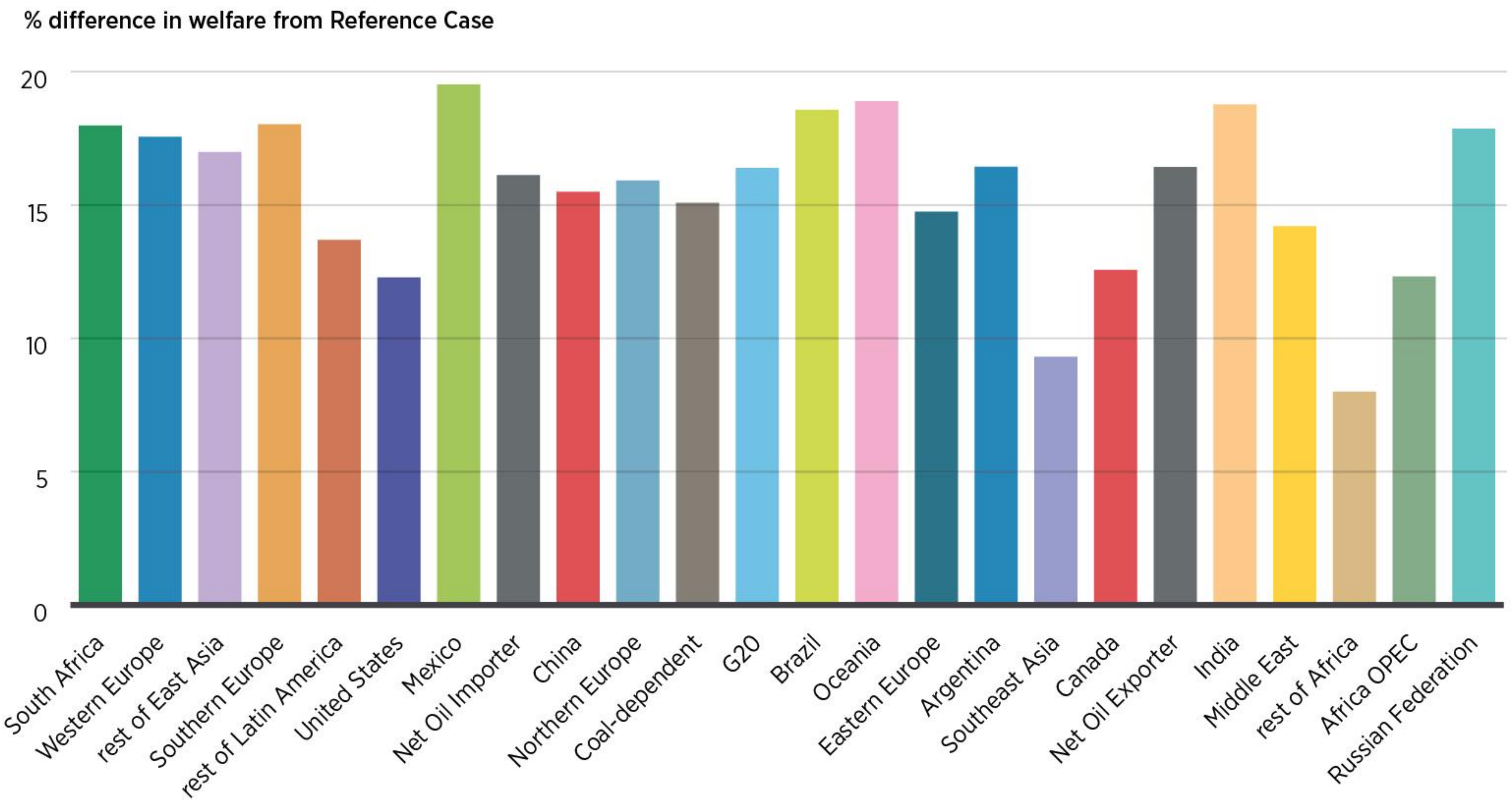
Impact of the energy transition on GDP

GDP impacts in select regions & countries - the REmap Case compared to the Reference Case, 2050



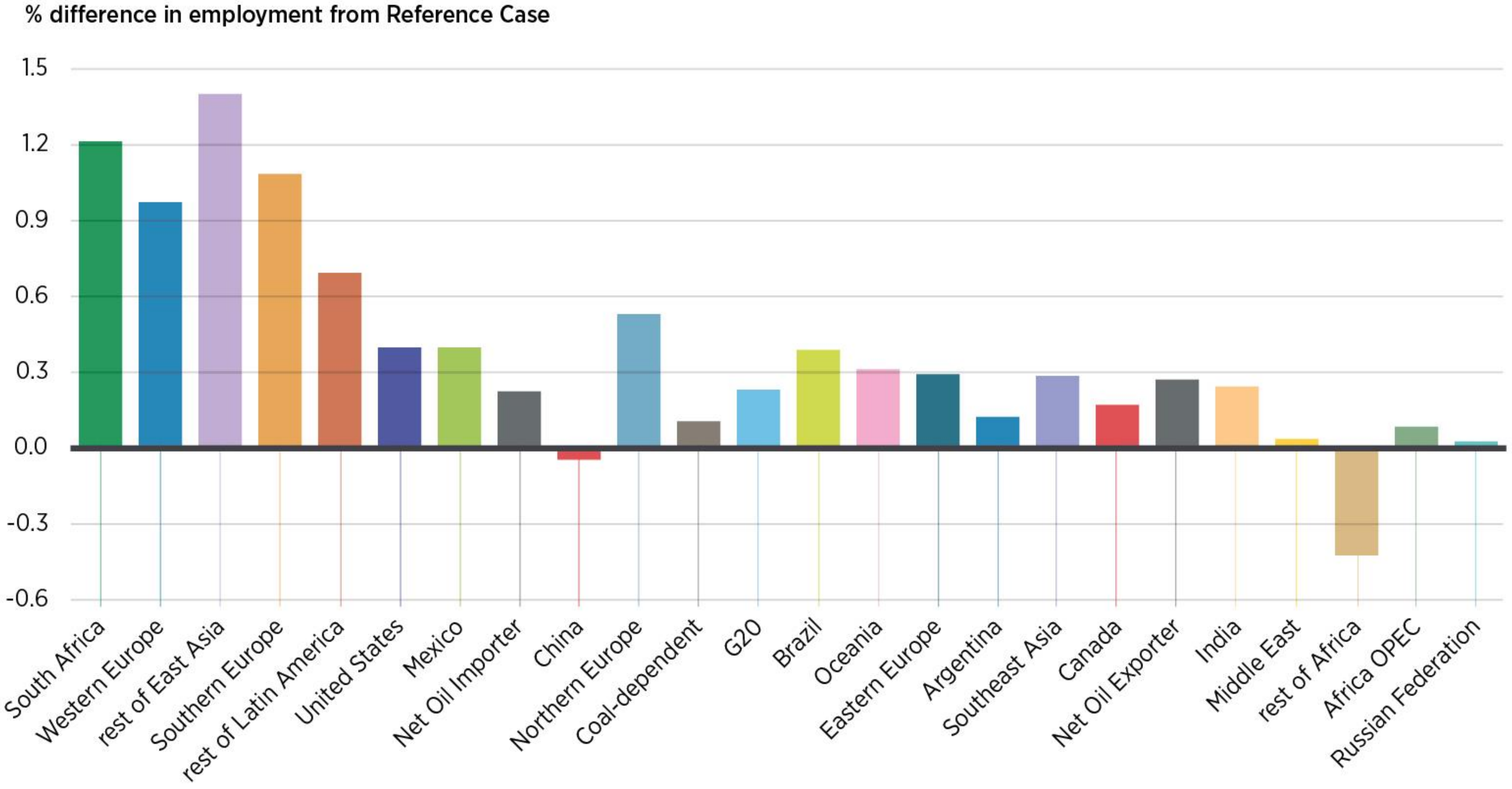
Impact of the energy transition on welfare

Welfare impacts in select regions & countries - the REmap Case compared to the Reference Case, 2050



Impact of the energy transition on employment

Employment impacts in select regions & countries - the REmap Case compared to the Reference Case, 2050



Energy Access and the transition

- The transition has to include the needs and role of approximately one-seventh of the human population who do not have access to modern energy.
  - » Failure to do so means an incomplete transition, with the socio-economic disequilibrium ultimately leading to failure in achieving global climate goals.
  - » Access to services requires integral approaches (synergies between renewable energy and energy efficiency), spurring socio-economic activity.
  - » Holistic planning is required to facilitate an organic evolution of infrastructures and socio-economic structures, avoiding stranding assets and resources.
  - » Completing the transition requires converging in the access to services throughout different regions and communities.
  - » The role of finance in access. Additional evolution is required in all the public, private and community fronts, favoring integral approaches pursuing local socio-economic articulation.

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THE ROLE OF FINANCE IN THE ENERGY TRANSITION

Financing the energy transition

- Implementing the transition within climate boundaries requires deploying significant amounts of additional investment in a relatively small time window, with additional simultaneous investment requirements for climate adaptation.
- The resulting additional pressure in the finance system needs to be addressed with appropriate policies in order to avoid transition barriers:
  - » Realigning economic flows with the transition requirements.
  - » Unlocking new sources of capital, for example from institutional investors or socially driven and community-based finance.
  - » Preventing capital cost increases.
  - » Reducing crowding out or its negative impacts.

Financing the energy transition: Cost of capital

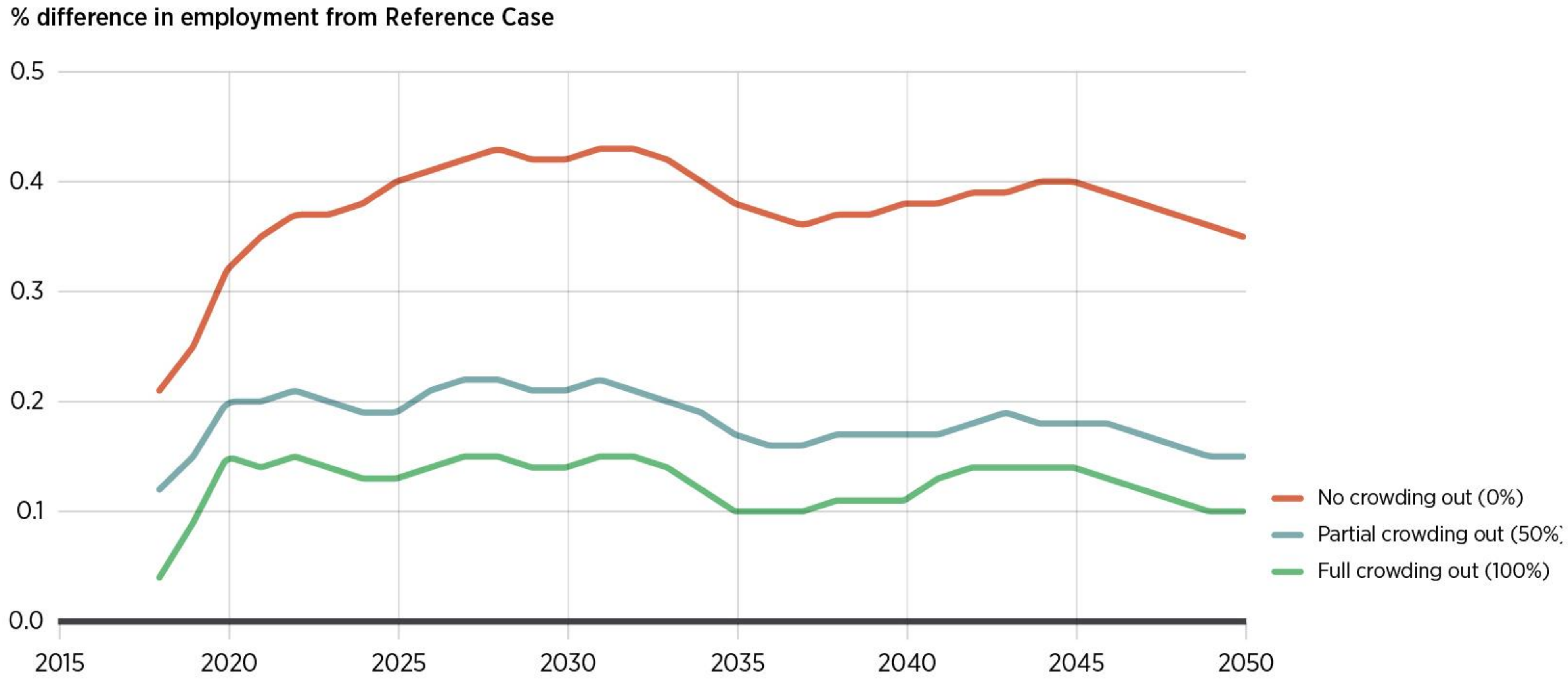
- Increased cost of capital because of higher indebtedness:
  - » A potential transition barrier.
  - » For the REmap ambition its impact is marginal, though it reduces improvements over the Reference.
  - » Higher levels of ambition could lead to significant impact.
  - » Low-income countries, which already face high borrowing costs, are more sensitive to additional cost of capital increases and required dedicated policies.
  - » Close monitoring of the cost of capital for the transition is needed so that policymakers can anticipate emerging barriers.

Financing the energy transition: Crowding out

- Crowding out has an important impact on the socio-economic benefits. Cumulative GDP increases over the reference up to 2050 are:
    - 90 USD trillion for 0% crowding out
    - 52 USD trillion for 50% crowding out
    - 40 USD trillion for 100% crowding out
- A 50% crowding out assumption seems to be overly conservative, and lower crowding out should be expected in many regions. The higher crowding out is to be expected in low-income countries, contributing to the increasing inequality along the energy transition.
- Appropriate policy and investment structure can minimize crowding out and its negative impact in socially sensitive parts of the economy.

Crowding out of capital affects employment, but the energy transition still generates positive employment growth

Relative increment of employment for different crowding-out assumptions - the REmap Case relative to the Reference Case, global



Minimizing crowding out has a significant impact on employment

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COUNTRY AMBITION FOR THE ENERGY TRANSITION

Country ambition for the energy transition

- The renewable energy mix will change considerably over the coming decades.
  - » According to current and planned policies (the Reference Case), most countries foresee modest increases in renewable energy while some even forecast a decline by 2050.
  - » **IRENA analysis shows that all countries can substantially increase renewable energy as a proportion of total energy by 2050.**
- Along with **renewable energy, energy efficiency is a key driver** of reduced energy-related CO_2 emissions in the energy transition.
  - » At country level, **the energy intensity of GDP would fall by between 50% and 75%.** Such a fall is required across all energy consuming economies.
  - » Under the **REmap Case, emissions in countries fall** to **between 20% and 40% of 2015 levels** by **2050**.

A rapid and significant decline in energy-related CO_2 emissions is necessary in all countries

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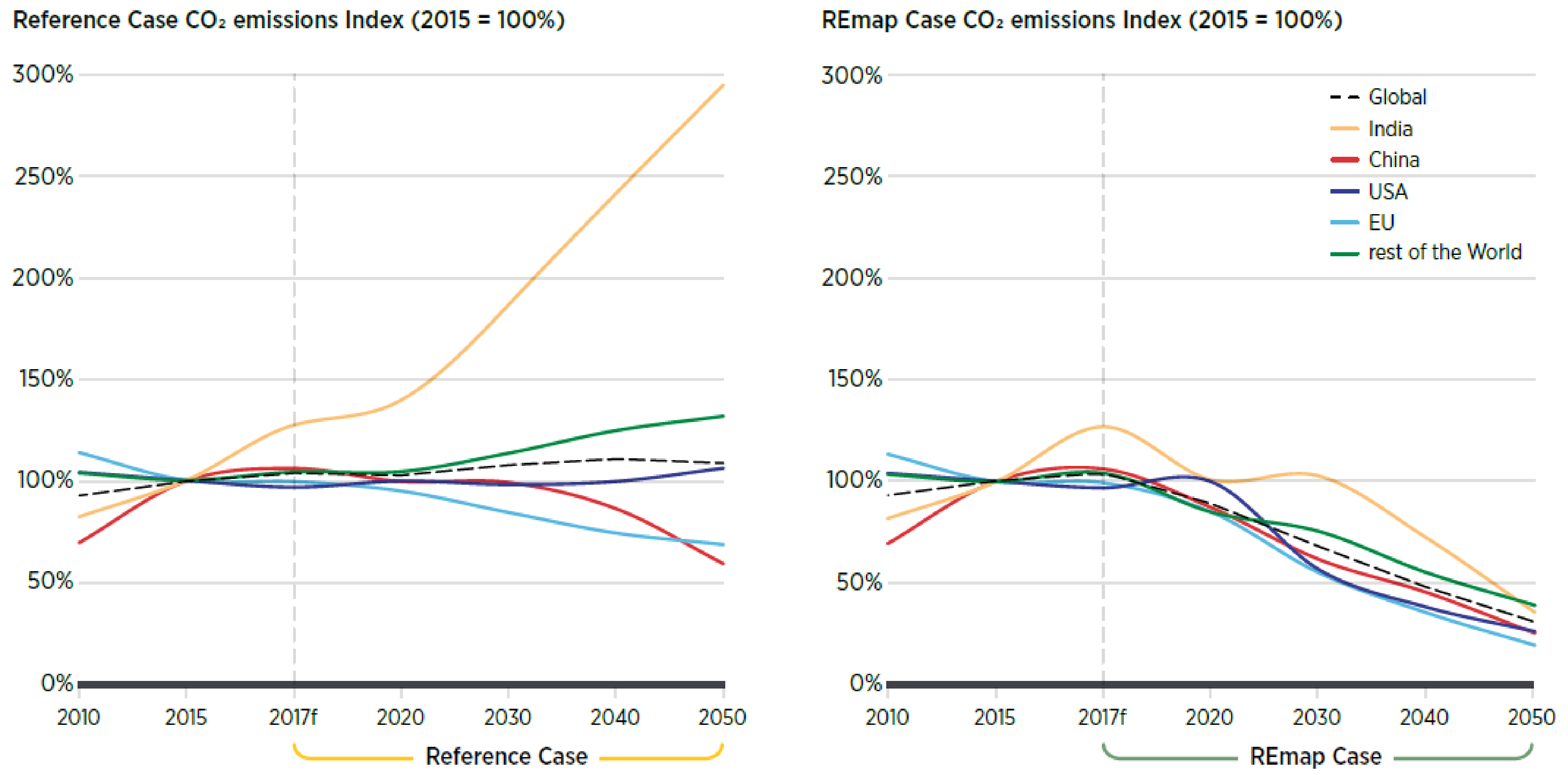
Energy-related CO_2 projections in selected countries, 2010-2050 (% change compared to 2015)



Under the REmap Case, emissions in countries fall to between 20% and 40% of 2015 levels by 2050.

Key indicators relevant to the energy transition in selected countries (REmap Case) (I)

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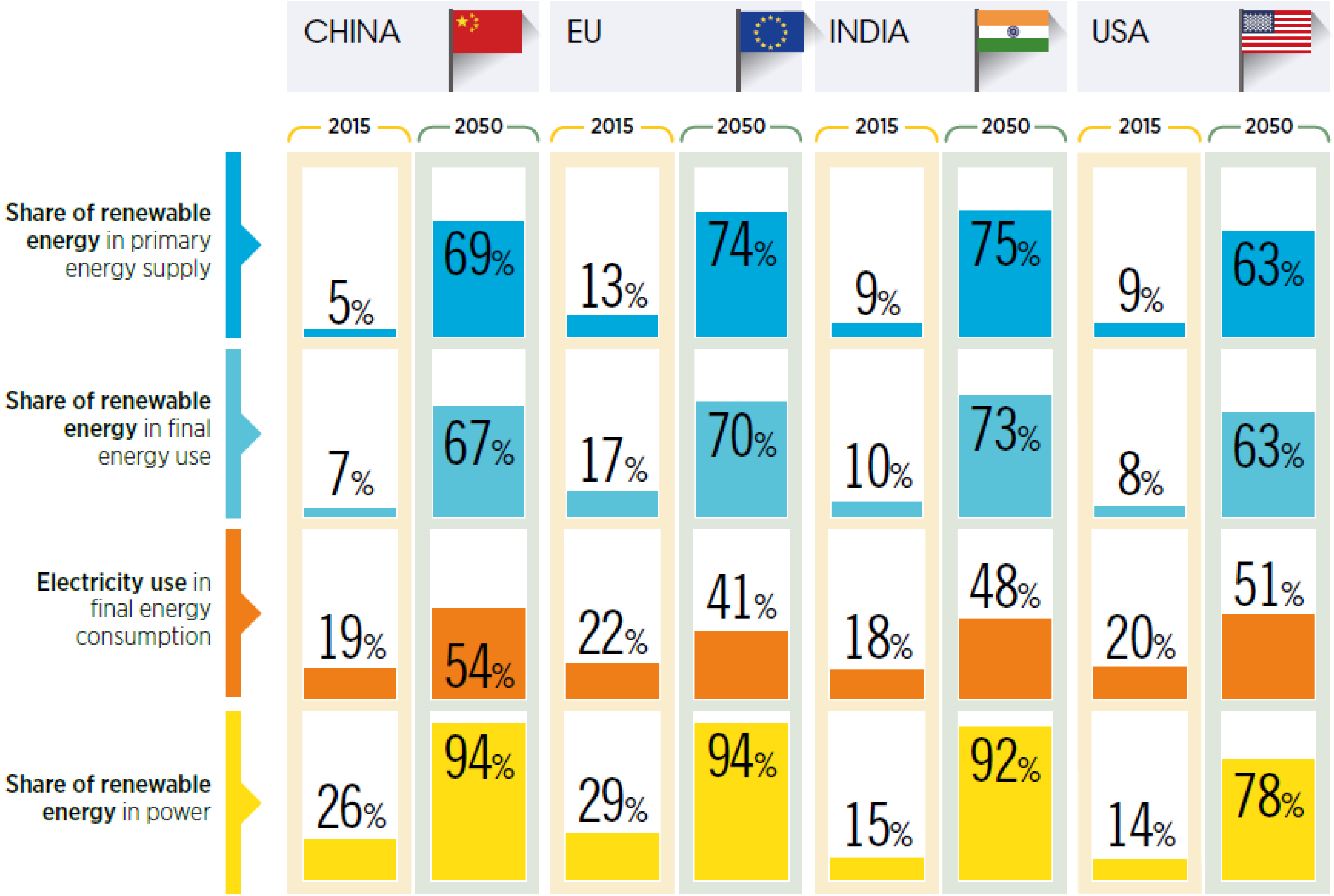
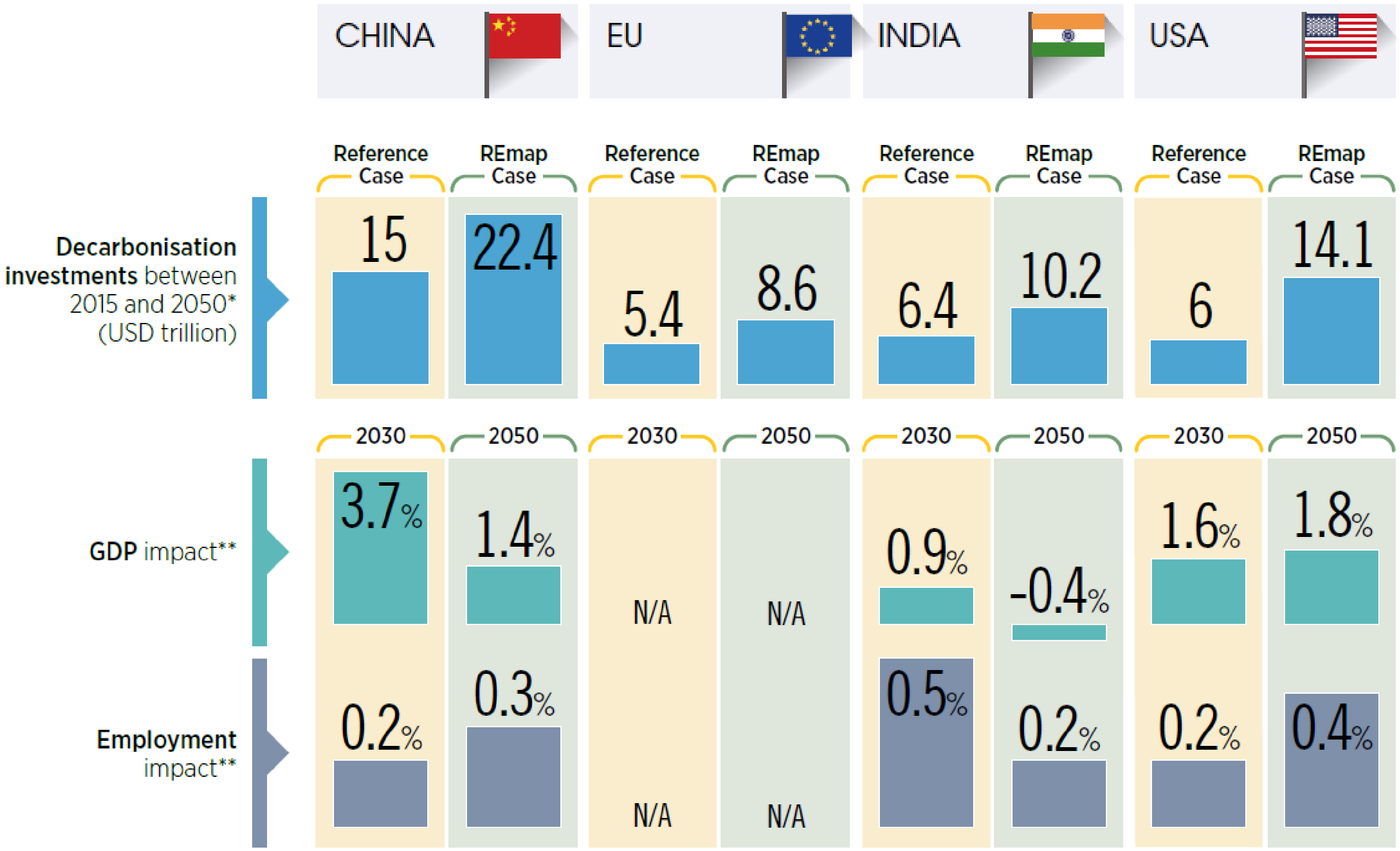


Note: Shares of renewable energy in final energy use refer to modern renewable energy

Key indicators relevant to the energy transition in selected countries (REmap Case) (II)



* Investments include investments in renewable energy (for power and end-uses), in energy efficiency and infrastructure, and in energy flexibility to integrate renewables in the power sector.

** The figures show the difference in GDP and employment between the REmap Case and the Reference Case.

HOW TO FOSTER THE GLOBAL ENERGY TRANSFORMATION: KEY FOCUS AREAS

Planning for the Global Energy Transformation

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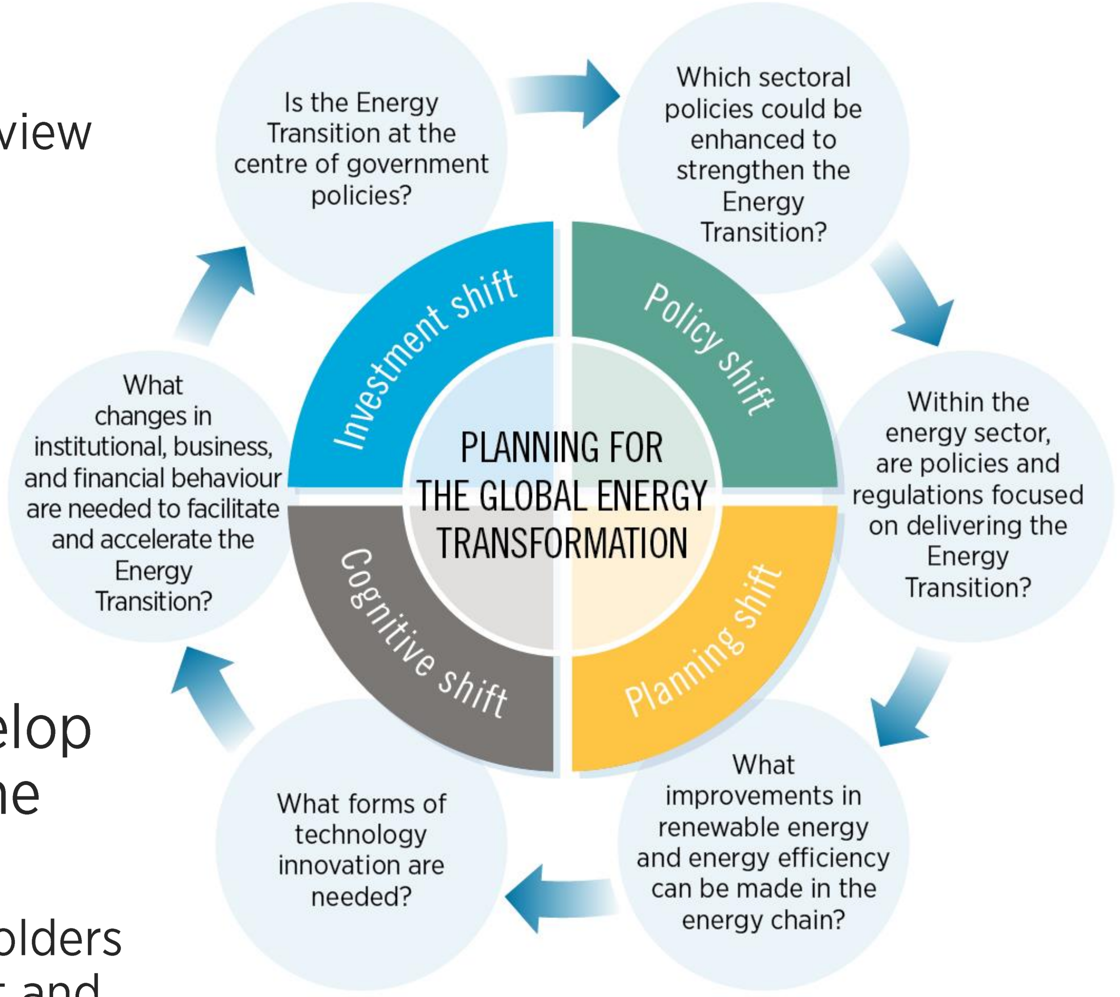
- The challenge that policy makers around the world face is how to accelerate the energy transition.
  - » Delivering this will require a transformation in how we view and manage the energy system and shifts in policy, investment, planning and behavior.

- Transitioning from a global fossil-fueled energy system, to one that is sustainable, will require a much greater transformation than current and planned envisage.

- Governments should lead the transition and develop new relationships and closer partnerships with the private sector.
  - » Coordination of the efforts of this network with stakeholders is vital, using the state's convening power to build trust and targeted policy instruments to achieve clear goals.



Key focus areas to foster the Global Energy Transformation (I)

Focus Area 1: Tap into the strong synergies between energy efficiency and renewables

- **Combine energy efficiency and renewable energy measures**, for example:
  - Public sector policies that integrate renewable technologies in the renovation of public buildings.
  - Deployment of technologies that promote renewable energy and increase energy efficiency (e.g. CHP).

Focus Area 2: Plan a power system with high shares of renewable energy

- Support **investment** to enable **infrastructure to integrate VRE and smart technologies.**
- Promote **time-responsive power-to-X** that can absorb excess renewable electricity.
- Promote **innovative business models** that enhance the system's flexibility and incentivize deployment of renewable technologies.

Key focus areas to foster the Global Energy Transformation (II)

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Focus Area 3: Increase the use of electricity in transport, buildings and industry

- Set targets for the **replacement of fossil fuel-based technologies by electrification measures**, including electric vehicles, heat pumps and electrical stoves
  - This also unlocks efficiency gains and yield a wide range of other benefits, including the reduction of air pollution in cities.
- Facilitate **sector coupling between power and end-use sectors**, to facilitate the integration of variable renewables in the power sector.
  - Increase demand flexibility through demand side management, smart charging and vehicle-to-grid for electric vehicles, flexible heat pump heating and cooling, thermal storage fed by electricity, etc.
- **Use information communication technologies and digitalisation**, along with demand side management, to reduce peak electricity demand, lower the need to invest in power capacity, and reduce operational costs.

Key focus areas to foster the Global Energy Transformation (III)

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Focus Area 4: Foster system-wide innovation

- **Innovation** is broader than technology R&D and it **should also cover** new approaches to power system operation, market design, enabling technologies, and business models, across the energy system.
- Focus should be on RD&D efforts to **assist sectors that lack commercially available decarbonization solutions**.
  - Establish more bilateral and multilateral demonstration projects, at commercial scale and funded publicly or privately.
- **Co-operate with and strengthen international programmes** to define a joint agenda for renewable energy technology innovation.
  - Encourage the development of internationally harmonised technical and quality control standards.
  - Improve global understanding among key public and private sector actors of critical innovation needs.

Key focus areas to foster the Global Energy Transformation (IV)

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Focus Area 5: Align socio-economic structures and investment with the transition

- The socio-economic and financial systems need to be aligned with broader sustainability and energy transition requirements.
  - Restructure the whole-economy flows **divesting from those sectors which are not aligned** with the transition needs and **redirecting the resulting savings** to facilitate the transition.
  - **Eliminate fossil fuel subsidies** from the whole economy, and internalize the climate externality from fossil fuels, aligning the associated savings and incomes with the transition requirements.
- A timely mobilisation of investments requires addressing the barriers that conventional financing faces, as well as mobilising additional investment streams.
  - Create the **right regulatory and market conditions** for investment in clean energy, while providing a **stable and predictable regulatory framework**. Use scarce public finance to help mitigate key risks, attract local private sector capital and help lowering the cost of capital in high risk countries/regions.
  - Increase the participation of **institutional investors** (pension funds, insurance companies, endowments and sovereign wealth funds) in the transition.
  - Participation of **social investment and community-based finance** for the transition, unlocking new sources of finance and actively involving society in the transition.

Key focus areas to foster the Global Energy Transformation (V)

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Focus Area 6: Ensure that transition costs and benefits are fairly distributed

- Materializing the transition requires **collaborative process** involving society as a whole. A **fair share of transition costs and benefits**, as well as effective implementation of **just transition considerations**, are the key to unlock such effective collaboration and avoid transition barriers
- A **fair transition** seeks to reduce historical divergences in levels of energy access. Universal **energy access** is a key component of a fair transition. Beyond basic energy access, huge disparities exist in the energy services available in different regions. The transition process will only be complete when **energy services converge in all regions**. Access and convergence considerations need to be an explicit part of any socio-economic footprint evaluation of transition roadmaps.
- Structures and contexts that enable a fair share of transition costs and benefits among the different regions and communities need to be implemented. A **social accounting framework** giving visibility and contextualizing the value of each individual contribution would support effective social collaboration.
- A **just transition**, both at macro (regions, countries) and micro (communities, individuals) levels, has to underpin the creation of structures providing alternatives that allow those individuals and regions that have been trapped into the fossil fuel dynamics to participate in the benefits of the transition.
- Just transition entails a number of policies, and the mix of policies that are needed will vary from country to country. **Education and training** policies are also critical. Because reskilling and other adjustments take time and are not always certain to succeed, there is also a need to provide **interim support**, such as unemployment insurance and other social protection measures.

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To know more about the Global Energy Transformation, this and other IRENA publications are available for download from www.irena.org/publications

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