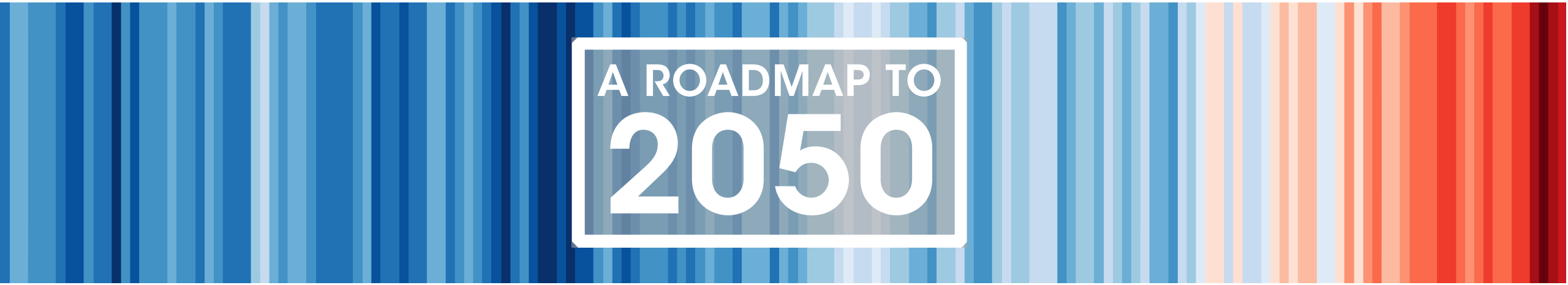
GLOBAL ENERGY TRANSFORMATION

Key technology solutions to achieve a global energy transformation

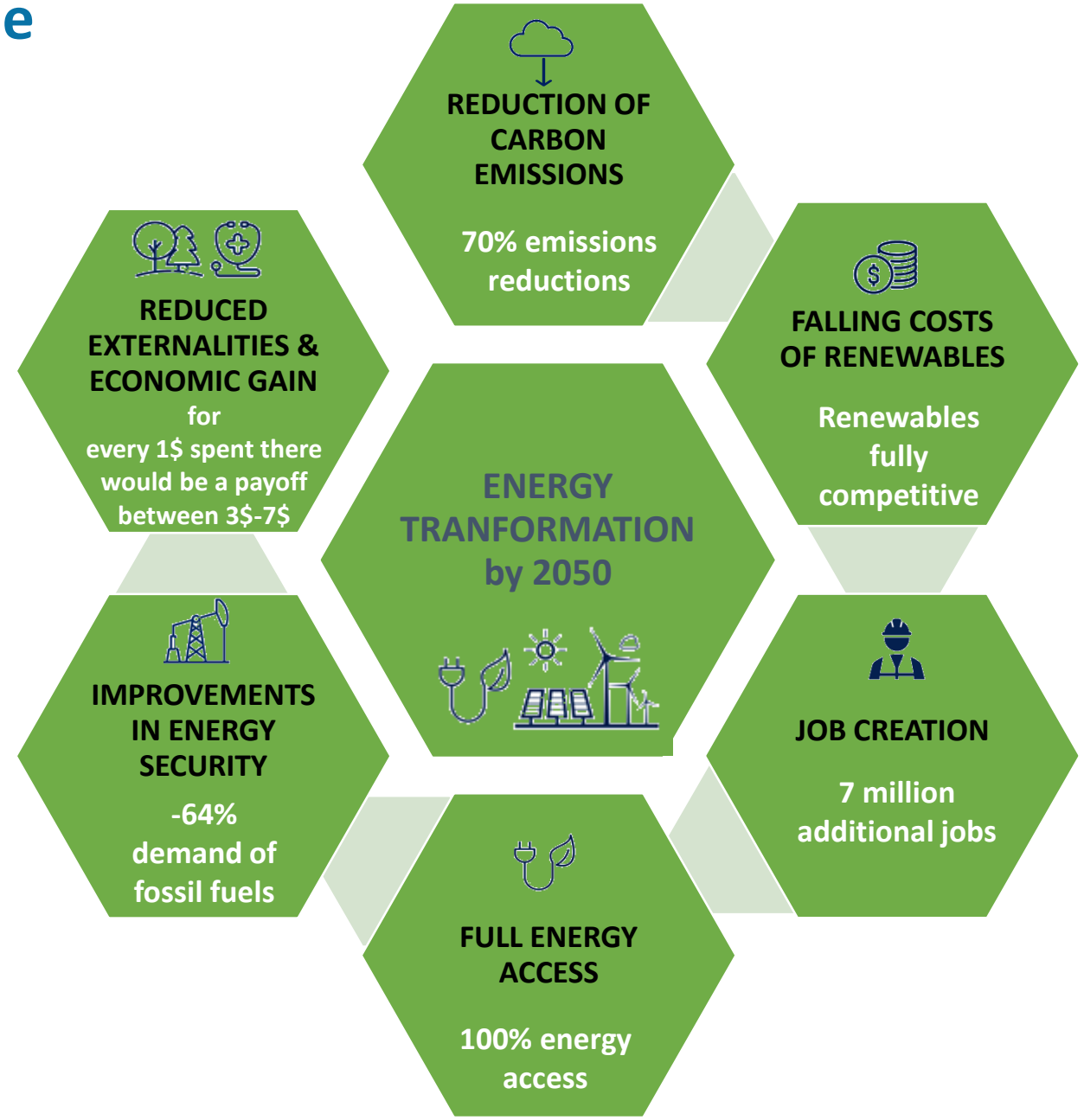


31 October 2019, Singapore – DDW at SIEW

Nicholas Wagner

Drivers for the energy transition: the role of renewable

- Local pollution, per capita emissions, floods
- Economy diversification: GDP dependence from oil&gas industry

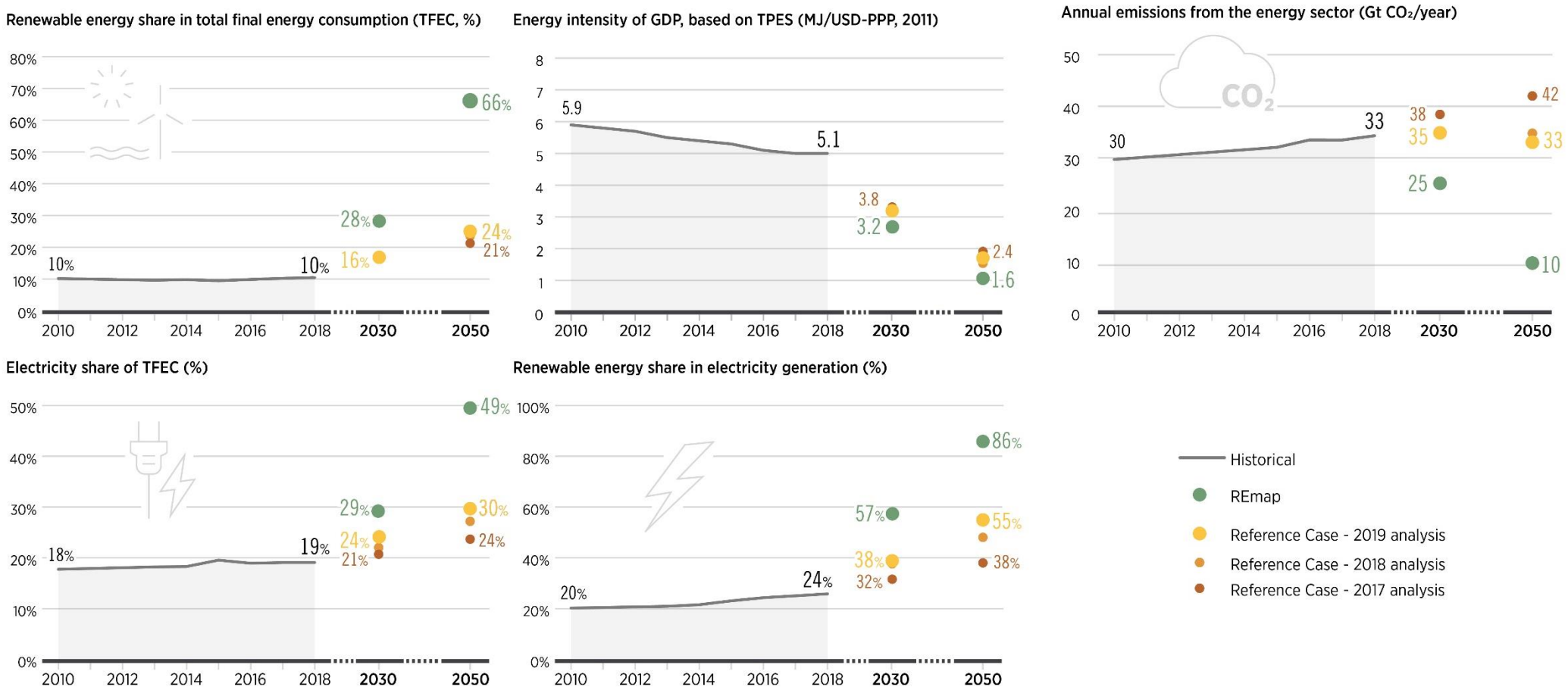


- Competitiveness, decreasing costs of renewables, fostering green growth
- Income and quality - jobs

What's happening now?

- Limited energy transition progress during the past decades
- GHG emissions continue to rise while 1.5 degrees becomes more pertinent
- Global energy transition needed in the coming 30 years – much faster than before
- Disagreement on how such a transition can be achieved and what it should look like
  - 2 degrees or 1.5 degrees, and their Gt CO_2 pathway implications
- Complex questions:
  - CCS/CCUS uses and costs, Nuclear costs, "clean" coal, LNG and fuel switching
  - Solar PV and wind are cheap, now what?
  - Role of hydrogen and PtX: potentially very important but uncertain; electrification and batteries; biofuels
- Specific sectors with particular challenges: Aviation, shipping, petrochemicals, cement, etc.
- Energy transition will have a profound impact on fossil fuel supply and demand

Monitoring the energy transition, mixed indicators



Current plans – as reflected in Nationally Determined Contributions to meet climate goals – point in the right direction yet still fall short of what is needed to meet international climate goals. Serious action is needed to accelerate the energy transition.

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IRENA's energy transition series

- **View to 2050 for the energy transition.**

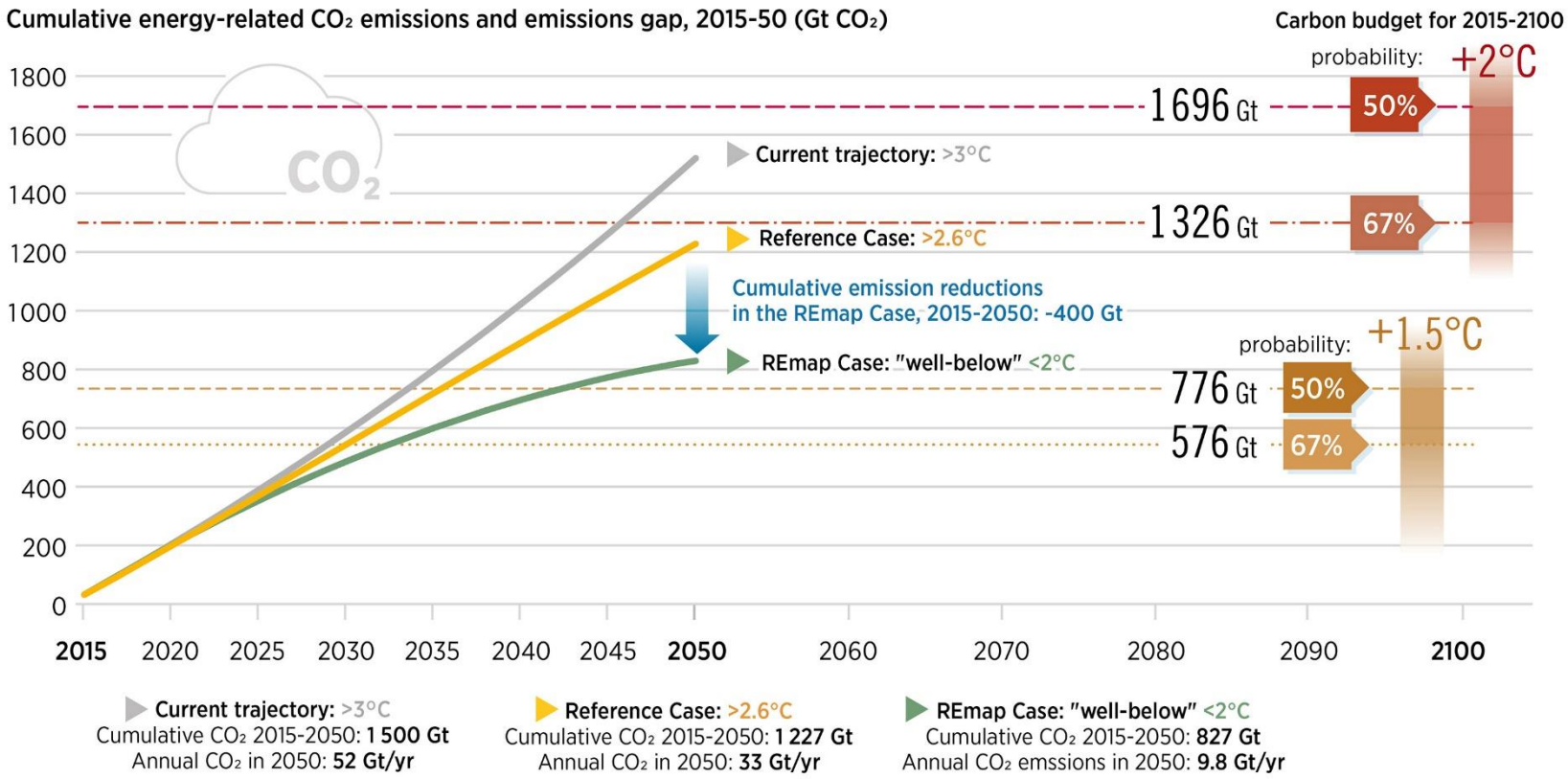
- **Third edition** launched at the Berlin Energy Transition Dialogue 2019.

- Joint report of IRENA's **Renewable energy roadmaps (REmap) programme** of Innovation and Technology Centre (IITC) and **socio-economic footprint of Knowledge, Policy and Finance Centre (KPFC).**

- However main focus of REmap **efforts are renewable energy and energy transition roadmaps** for regions and countries, currently completed/ongoing roadmaps for **15 countries, 5 regions**

PATHWAY FOR THE TRANSFORMATION

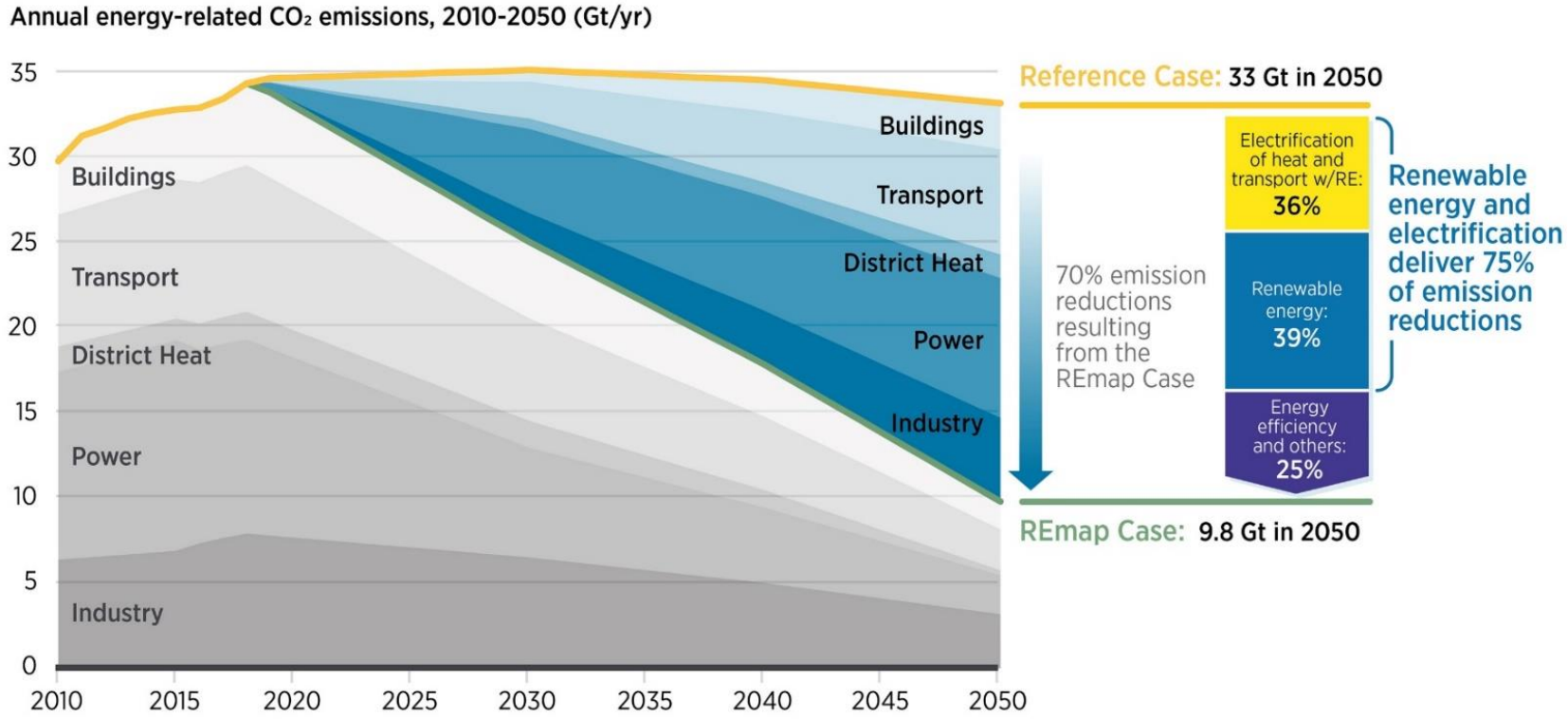
Bridging the gap: A pathway for a well-below 2°C climate target, towards 1.5°C



- The **global carbon budget** is set to **run out by 2030 based on current and planned policies**.
- **Energy-related emissions would need to fall by 3.5% per year** to the world to meet the **Paris Agreement**.

Notes: 1) Taking into account 2015-2017 emissions on top of the budget provided in IPCC (2018) (Table 2.2 – with no uncertainties and excluding additional Earth system feedbacks); 2) Budgets exclude industrial process emissions of 90 Gt; for this study, the assumption is that CO2 emissions from land use, land-use change and forestry (LULUCF) fall from 3.3 Gt in 2015 to zero by mid-century. LULUCF subsequently becomes a net absorber of CO2 over the remainder of the 21st century, and, as a result, cumulative CO2 emissions from LULUCF between 2015 and 2100 are close to zero; 3) Current trajectory shows the recent historical trend line, assuming the continuation of the annual average growth in energy-related CO2 emissions from the last five years (2013-2018) of 1.3% compound annual growth up to 2050; 4) Emissions budgets represent the total emissions that can be added into the atmosphere for the period 2015-2100 to stay below 2°C or 1.5°C at different confidence levels (50% or 67%) according to the IPCC (2018) report.

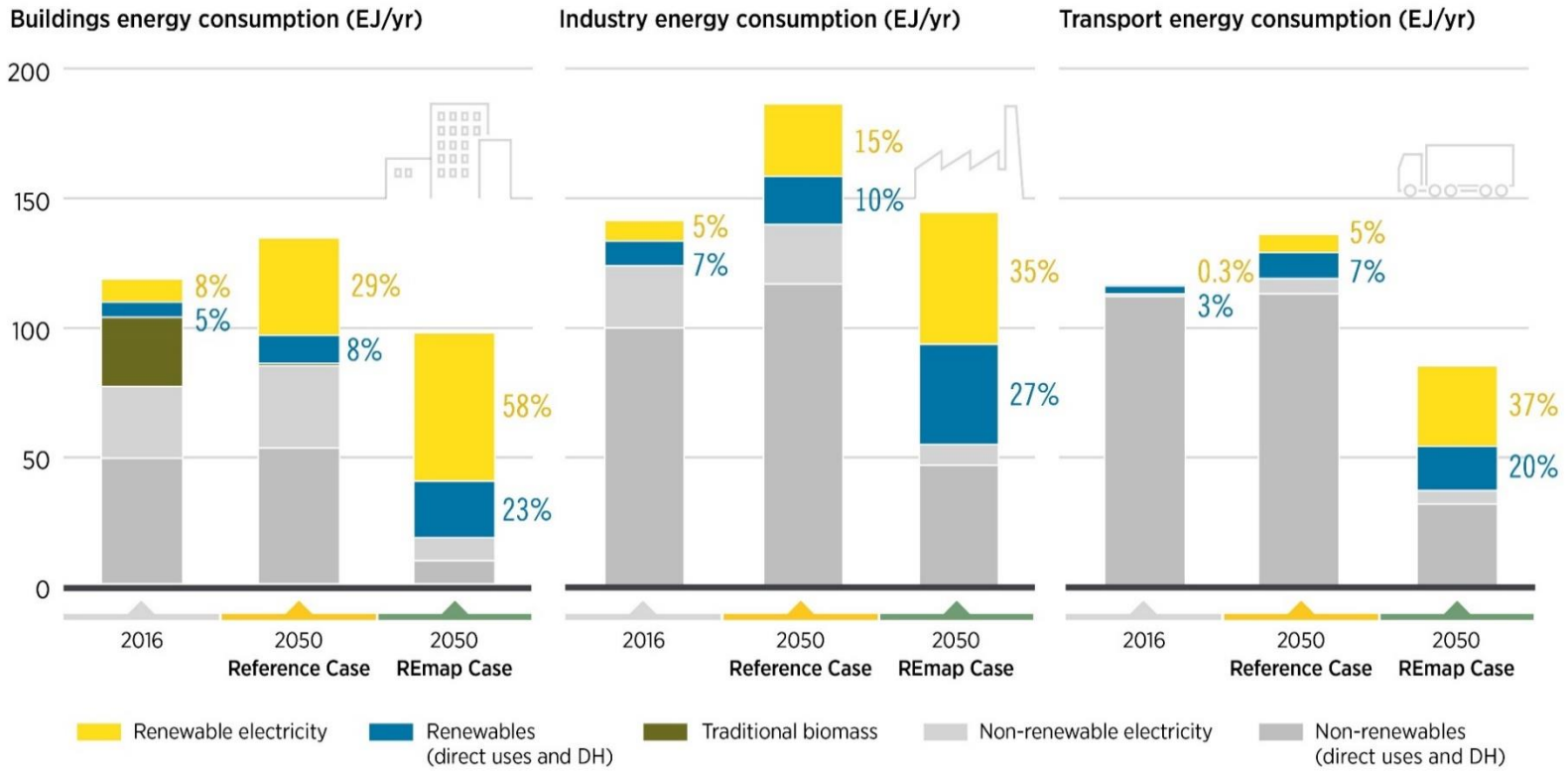
Key enabling solutions: Renewables and energy efficiency, boosted by substantial electrification



- Annual energy-related **CO_2 emissions under current and planned policies** – the Reference Case – are expected to remain **flat** but **must be reduced by 70% to bring temperature rise to the well-below 2°C climate goal.**
- **Electrification, renewable energy and energy efficiency** measures provide over **90% of the reductions required by 2050**. **Renewable power and electrification of heat and transport** alone **reduce emissions by 75%.**

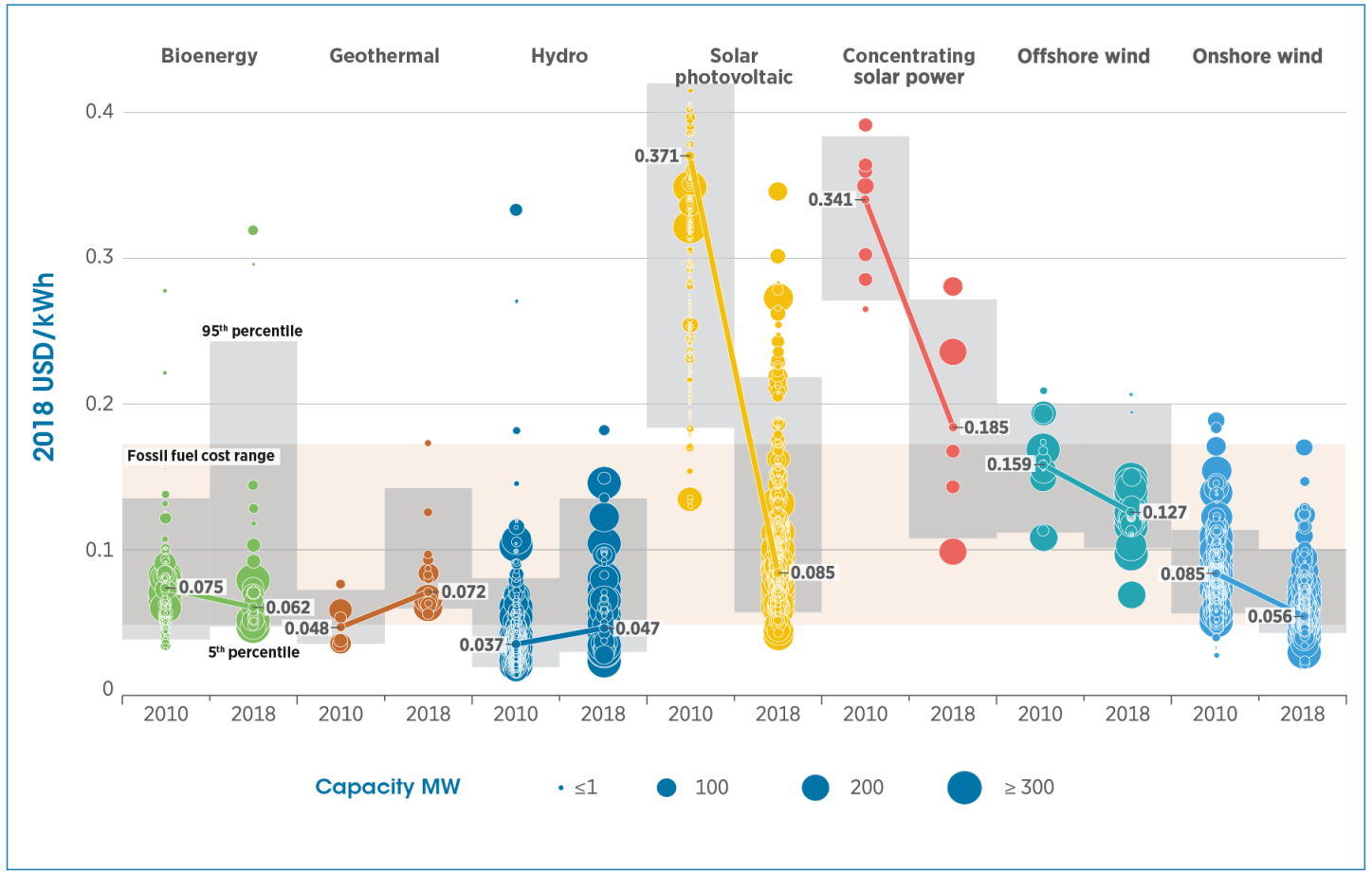
Note: "Renewables" implies deployment of renewable technologies in the power sector (wind, solar PV, etc.,) and end-use direct applications (solar thermal, geothermal, biomass). "Energy efficiency" contains efficiency measures deployed in end-use applications in industry, buildings and transport sectors (e.g., improving insulation of buildings or installing more efficient appliances and equipment). "Electrification" denotes electrification of heat and transport applications, such as deploying heat pumps and EVs.

Renewable energy shares increase in all end-use sectors



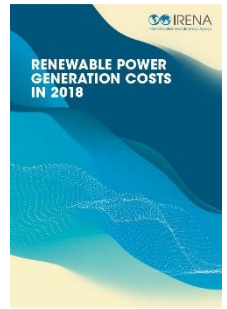
- By 2050, **renewables could dominate the transport and buildings sectors reaching 57% and 81% of the sectors' final energy consumption**.
- **Electricity would account for the largest share of renewable energy use**, complemented by biomass, geothermal and solar thermal.

Renewable Energy: Recent cost evolution

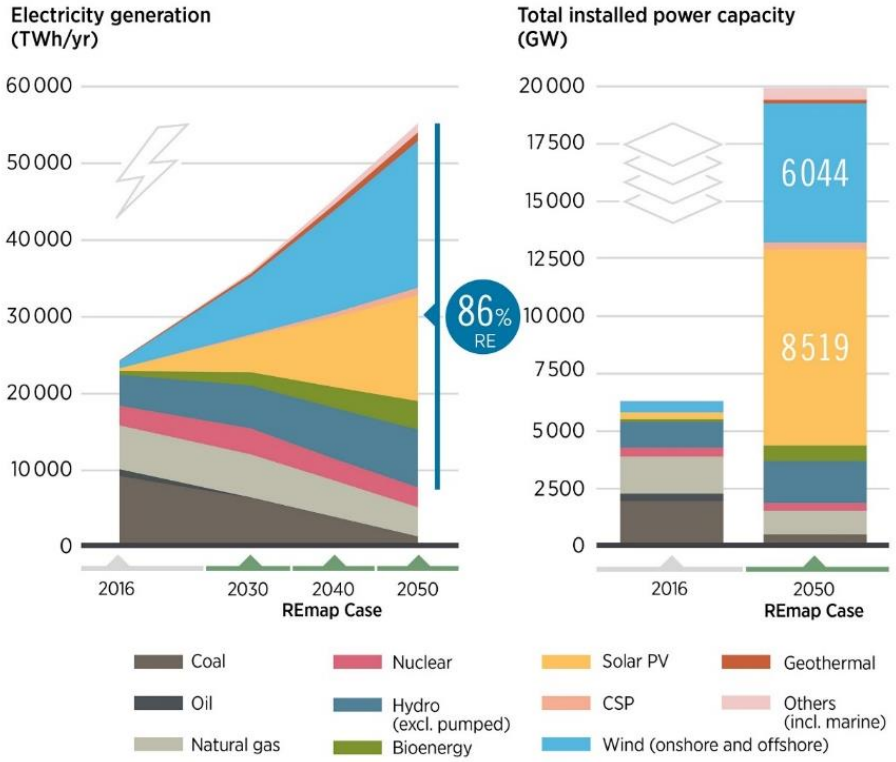


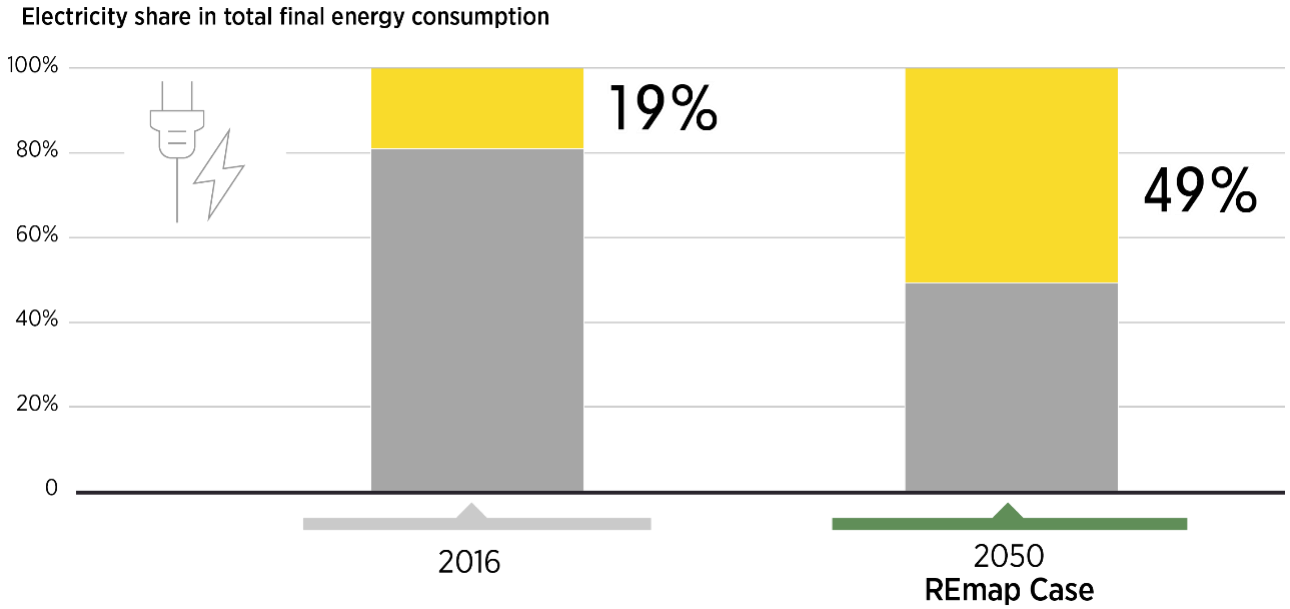
Note: This data is for the year of commissioning. The diameter of the circle represents the size of the project, with its centre the value for the cost of each project on the Y axis. The thick lines are the global weighted-average LCOE value for plants commissioned in each year. Real weighted average cost of capital (WACC) is 7.5% for OECD countries and China and 10% for the rest of the world. The single band represents the fossil fuel-fired power generation cost range, while the bands for each technology and year represent the 5th and 95th percentile bands for renewable projects.

- **Average LCOE of all renewable power generation technologies**, except CSP **fall in fossil fuel cost range**
- Bioenergy, geothermal, hydro and onshore wind all at lower end of fossil cost range
- Solar PV rapidly falling towards lower end.
- Offshore wind and CSP have much lower deployment. Data suggests costs will continue to fall.



Electrification paired with renewables is a major solution for decarbonisation



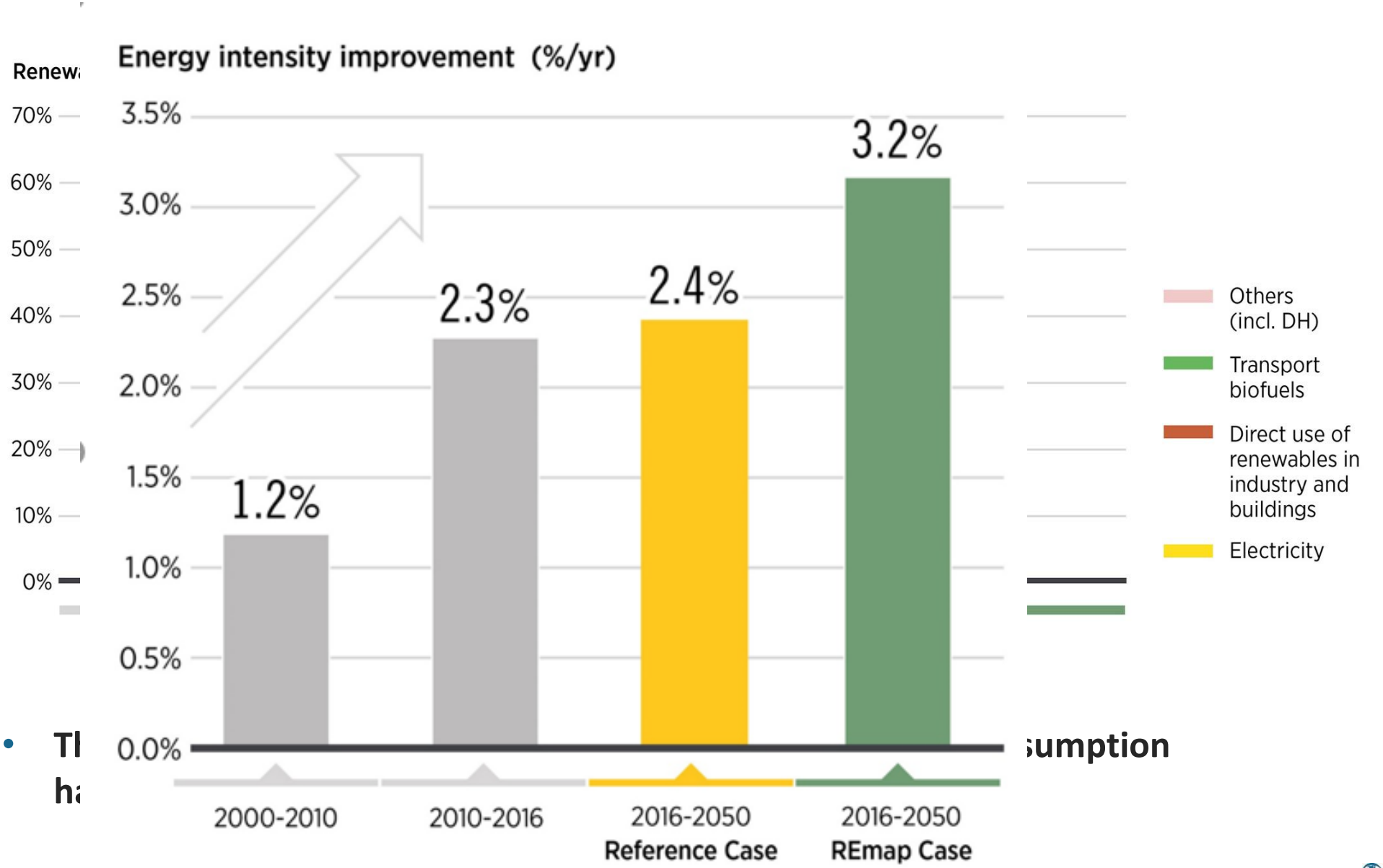


By 2050:

- Electricity becomes the central energy carrier
- 86% of electricity generation will come from renewables

A transformed energy system: Scaling up renewables not just for power, but also for heat and transport

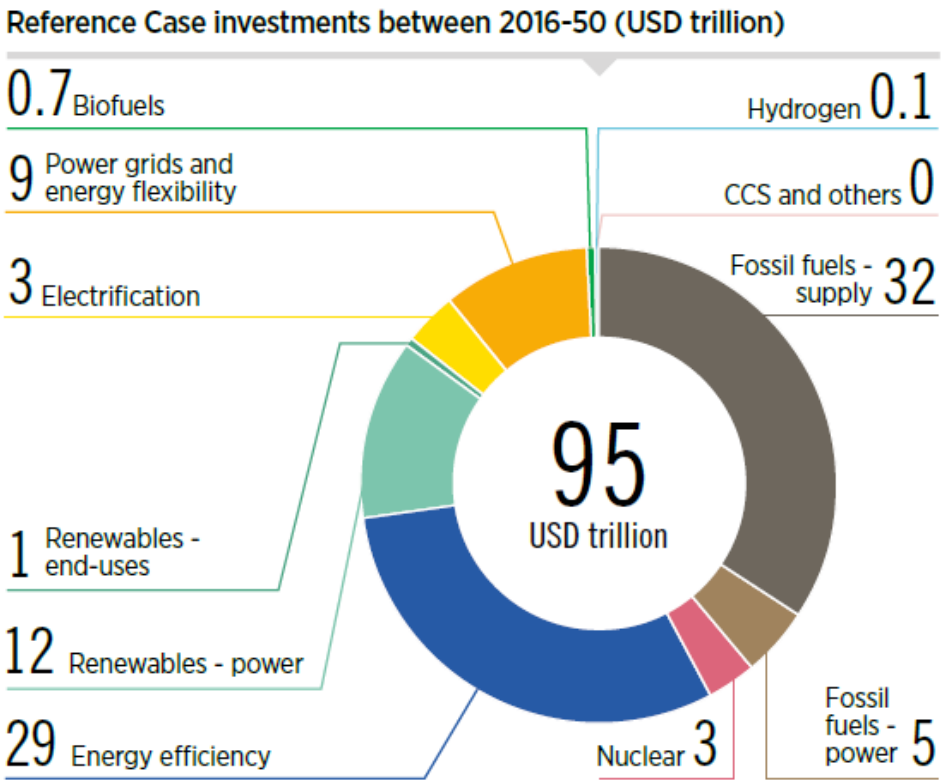
A transformed energy system: Renewables growth must increase six-fold

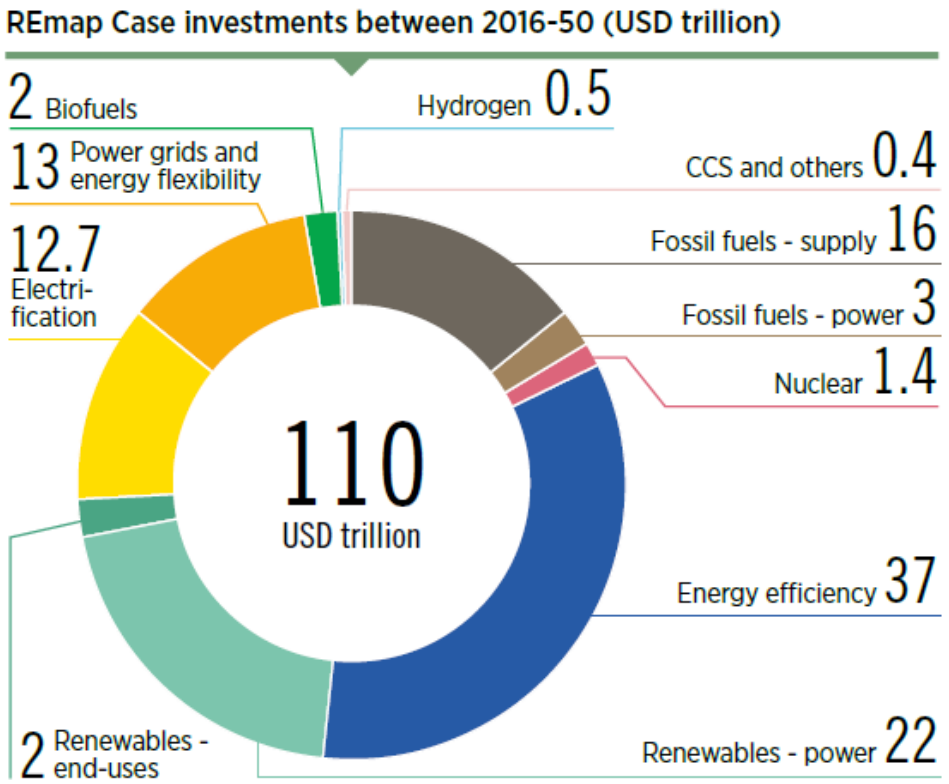


- **Tl … sumption ha…**

Note: DH refers to district heat and ppt refers

Shifting investments to energy efficiency, renewables and the electrification of heat and transport

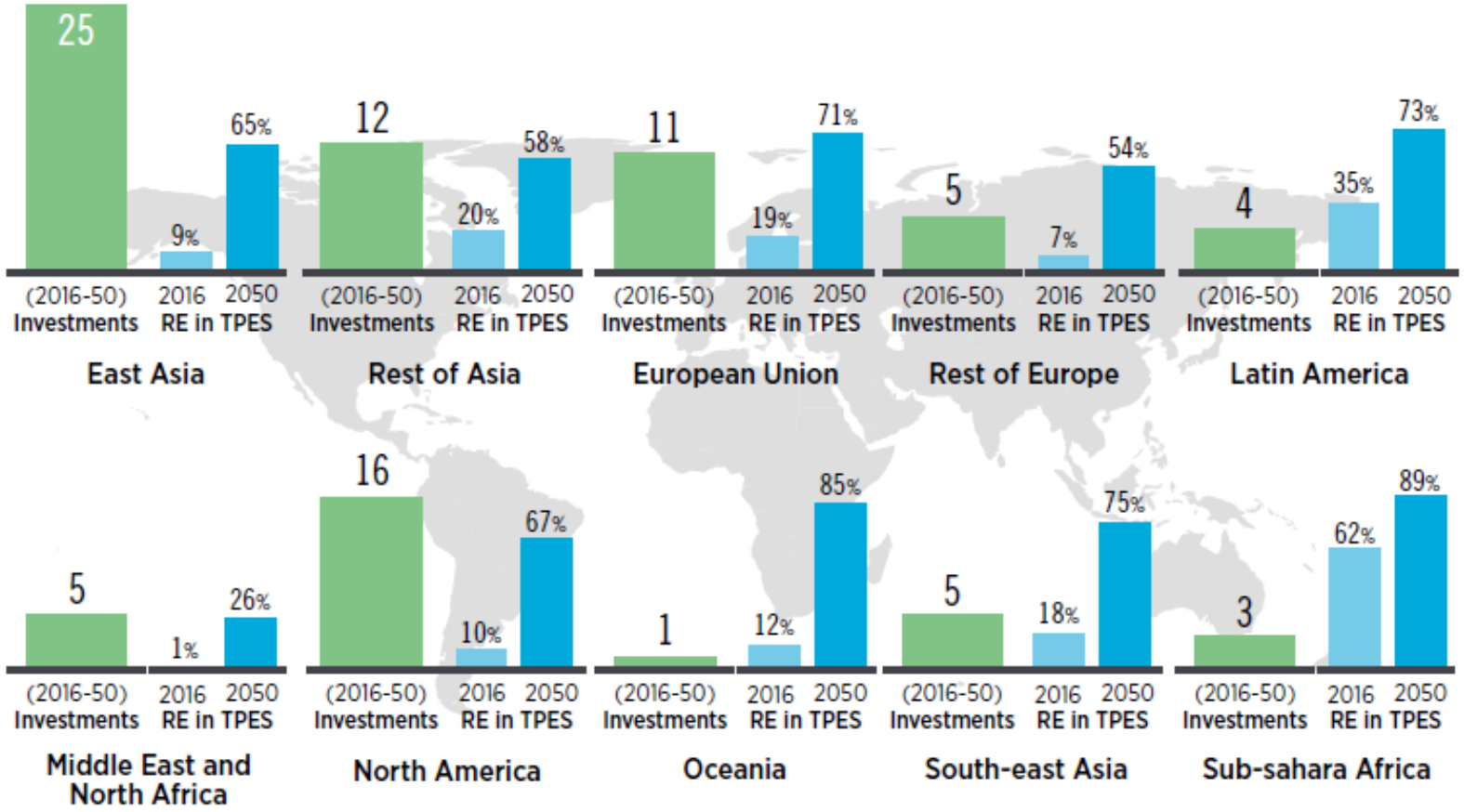




- **The REmap Case increases investments in the global energy system by USD 15 trillion,** and **shifts investment into electrification, renewable energy and energy efficiency technologies,** which together, would make up **four-fifths of the cumulative energy sector investments** over the period to 2050.

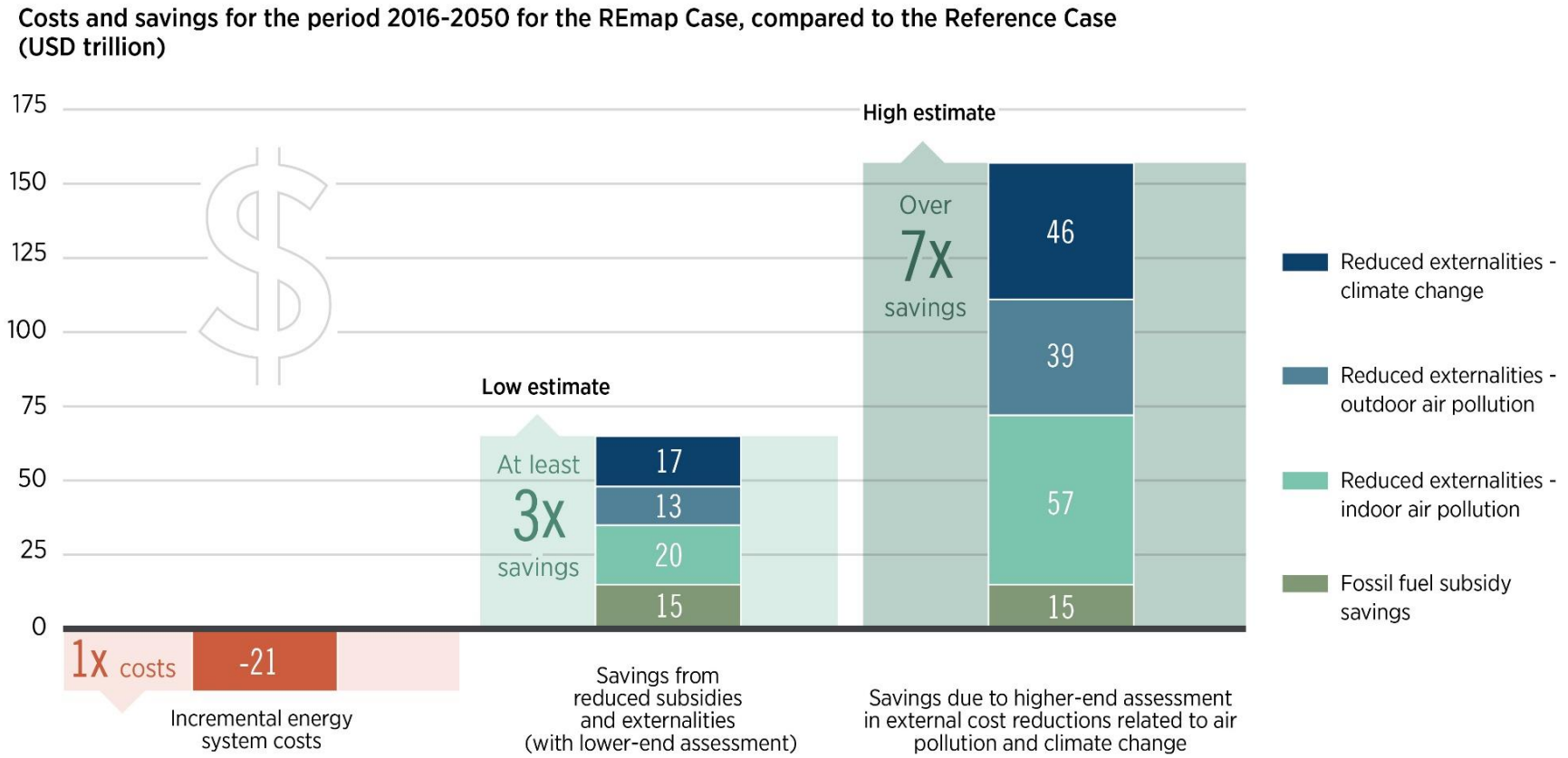
Notes: *includes nuclear, carbon capture and storage (CCS); **includes investments in power grids, energy flexibility, electrification of heat and transport applications as well as renewable hydrogen. USD value in 2015.

Investments are widespread around the world



The **renewables share in the energy mix will need to increase in all regions up to 2050**. Sub-Saharan Africa (89%), Oceania (85%), South-East Asia (75%) and Latin-America (73%) and Europe (71%) will see the highest share. East Asia and North America will, however, require almost 50% of the total energy investment over the period in the REmap Case due to increasing energy demand.

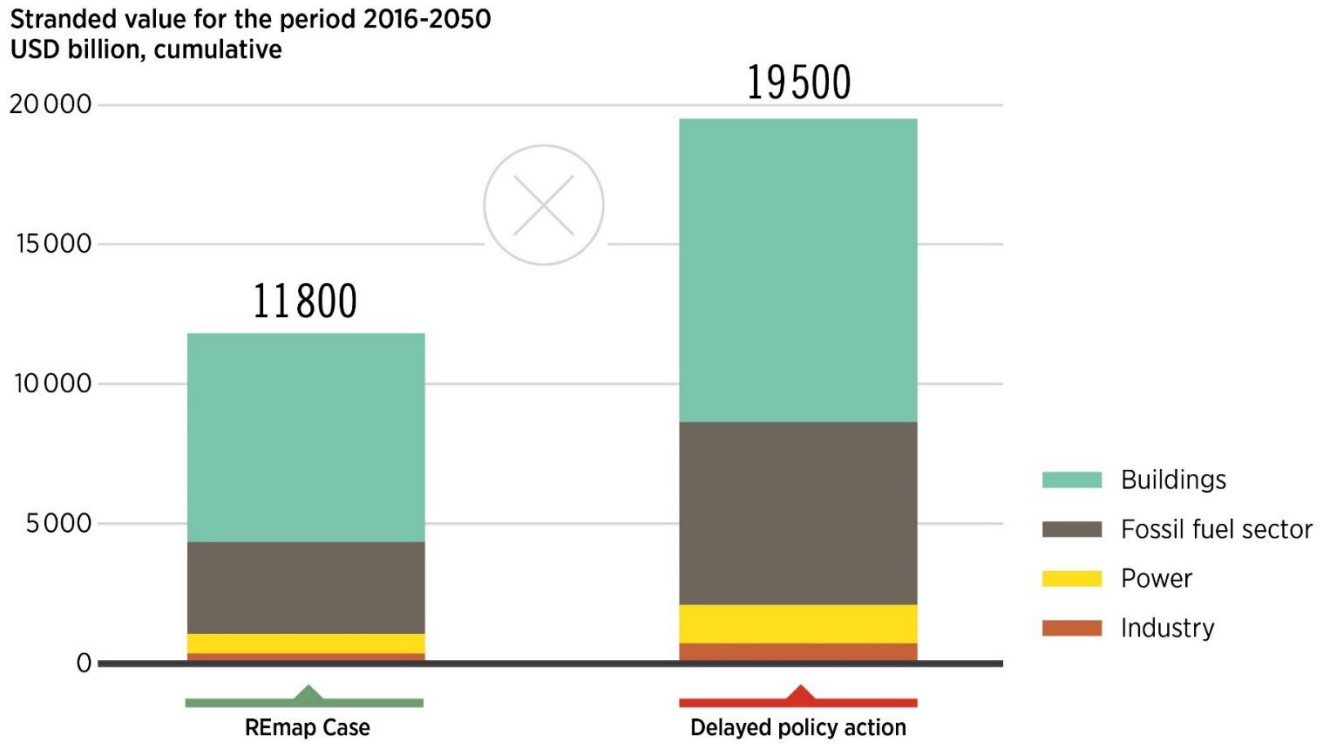
Investing in the energy transition is beneficial for society



- For every dollar spent for the energy transition, **the payoff amounts to at least three dollars and, depending on how externalities are valued, up to seven dollars.**

- As renewables rise, net **energy subsidies fall**, as do health costs from air pollution and climate impacts. Half of the USD 21 trillion in additional expenditures, including investment and operational costs, could be covered by the savings on avoided subsidies

Stranded assets increase significantly if action to decarbonise the energy sector is delayed



- If Paris Agreement aims are met, the resulting stranded assets would amount to **almost USD 12 trillion by 2050.** This equals about one-third of additional investment needs or around 3% of today's global capital stock. **Delaying action, however, would increase those losses to as much as USD 20 trillion.**

Technologies

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Power Sector Transformation at IRENA

Market design, regulation, business models

Long term, least cost capacity expansion plan

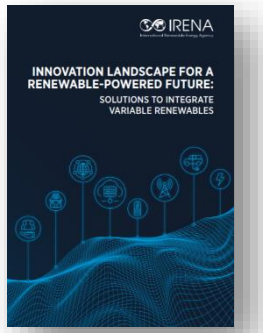
Unit commitment and economic dispatch

Grid studies

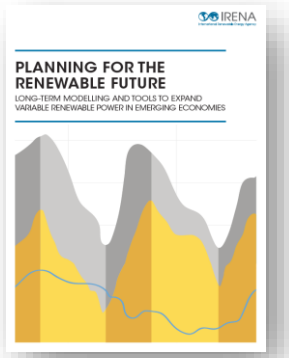
Find the optimal pathway for power sector transformation

PST Knowledge Framework

- ***Adapting electricity market design to high shares of VRE (2017)***
- Country regulatory advice
- **Innovation Landscape for a renewable-powered future (Jan 2019)**



- Best practices in long-term scenario-based modelling* report, ***Planning for the renewable future***
- Recommendations werediscussed at a **different regional workshops (LATAM, MENA, Kazakhstan)**

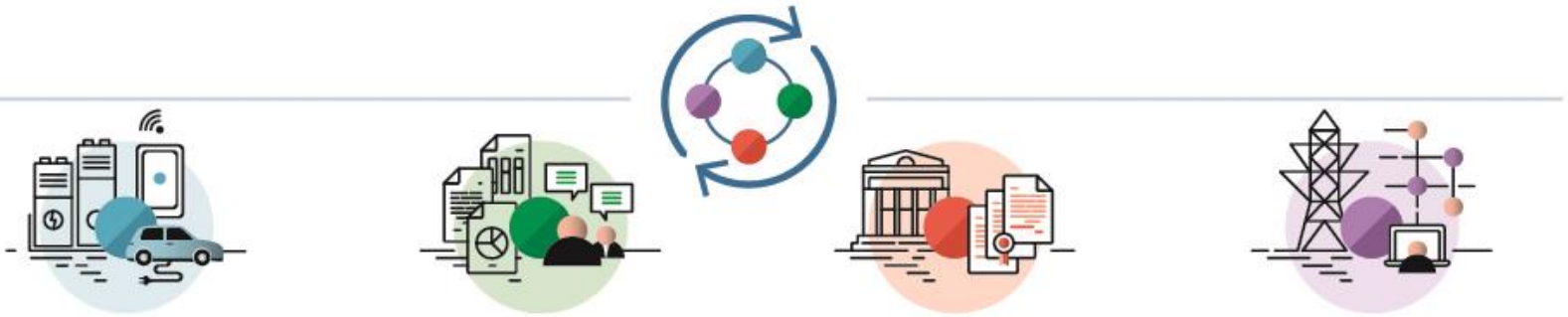


- **Production cost modeling with PLEXOS**
- *Power system flexibility for the energy transition* and IRENA FlexTool
- Developing a electricity storage valuation framework (Q3 2019)
- Analytical briefs on integration costs and demand side flexibility

- Technical network studies (Fiji, Vanuatu)
- ***Transforming small-island power systems*** – SIDS Guide
- Technical assessments for larger systems – Dominican Republic

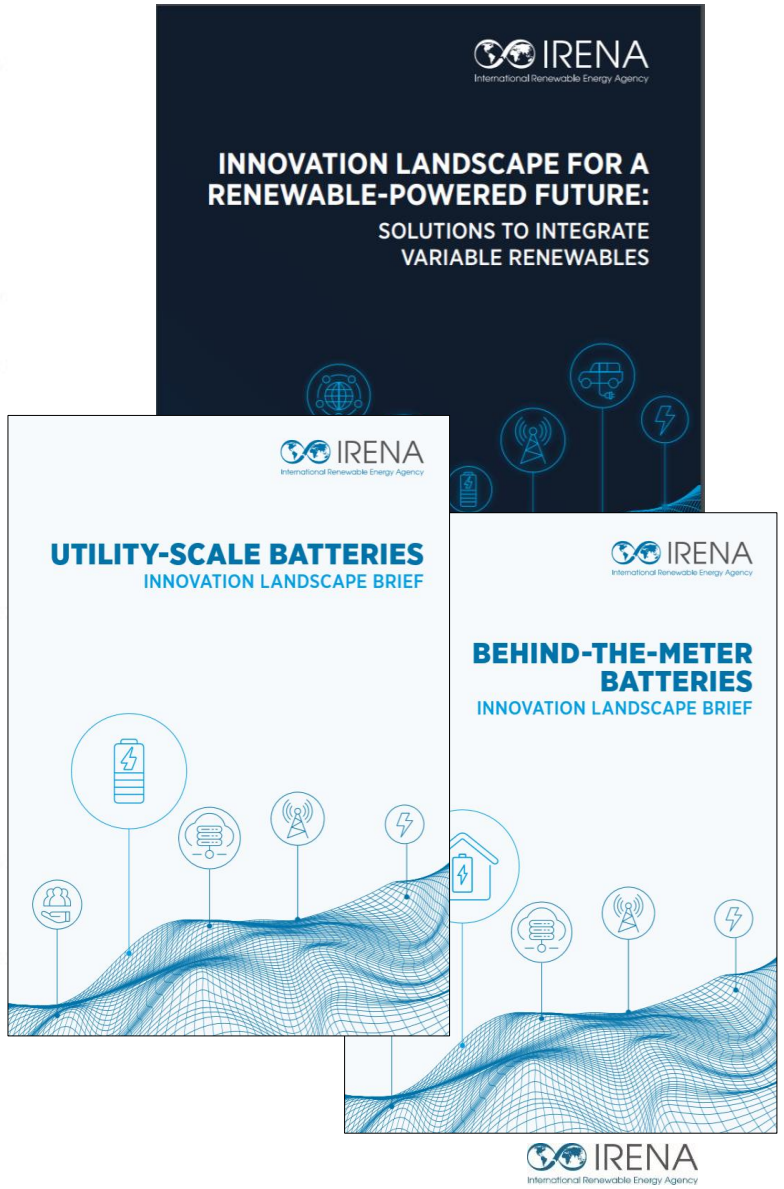
- Help Members identify next steps on their pathway for power system decarbonization
- Development of a **tool to measure progress on integration of renewables** based on experience from front runner countries

Innovation landscape for power-sector flexibility



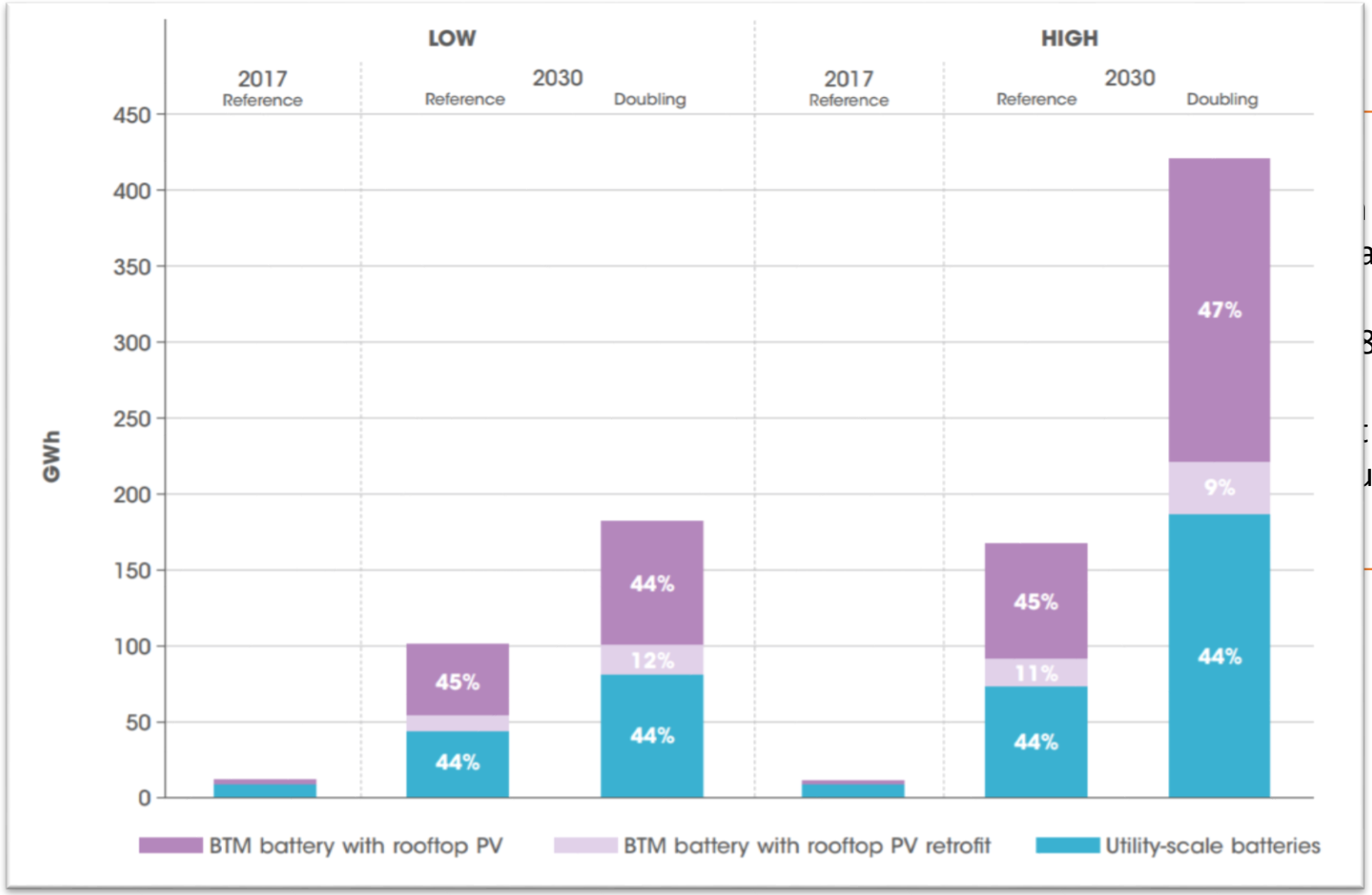
ENABLING TECHNOLOGIES	BUSINESS MODELS	MARKET DESIGN	SYSTEM OPERATION
1 Utility-scale batteries 2 Behind-the-meter batteries	12 Aggregators 13 Peer-to-peer electricity trading 14 Energy-as-a-service	17 Increasing time granularity in electricity markets 18 Increasing space granularity in electricity markets 19 Innovative ancillary services 20 Re-designing capacity markets 21 Regional markets	25 Future role of distribution system operators 26 Co-operation between transmission and distribution system operators
3 Electric-vehicle smart charging 4 Renewable power-to-heat 5 Renewable power-to-hydrogen	15 Community-ownership models 16 Pay-as-you-go models	22 Time-of-use tariffs 23 Market integration of distributed energy resources 24 Net billing schemes	27 Advanced forecasting of variable renewable power generation 28 Innovative operation of pumped hydropower storage
6 Internet of things 7 Artificial intelligence and big data 8 Blockchain			29 Virtual power lines 30 Dynamic line rating
9 Renewable mini-grids 10 Supergrids			
11 Flexibility in conventional power plants			

Innovations involving energy storage



Stationary battery storage's energy capacity growth 2017–2030

Total battery capacity in stationary applications could increase from a current estimate of 11 GWh to between 100 GWh and 167 GWh in 2030 in the REmap's reference case.



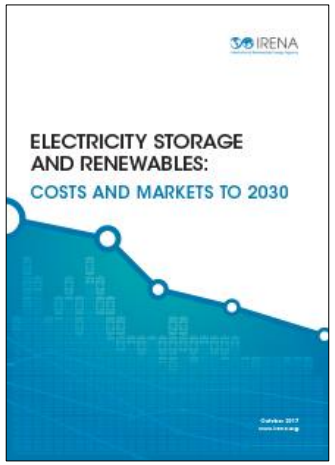
REmap's doubling case…
attery capacity can grow to

31-421 GWh by 2030…

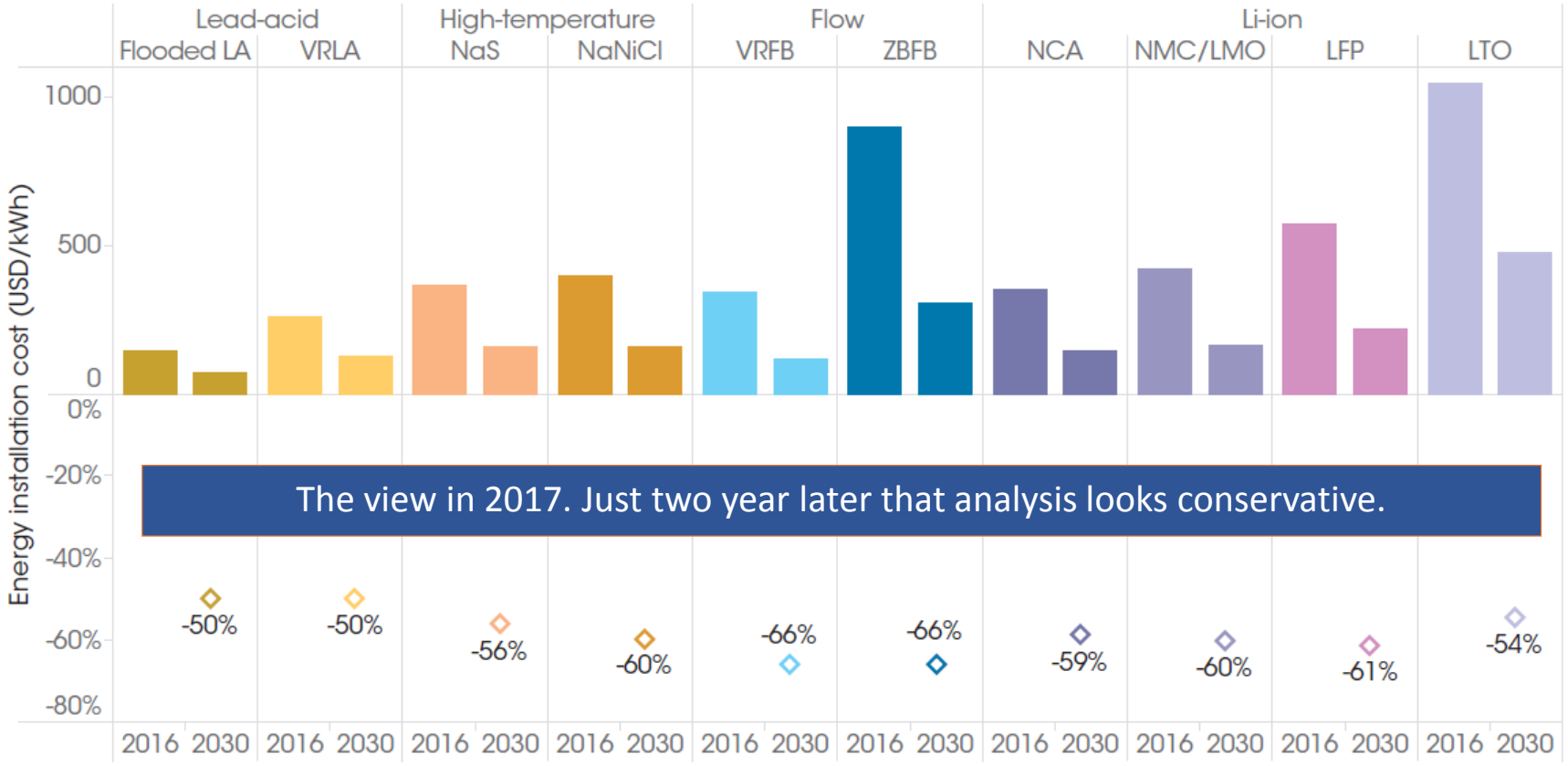
least a 17-fold growth from
urrent market.

Costs are falling – IRENA's 2017 Analysis of Energy Storage

The total installed cost of a Li-ion battery could fall by an additional 54-61% by 2030 in stationary applications



Energy installations costs (USD/kWh of storage) Reference case 2016



The view in 2017. Just two year later that analysis looks conservative.

Note: LA = lead-acid; VRLA = valve-regulated lead-acid; NaS = sodium sulphur; NaNiCl = sodium nickel chloride; VRFB = vanadium redox flow battery; ZBFB = zinc bromine flow battery; NCA = nickel cobalt aluminium; NMC/LMO = nickel manganese cobalt oxide/lithium manganese oxide; LFP = lithium iron phosphate; LTO = lithium titanate.

Central estimate for the energy installation costs from between USD 150 and USD 1 050/kWh in 2016 to between USD 75 and USD 80/kWh by 2030

The market for electricity storage would grow by 2-3 times with battery storage growing by 17-38 times by 2030.

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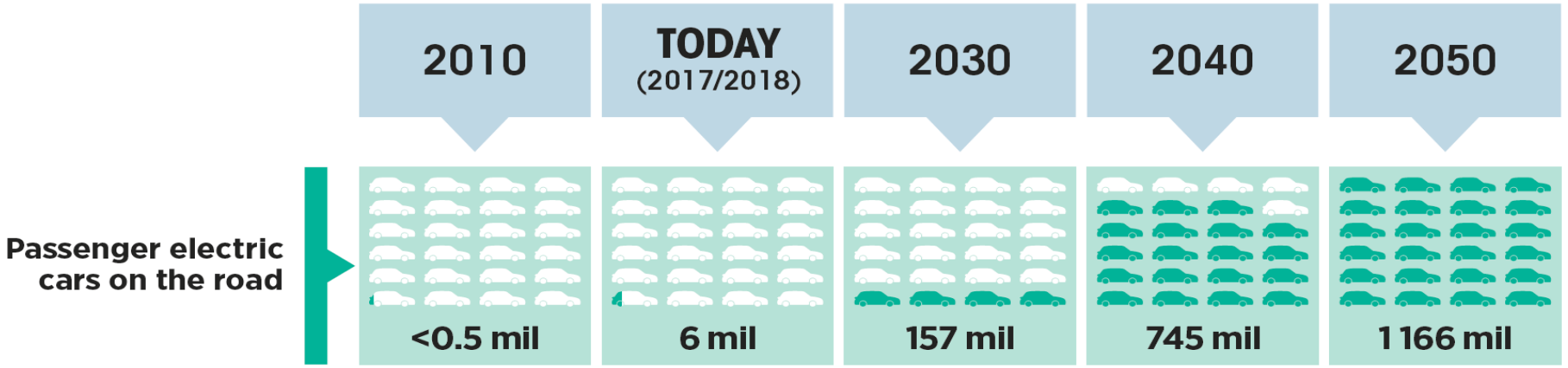
Decarbonising and digitalising the transport sector

- Decarbonizing:
  - **Transport electrification** (i.e. direct) **–** particularly in cars (batteries), but also public systems (trams, buses)
  - **Hydrogen and synthetic fuels, or e-fuels** (i.e. in-direct) **–** produced from electricity (needs to be zero-carbon) and uses a hydrogen or other synthetic fuels (ammonia, methanol, etc)
  - **Biofuels** – conventional, advanced, biomethane
  - **Others** – energy efficiency (materials, motors, etc) and modal shift (cars->trains)
- Digitalisation
  - **Sharing mobility** – bike/car sharing, carpooling
  - **Mobility as a service** – apps and digital platforms that enable combined travel planning, including ride hailing
  - **Autonomous vehicles**
  - **AI and big data learning** to support optimized planning and operation of transport systems
  - Others including **remote work, e-commerce**, etc

Uptake of EVs - the battery bank of the future

Growth in EV deployment between 2010 and 2050 in a Paris Agreement-aligned scenario

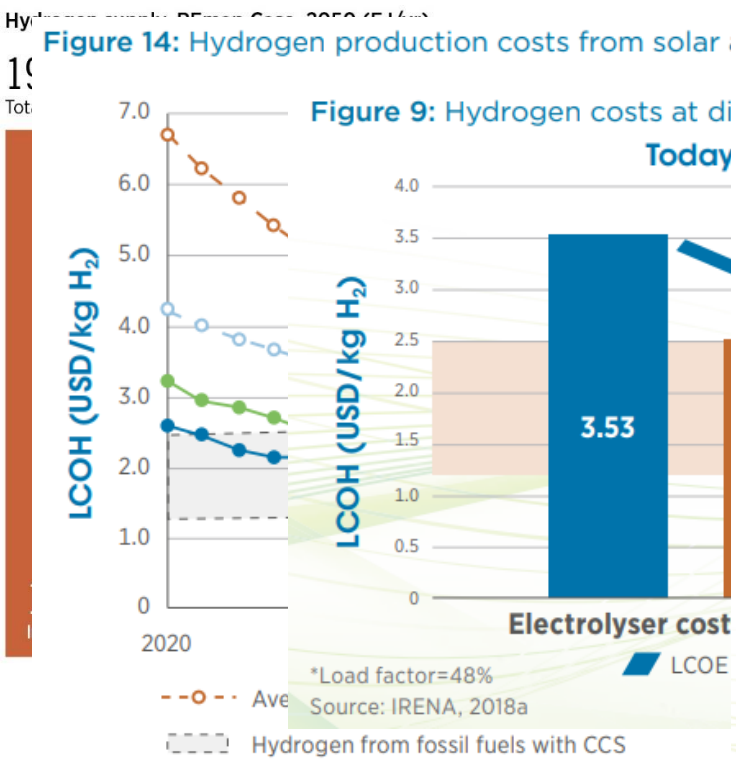


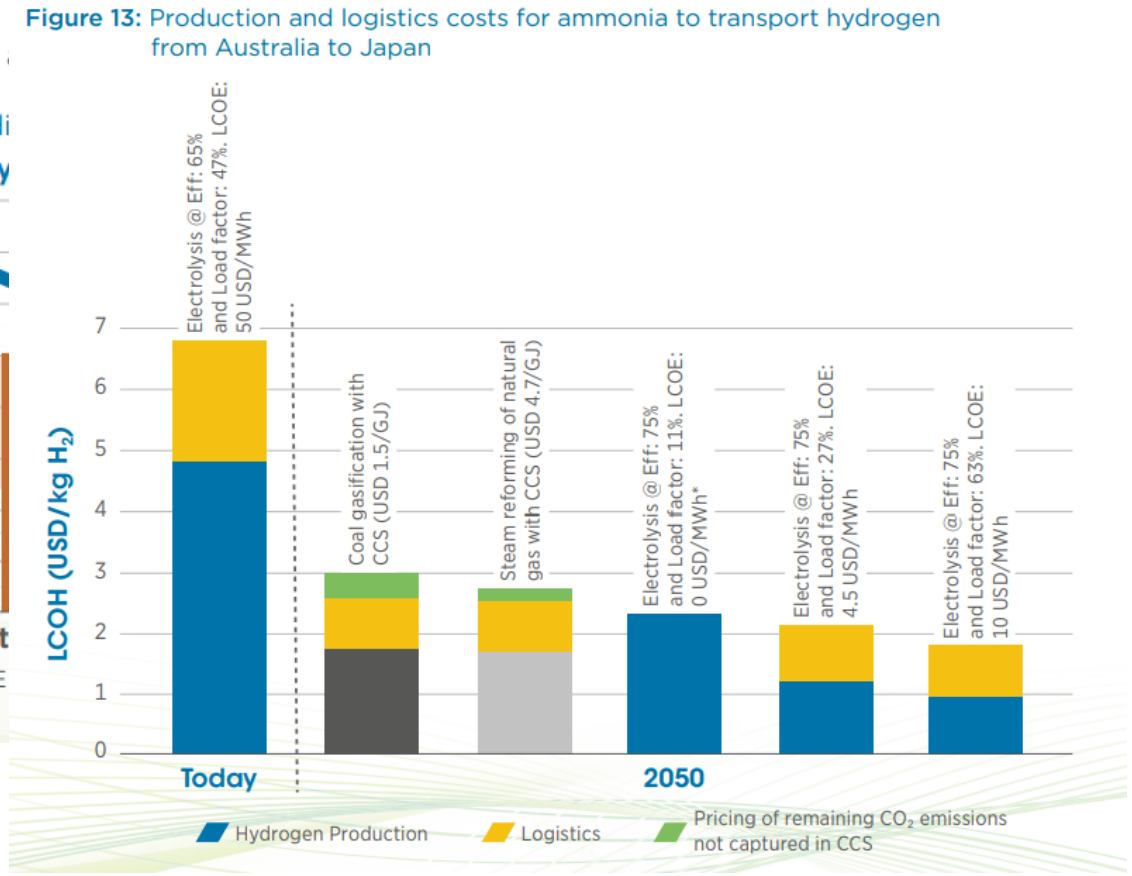
By 2050, potential storage capacity to provide grid services:

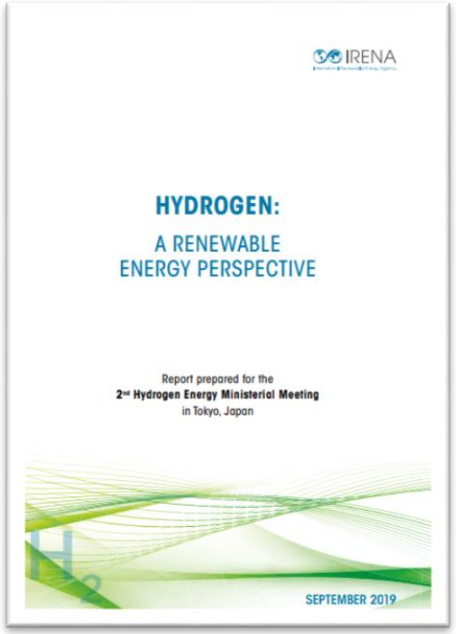
~ 14 TWh EV batteries vs ~ 9 TWh stationary batteries

Source: IRENA (2019) Innovation Outlook: Smart charging for electric vehicles

Hydrogen and synthetic fuels

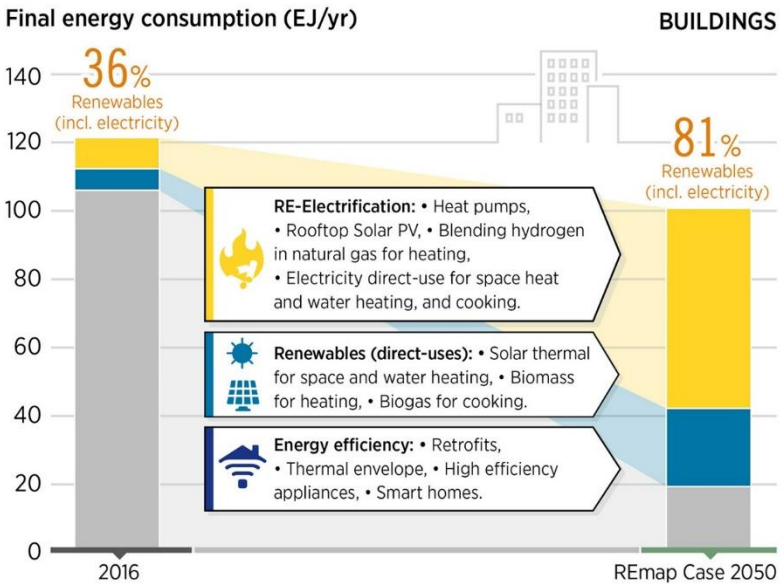


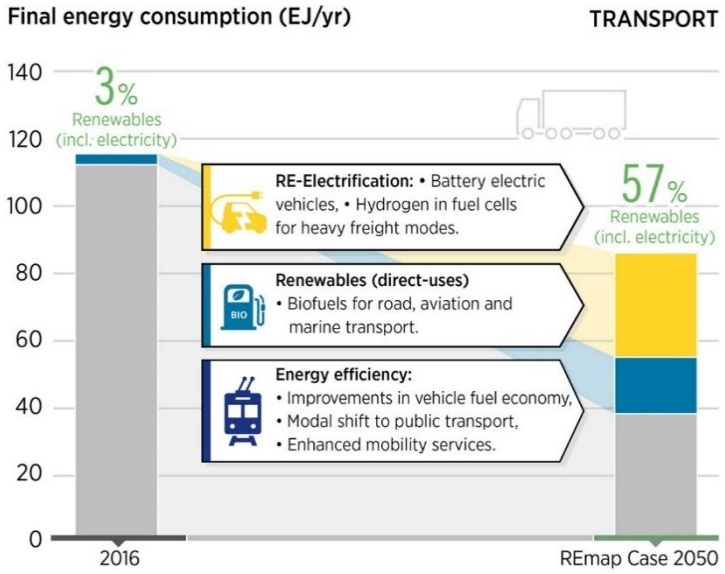


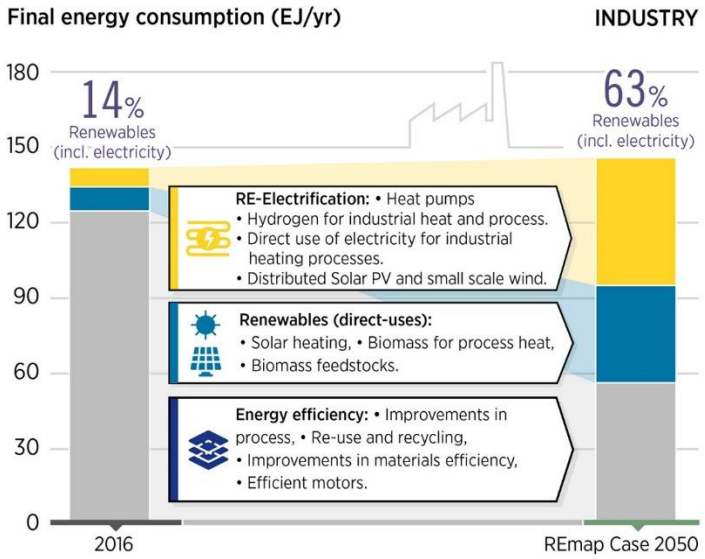


- Hydrogen can be used in the **industry, transport and buildings** sectors for a variety of purposes, i.e. energy vector, feedstock, fuel - **Ensuring a low-carbon, clean hydrogen supply is essential**!
- It offers a way to recycle assets and **potentially transport a renewable, multi-purpose energy carrier** and feedstock over long distances

Transforming the end-use sectors







Focus Ares include:

- Solutions in industry for iron/steel, cement, chemicals
- Deep-electrification
- Hydrogen
- Cities
- Innovation in areas such as shipping, aviation
- Energy efficiency

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Conclusions

- **The power sector needs to be transformed to accommodate growing shares of variable renewables.**

- **Accelerating the electrification of the transport and heating sectors is crucial for the next stage of energy transformation.**

- **Hydrogen produced from renewable electricity could help to reduce fossil-fuel reliance.**

- **Solutions are needed for the hard to decarbonize sectors**

- **Supply chains are key to meet growing demand for sustainable bioenergy.**

Decarbonising the global energy system requires swift and decisive policy action

- *With best of available technologies, policies should create right conditions to accelerate clean energy investments.*
- *Foster innovations and technology advancements.*
- *Need for better alignment and co-ordination between energy and climate policies (SDGs, NDCs).*
- *Close co-operation between the public and private sectors will be key.*

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Thank you!

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Continued reports and activities for Global Energy Transformation Roadmap

Available online

Forthcoming in Nov 2019

Global energy transformation: The REmap transition pathway (+background report)

- Status of the energy transition
- Perspective for the global energy system to 2050 based on current and planned policies (the Reference Case).
- Detailed REmap transition pathway to 2050 – an energy pathway aligned with the well-below 2°C target of the Paris climate goals.

Wind roadmap to 2050

- Technology deployment pathway.
- Annual and cumulative investments.
- Cost reductions and improvements in capacity factor.
- Innovations and technology advancements.
- Employment, supply chain and market expansion
- Emissions reduction potential.

Clean energy investments

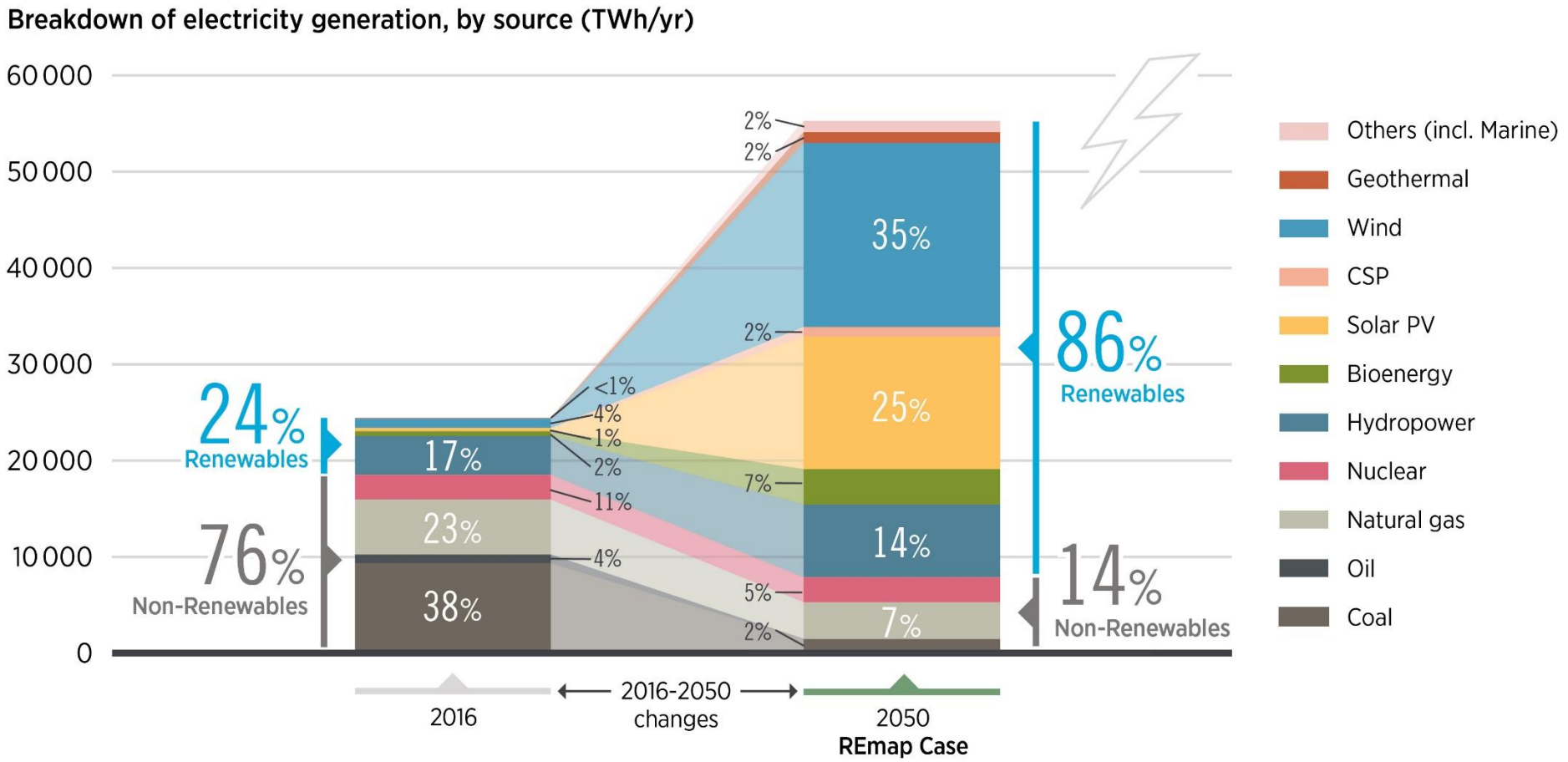
- Pathway for the global energy transformation by 2050.
- Investment needs to achieve Paris Climate goals – sectors and regions.
- Socio-economic footprint of the energy transformation.
- Drivers and barriers to meet the clean energy investments.
- Input for UN Climate summit in September 2019.

Solar PV roadmap to 2050

- Technology deployment pathway.
- Annual and cumulative investments.
- Cost reductions and improvements in efficiency of modules.
- Innovations and technology advancements.
- Business models.
- Employment.
- Supply chain and market expansion.
- Emissions reduction potential.

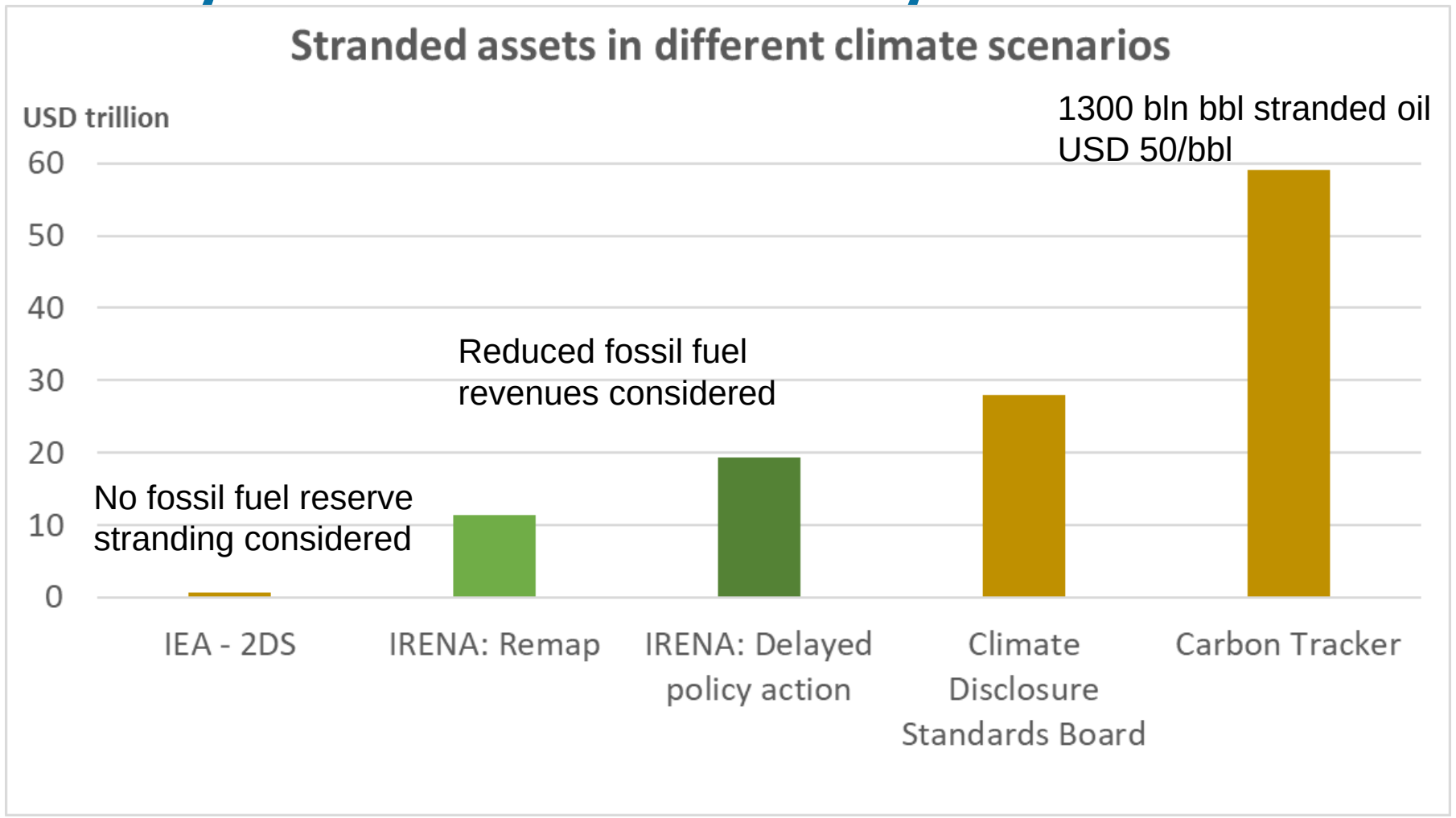
Sector views

The rising importance of solar and wind energy in the power sector



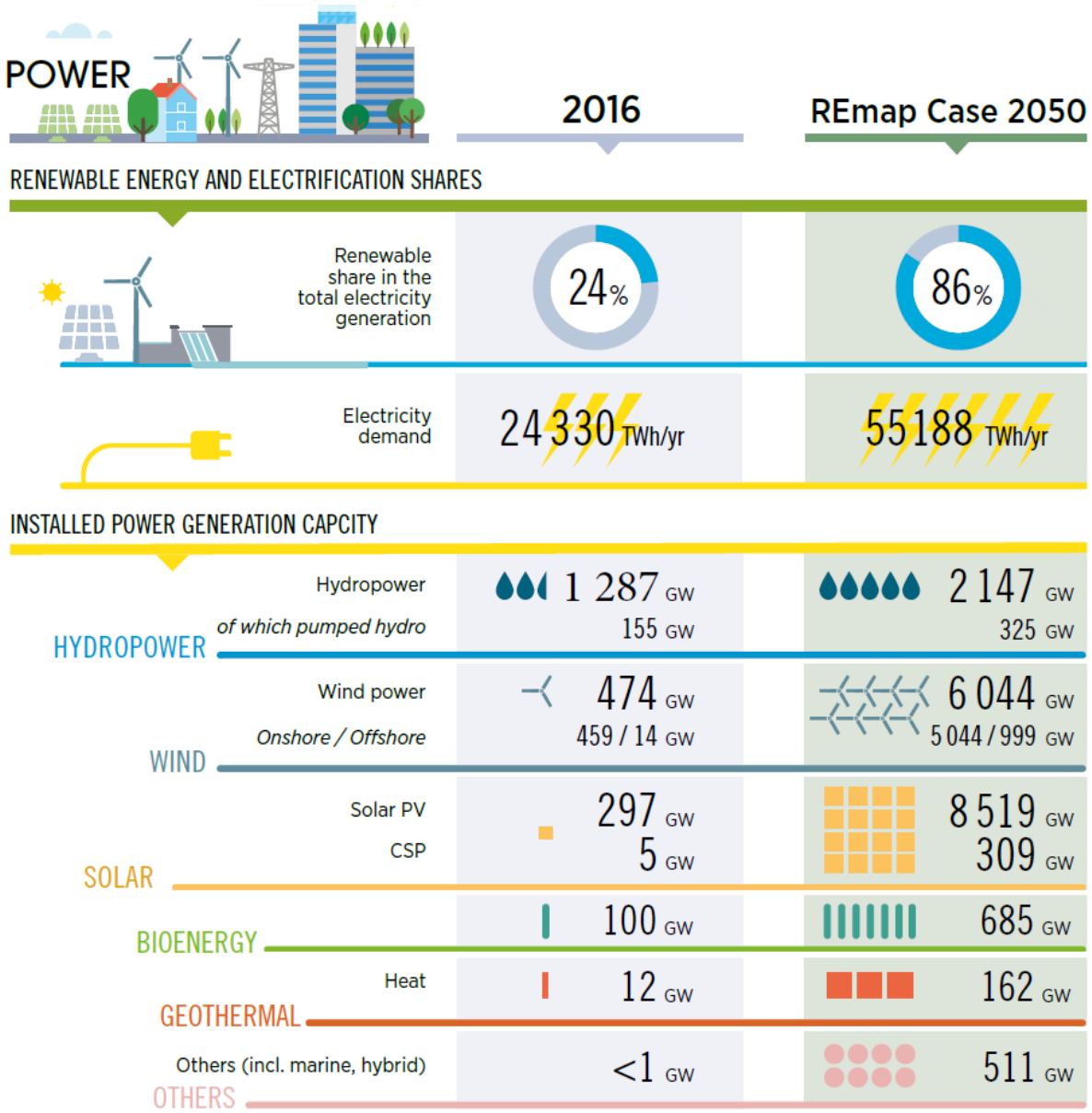
- **Gross power generation would almost double, with 86% coming from renewables.**

Stranded assets estimates and definitions in different scenarios vary significantly because definitions vary

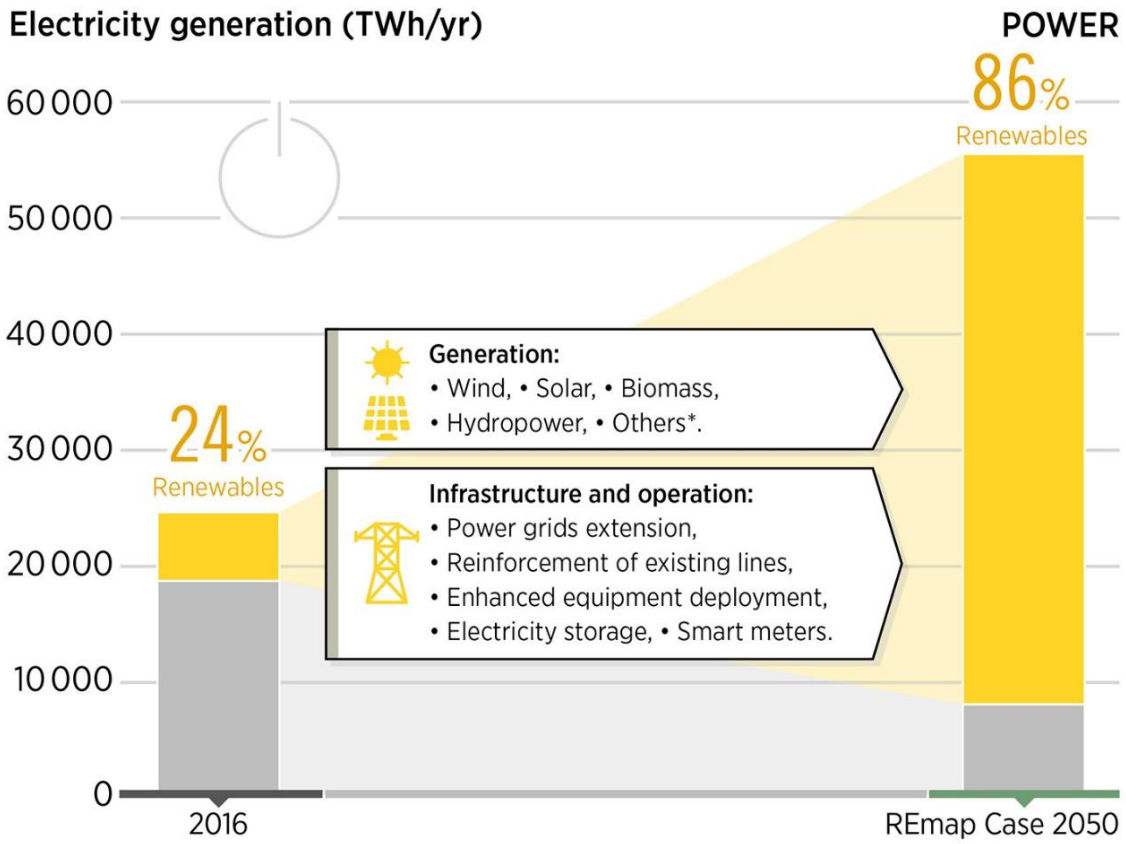


IRENA definition: Remaining book value of assets substituted or abandoned before the end of their anticipated technical lifetime and without recovery of any remaining value to stay within the carbon budget limit

Power sector key indicators infographic



Actions needed now - Power



ACCELERATE RENEWABLES CAPACITY ADDITIONS:

- Identify and map renewable energy resources and develop a portfolio of financeable projects.
- Construct no new coal power plants and plan and implement the phase-out of coal capacities approaching end of its lifetime.

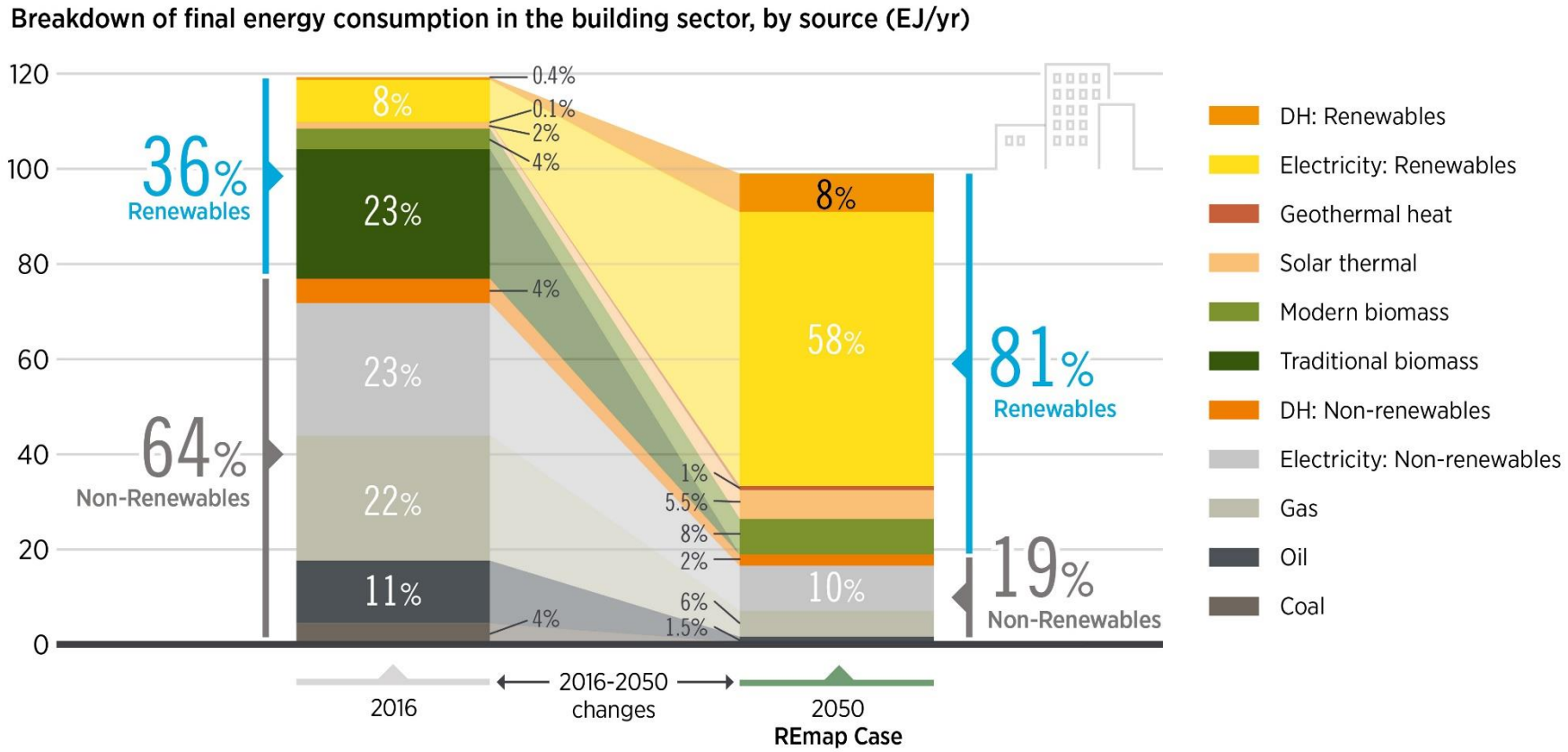
PLAN FOR THE POWER SECTOR TO ACCOMMODATE INCREASING SHARES OF VARIABLE RENEWABLE ENERGY:

- Prioritize to improve flexiblity of power system (with flexible supply, storage, demand response, power-to-X, electric vehicles, digital and information and communciation technologies technologies, *etc.,*). Update grid codes.
- Deploy microgrids to improve resilience of the grid and energy access rate with renewable sources. Deploy super grids to strengthen the interconnections among countries within a region.
- Deploy cost-reflective tariff structures by properly readjusting the balance between volumetric charges (USD/kWh), fixed charges (*e.g.,* USD/meter-month) and, where applicable, demand charges (USD/kW).

SUPPORT THE DEPLOYMENT OF DISTRIBUTED ENERGY RESOURCES:

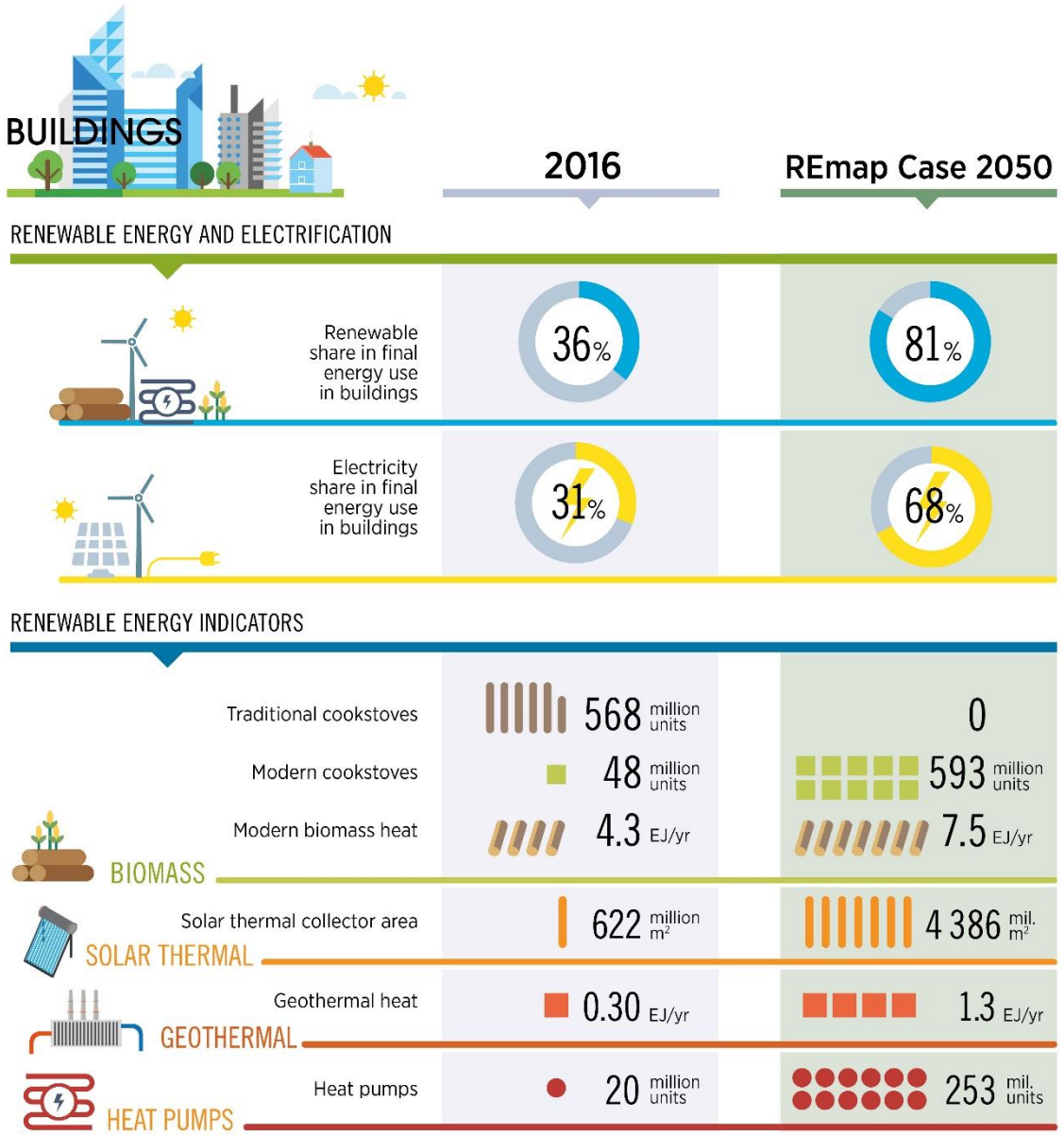
- Incentivise energy consumers to become prosumers.
- Support regulatory and pricing policies including the right to generate and sell electricity, tariff regulation and grid-arrival policies.
- Enable energy aggregators to foster the deployment of distributed energy resources.

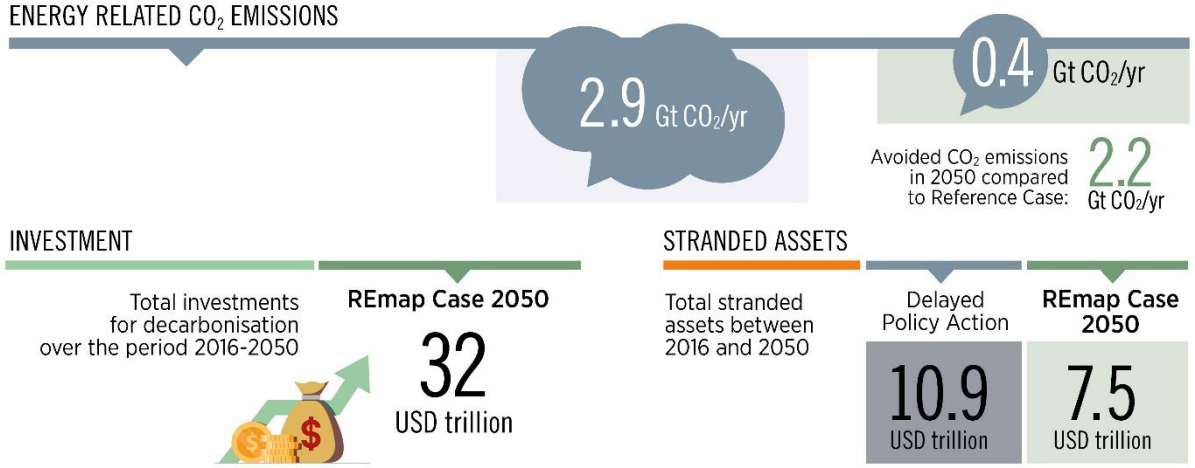
The increasing use of renewable electricity in buildings



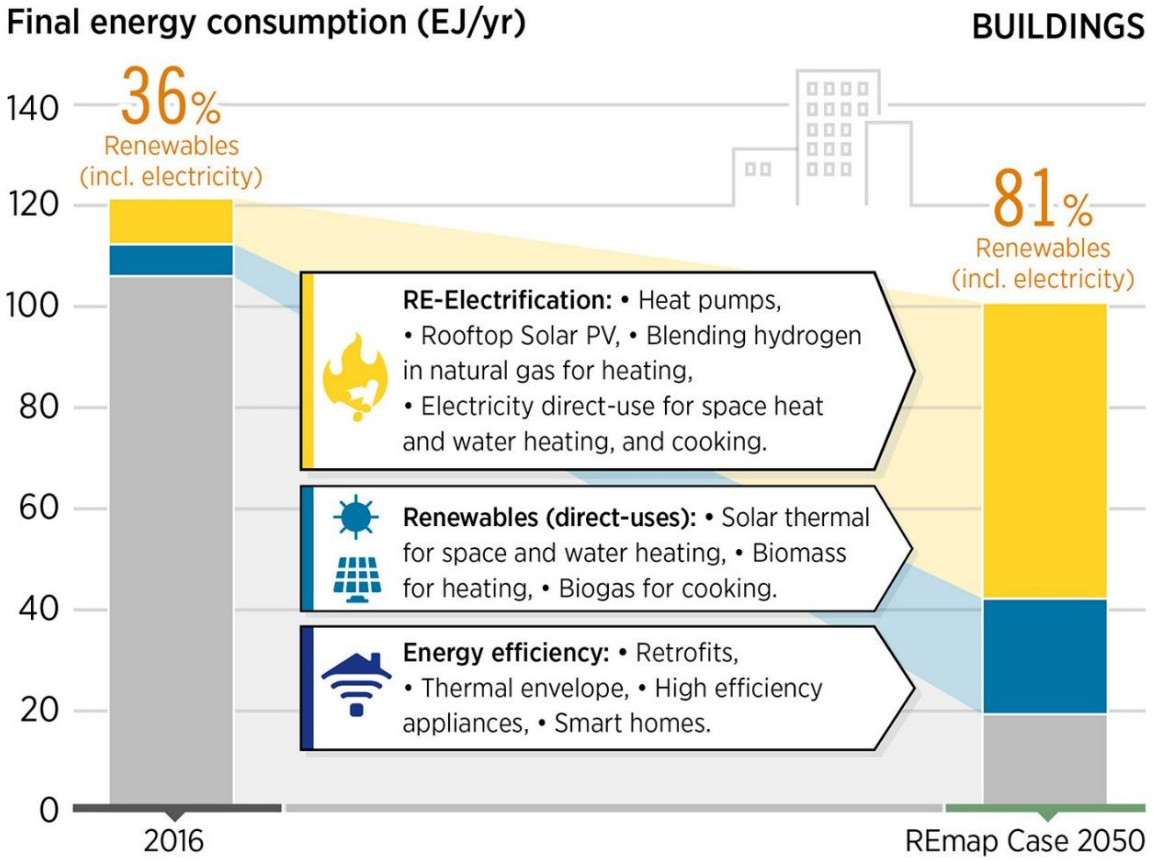
- **Renewable electricity would reach a 58% share in the buildings sector by 2050.**
- **Together with modern biomass, solar thermal and district heating, overall renewables could ramp up to 81%, from 36% today.**

Buildings sector key indicators infographic





Actions needed now - Buildings



REDUCE ENERGY CONSUMPTION IN BUILDINGS:

- Establish and improve energy efficiency building codes and standards (incl. appliances (eg. air conditioners), lighting (eg. LED lights) and equipment (eg. efficient boilers)).
- Adopt programmes for retrofitting/renovation including financing schemes.
- Align renewable heat and energy efficiency policies to leverage synergies and to accelerate the pace of energy efficiency improvements.

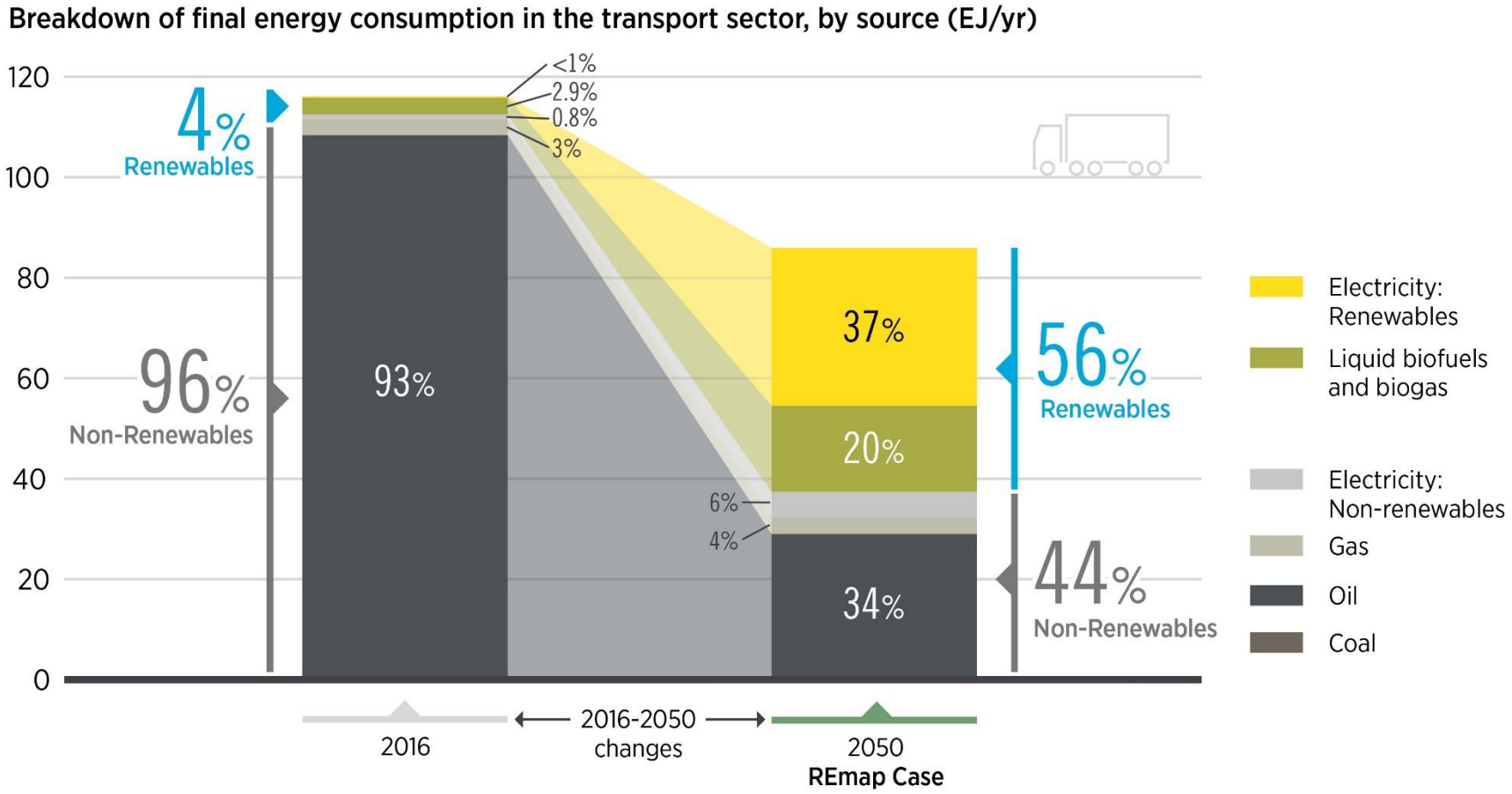
SUPPORT AND FOSTER THE DEPLOYMENT OF DISTRIBUTED ENERGY RESOURCES:

- Remove regulatory barriers for prosumers that restrict them from taking an active role in the energy system transformation. Capitalise on smart-homes and digitalisation to allow demand management.
- Promote community ownership models and innovative financing schemes.
- Accelerate rollout of smart meters.

SCALEUP RENEWABLE SHARE UPTAKE IN THE BUILDINGS SECTOR:

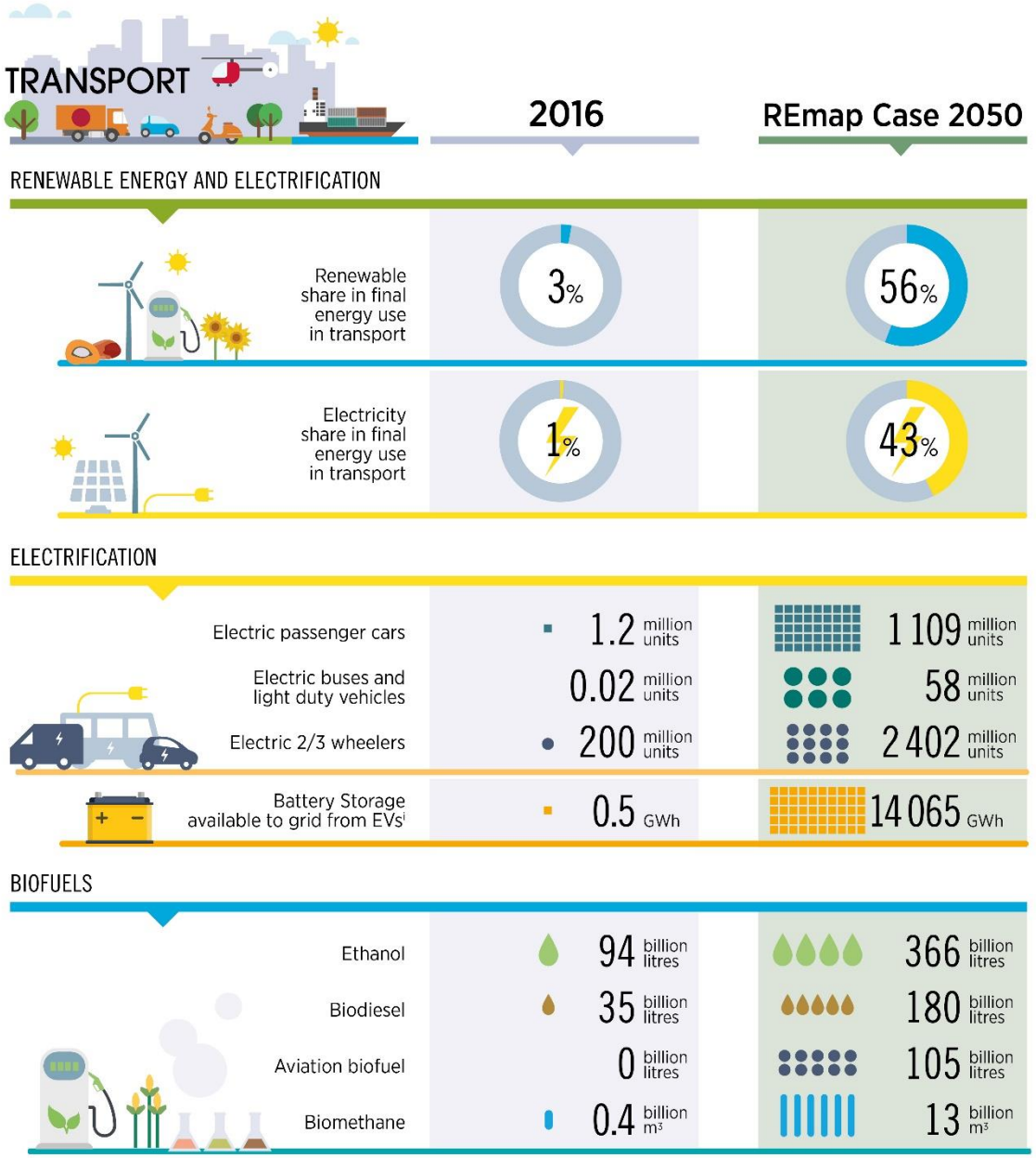
- Promote low-carbon heating technologies: heat pumps, solar heating, modern bioenergy for heating). Apply these renewable technologies for district heating.
- Establish a long term strategy for heat decarbonisation.
- Incentivise renewable based cooling solutions.
- Phase out traditional biomass as cooking fuel and replace with clean and efficient cookstoves (biogas, modern solid biomass and electricity).

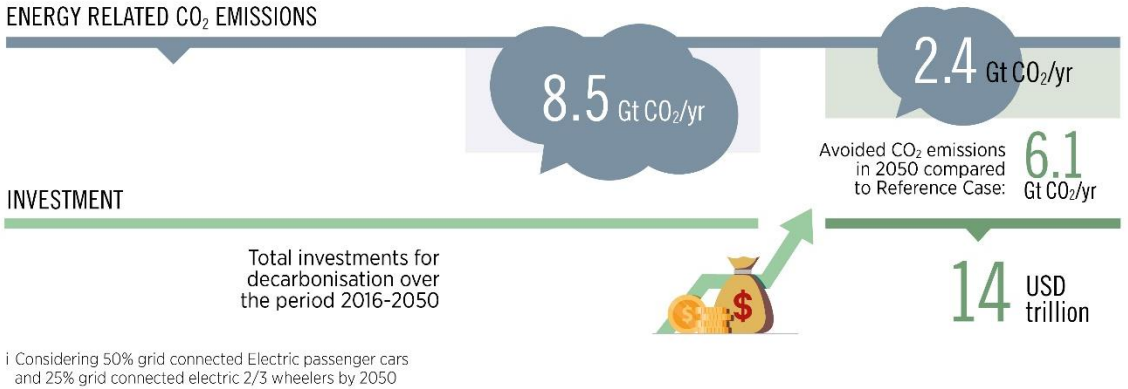
Increasing electrification in the transport sector



- **Renewable electricity use could increase significantly in the transport sector by 2050, providing 37% of total transport energy consumption and, due to higher efficiency, covering 60% of the overall transport activity.**

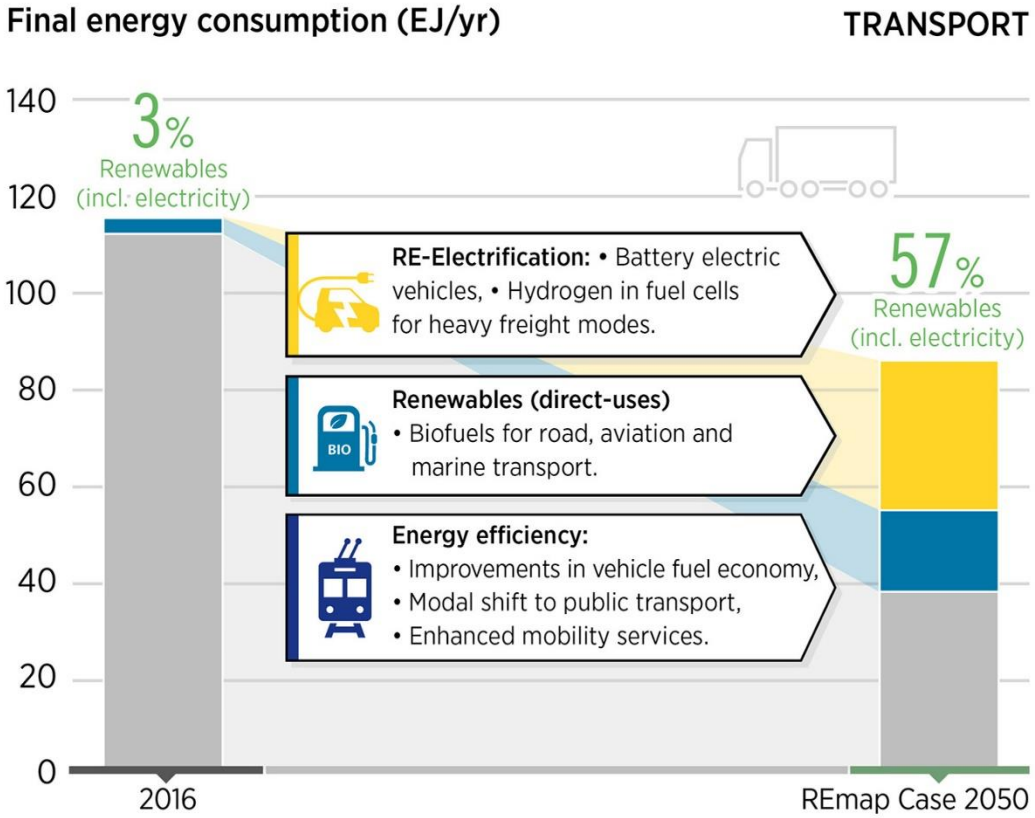
Transport sector key indicators infographic





i Considering 50% grid connected Electric passenger cars and 25% grid connected electric 2/3 wheelers by 2050

Actions needed now - Transport



REDUCE THE ENERGY NEED FOR TRANSPORT:

- Deploy advanced digital communication technologies to reduce the transport needs (eg. teleconferencing over traveling) and to improve efficiency of transport by better utlizing the assets (eg. re-routing due to traffic).
- Promote mobility services: Promote vehicle sharing and autonomous driving.
- Accelerate modal shift from passenger cars to public transport (electric railways or trams or electric buses).

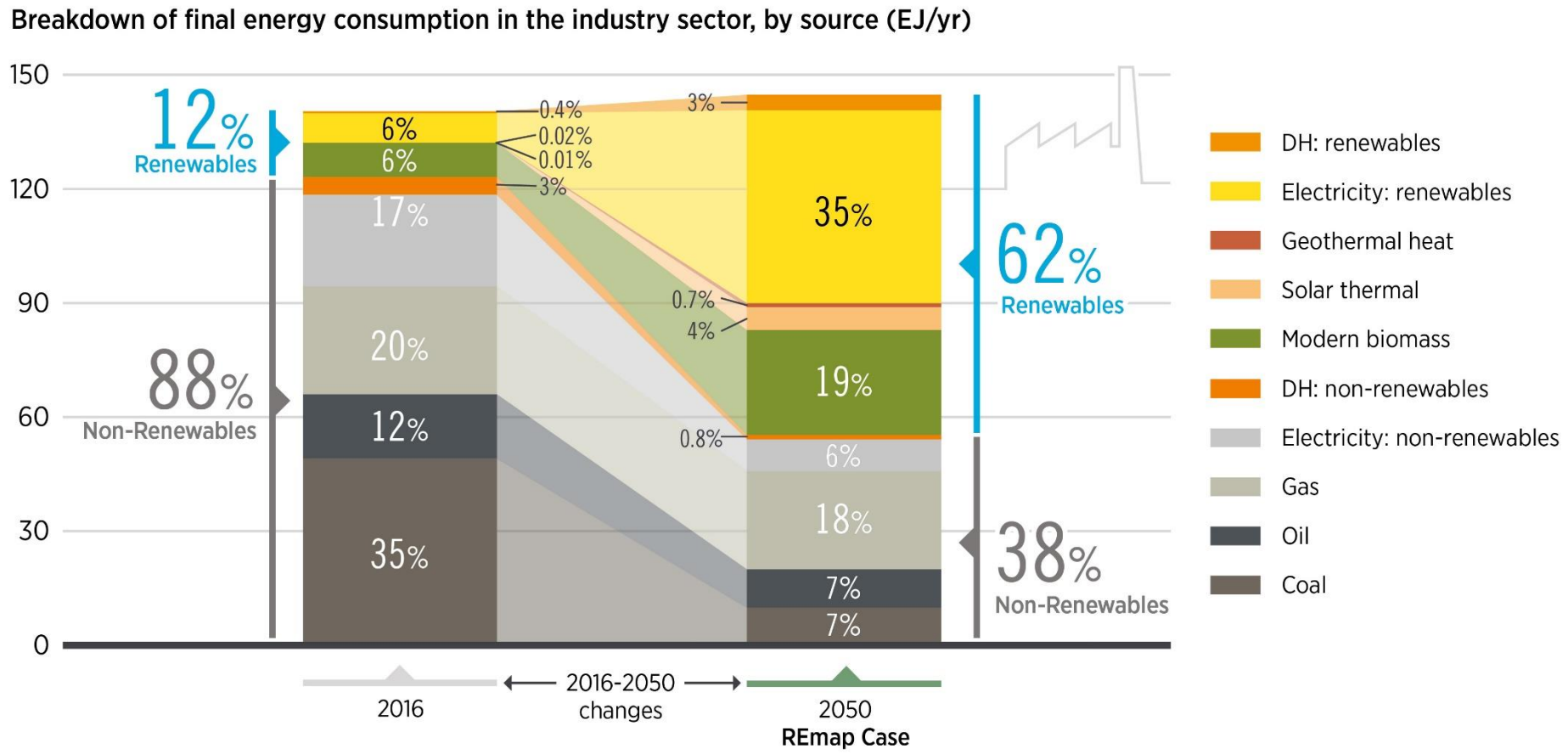
ACCELERATE THE UPTAKE OF ELECTRIC MOBILITY:

- Establish minimum standards for vehicle emissions. Give the priority for electric vehicles for city access.
- Incentivise charging infrastructure rollout.
- Strengthen link between the power and transport sectors for integrated planning and policy designs (vehicle-to-grid services).
- Deploy low-emissions city trucks.

FOSTER BIOFUELS IN ROAD, AVIATION AND SHIPPING:

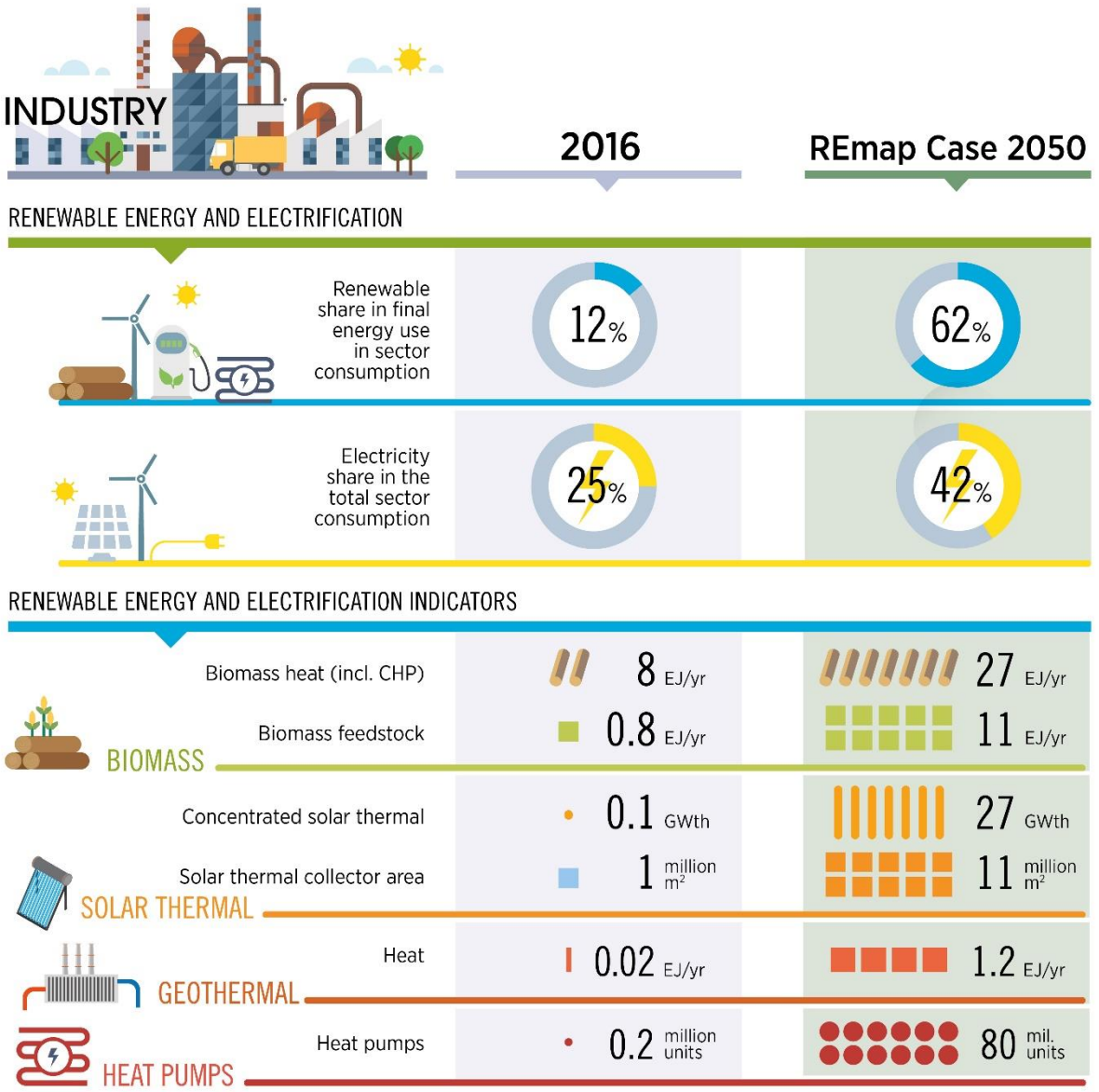
- Eliminate fossil fuel subsidies and implement carbon pricing to increase the competitiveness of renewable fuels in the shipping and aviation.
- Adopt supporting policies to scale up sustainable production of first- and second-generation biofuels. Introduce specific mandates for advanced biofuels and put in place direct financial incentives along with financial de-risking measures.

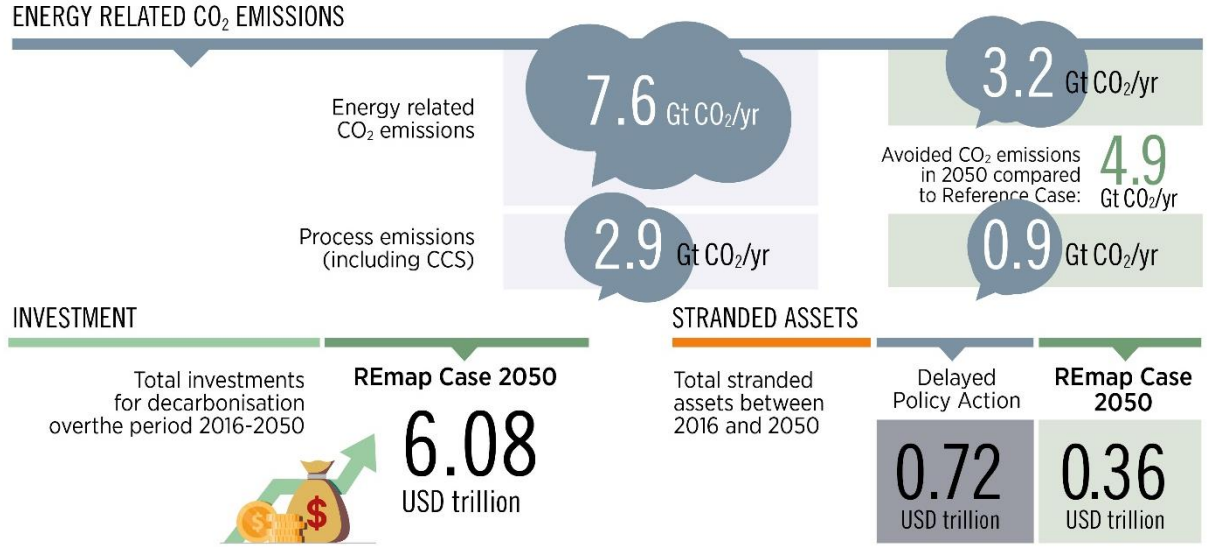
Renewable electrification and bioenergy taking the lead in the industry sector



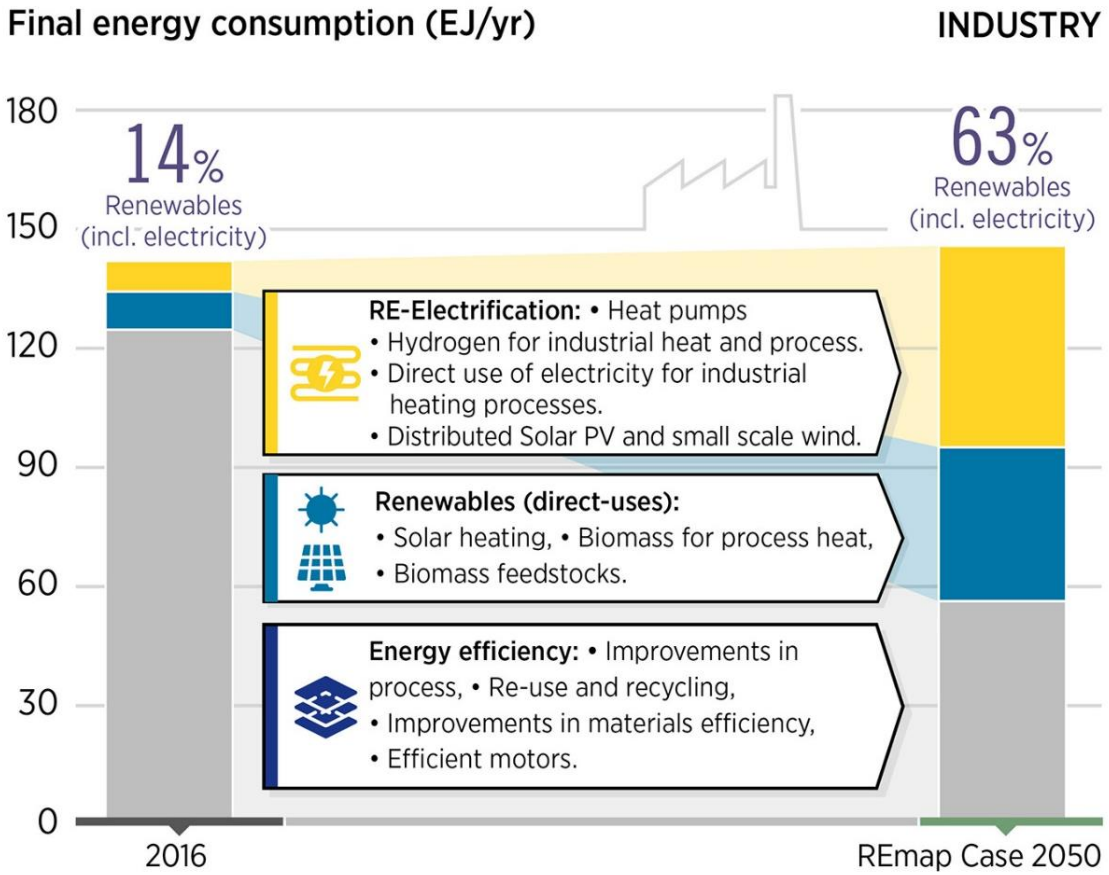
- **By 2050 the share of renewables in the industrial sector needs to grow by more than 5 times. Renewable electrification would make up around 1/3 of the sector's energy demand, followed by biomass providing 1/5.**

Industry sector key indicators infographic





Actions needed now - Industry



REDUCE ENERGY CONSUMPTION IN INDUSTRIES:

- Promote actions towards circular economy (material recycling, waste management, improvements in materials efficiency and structural changes such as reusing and recycling).
- Incentivise and adopt best available technologies (BAT) and efficiency standards.

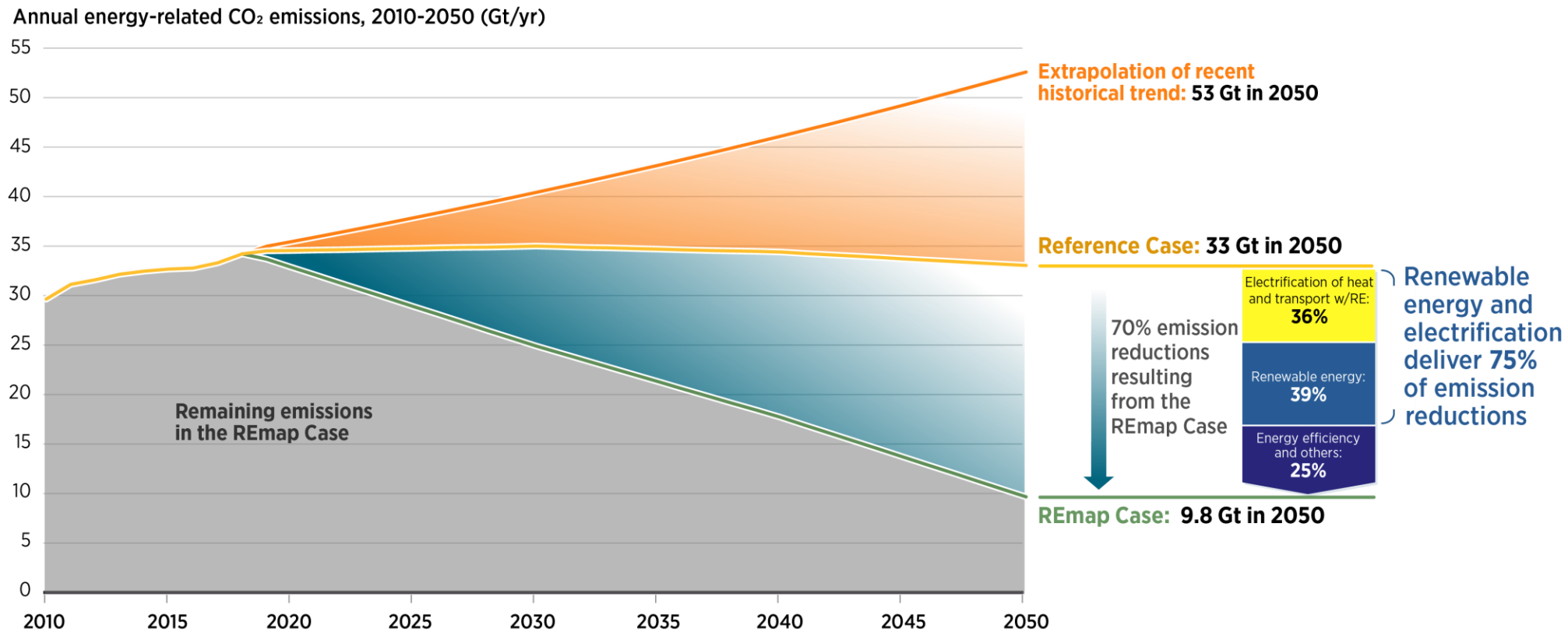
ENABLE CORPORATE SOURCING OF RENEWABLES:

- Support a credible and transparent system for certification and tracking of renewable energy attributes.
- Consider an energy market structure that allows for direct trade between companies of all sizes and renewable energy developers – such as through PPAs.
- Work with utilities or electric suppliers to provide green corporate procurement options.
- Empower companies to engage in direct investment for self-generation.

ACCELERATE THE DEPLOYMENT OF LOW-CARBON TECHNOLOGIES IN INDUSTRIAL PROCESS HEATING:

- Remove existing barriers and incentivise low-carbon heating technologies deployment: Solar thermal heating/modern bioenergy and heat pumps.
- Support emerging technologies in biomass and hydrogen. Use renewable-produced hydrogen to replace fossil fuel-based feedstocks and process heat (*e.g.,* iron and steel sub-sectors, ammonia production).
- Implement appropriate carbon pricing in line with the real costs of the externalities and the elimination of existing subsidies for carbon-intensive fuels (where those still exist).

Recent trends vs. Reference Case vs. REmap



- Annual energy-related CO2 emissions could range from **10 Gt to over 50 Gt by 2050**

About IRENA

Established in 2011.

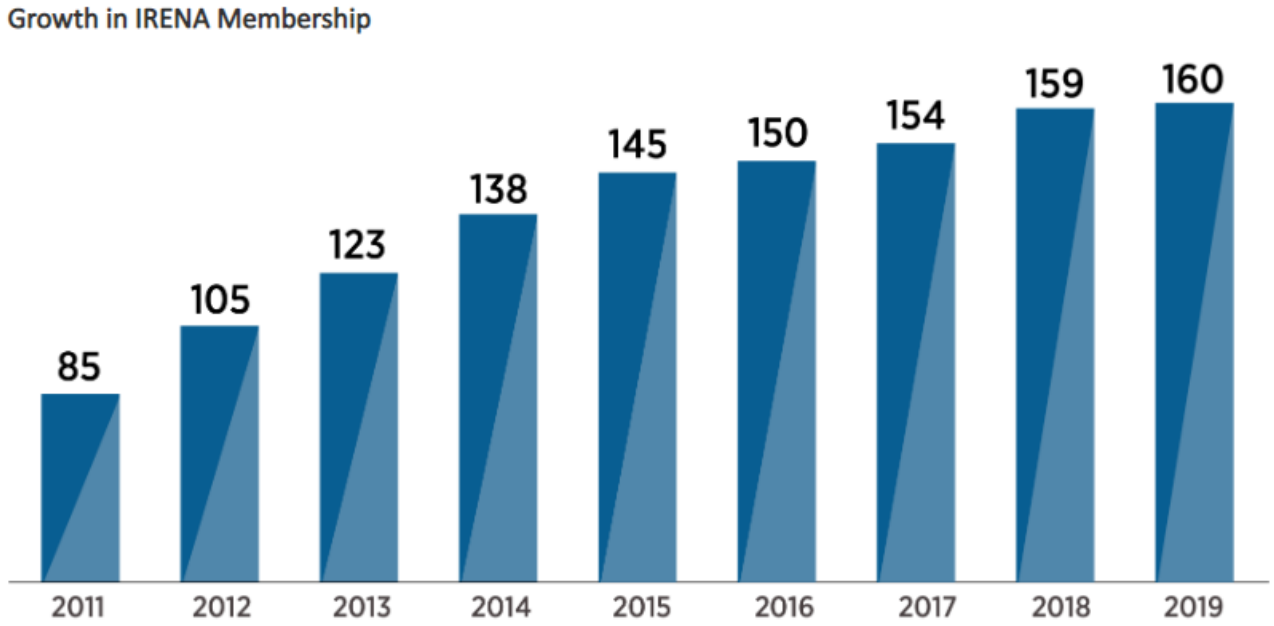
160 Members; 23 States in accession.

Mandate: to promote the **widespread adoption and sustainable use of all forms of renewable energy**

Scope: All renewable energy sources produced in a **sustainable manner**

IRENA serves as:

- Centre of excellence for knowledge and innovation
- Global voice of renewables
- Network hub
- Source of advice and support



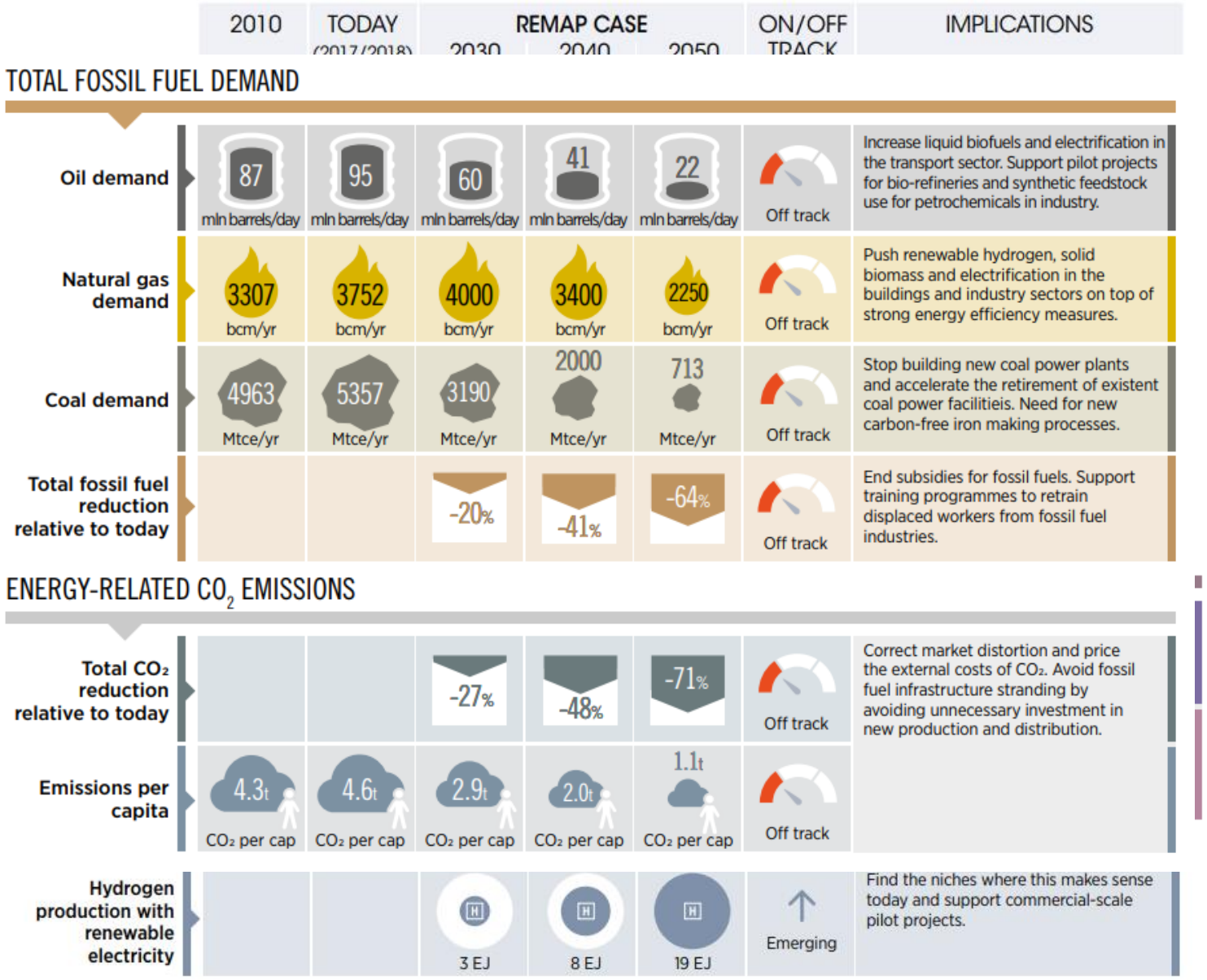
IRENA **Offices**

IRENA Headquarters
Masdar City

IRENA Innovation and Technology Center

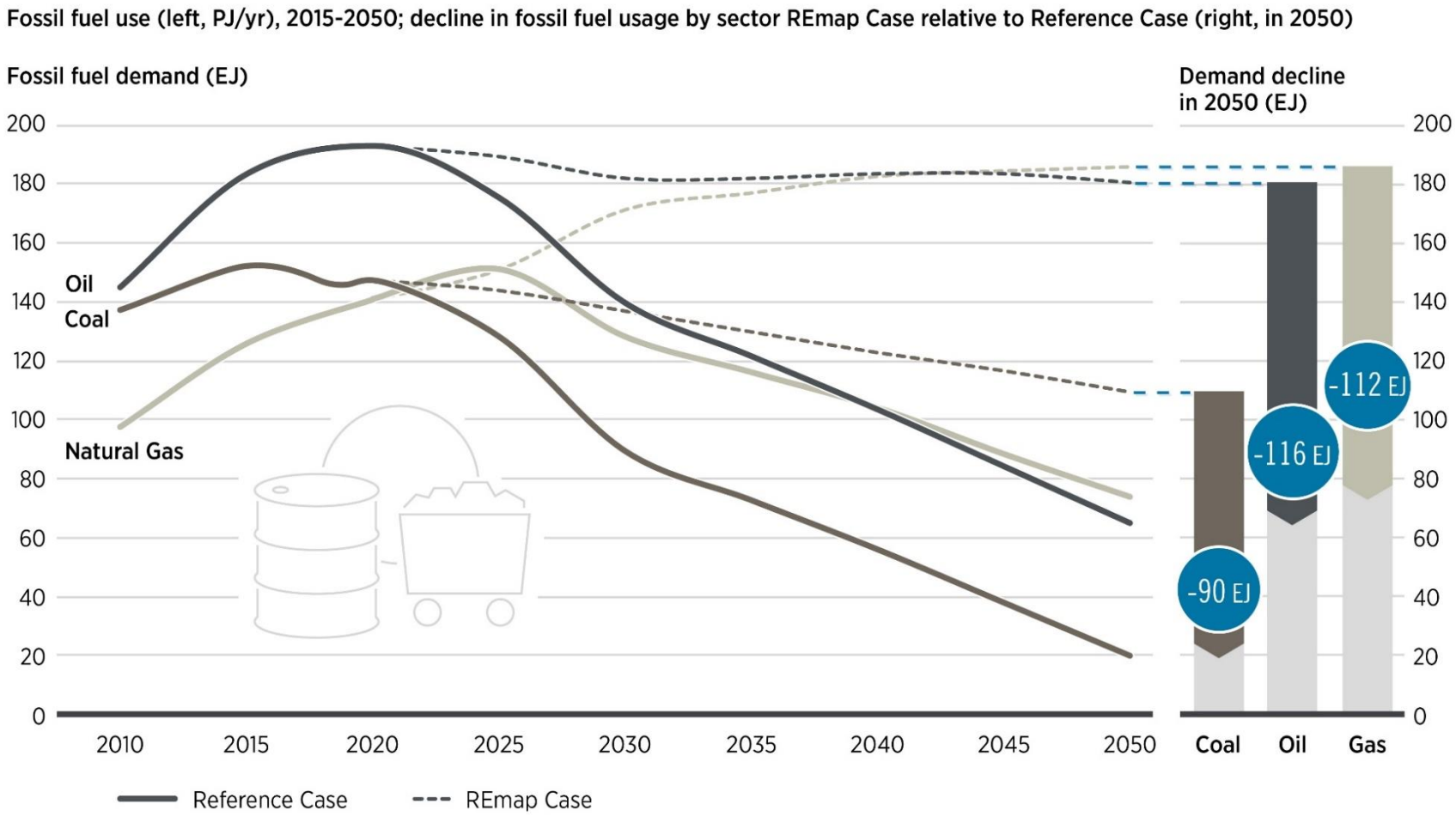
IRENA - Office of the Permanent Observer to the United Nations

Tracking progress to achieve the global energy transformation



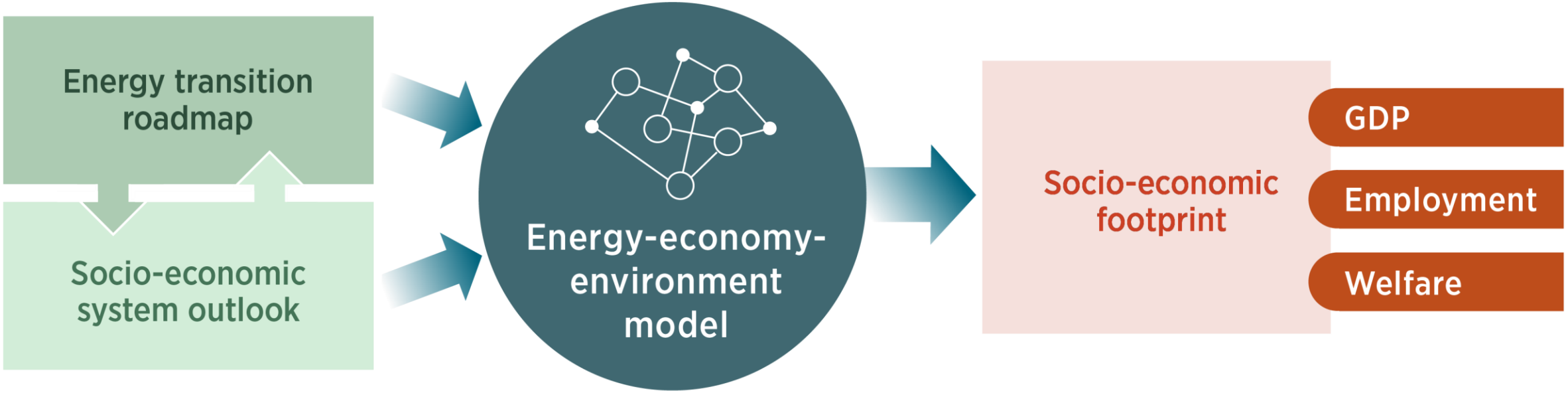
Notes: 1) TFEC – total final energy consumption; 2) Utility and distributed solar PV total additions (new as well as repowering); 3) Onshore and offshore wind total additions (new as well as repowering); 4) Passenger cars exclude 2/3 wheelers, buses and other electric mobility transport modes; 5) Heat pump estimates based on available data;

Decline global demand for fossil fuels



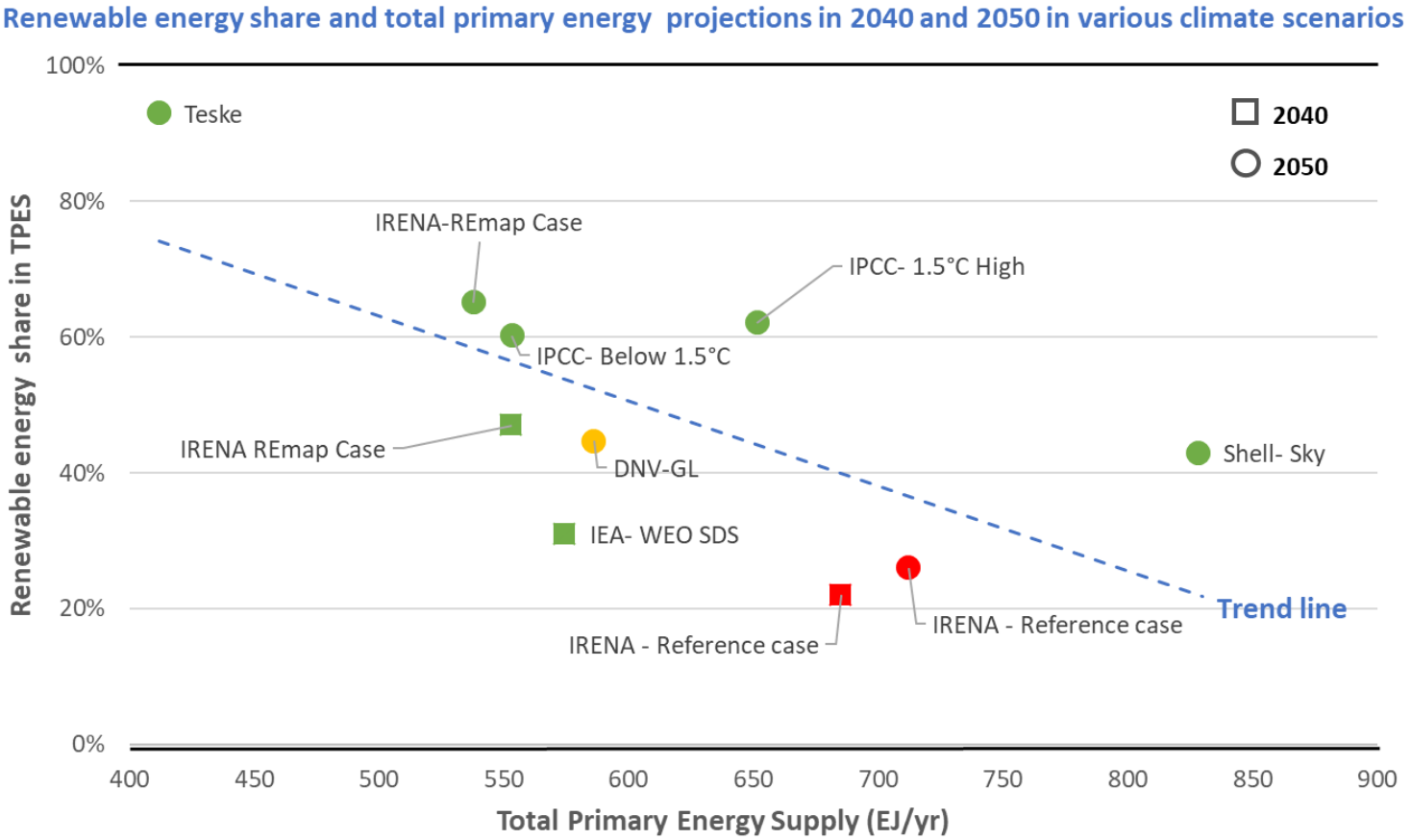
- With accelerated uptake of renewables, **both oil and coal demand decline significantly and continuously, with natural gas demand peaking around 2025**. Natural gas would be the largest source of fossil fuel in 2050.

The socio-economic footprint of the energy transition



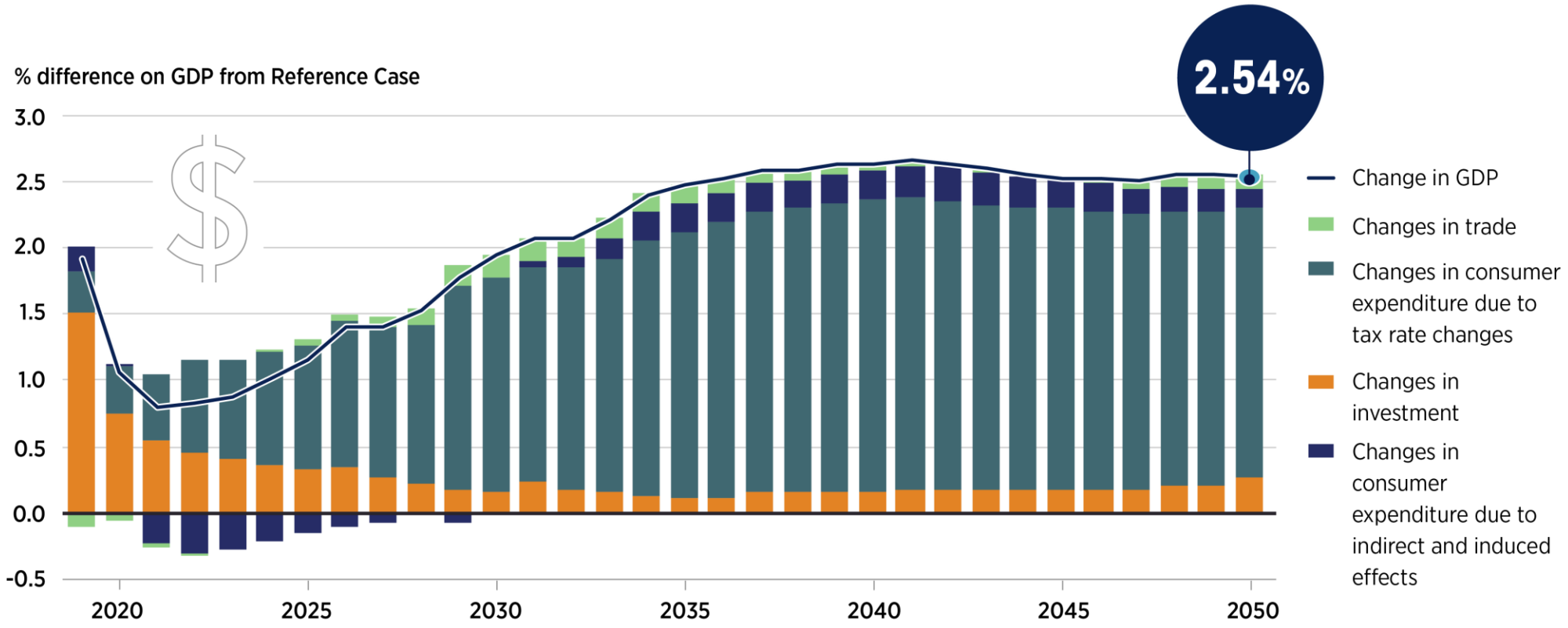
- **Both the energy and socio-economic systems will evolve during the transition**, with multiple feedback loops between them.
- **IRENA uses an integrated Energy-Economy- Environment model to evaluate the socio-economic footprint** that results from the interactions among different combinations of the energy transition roadmap and the socio-economic outlook.

There is a correlation between renewable energy share and energy demand



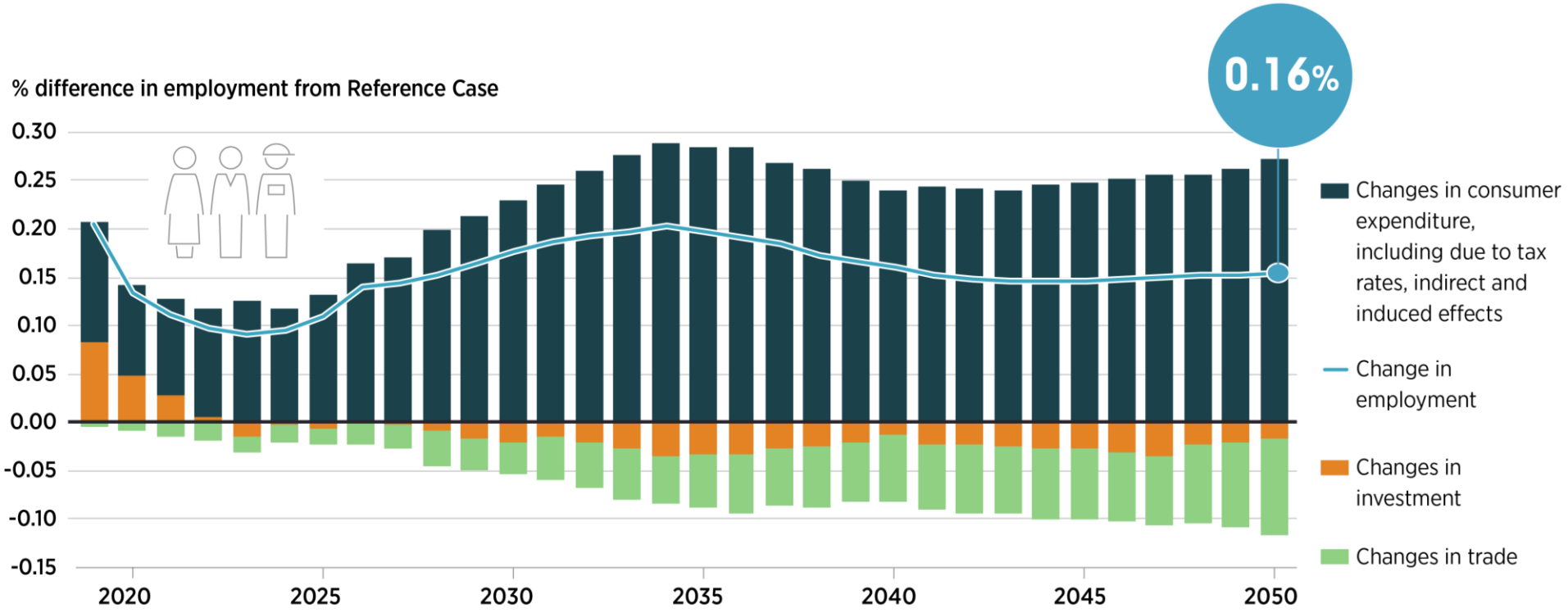
- Scenarios with higher renewable energy shares also have higher energy efficiency, **resulting in lower overall energy demand and emissions.**

The energy transformation boosts global GDP



- To gain insight about the structural elements underpinning the evolution of GDP as a consequence of the interactions between the energy transition and the socio-economic system, the macroeconomic modelling undertaken by IRENA disaggregates the **evolution of GDP into four main drivers**: **Trade, consumer expenditure due to tax rate changes, consumer expenditure due to indirect and induced effects and investment.**

Economy-wide employment witnesses growth



- **Global employment increases by 0.2% (7 million jobs).**
- To gain insight about the structural elements underpinning the evolution of Employment as a consequence of the interactions between the energy transition and the socio-economic system, **the macroeconomic modelling undertaken by IRENA disaggregates the evolution of Employment into three main drivers: Trade, consumer expenditure (including tax rates and indirect and induced effects) and investment.**