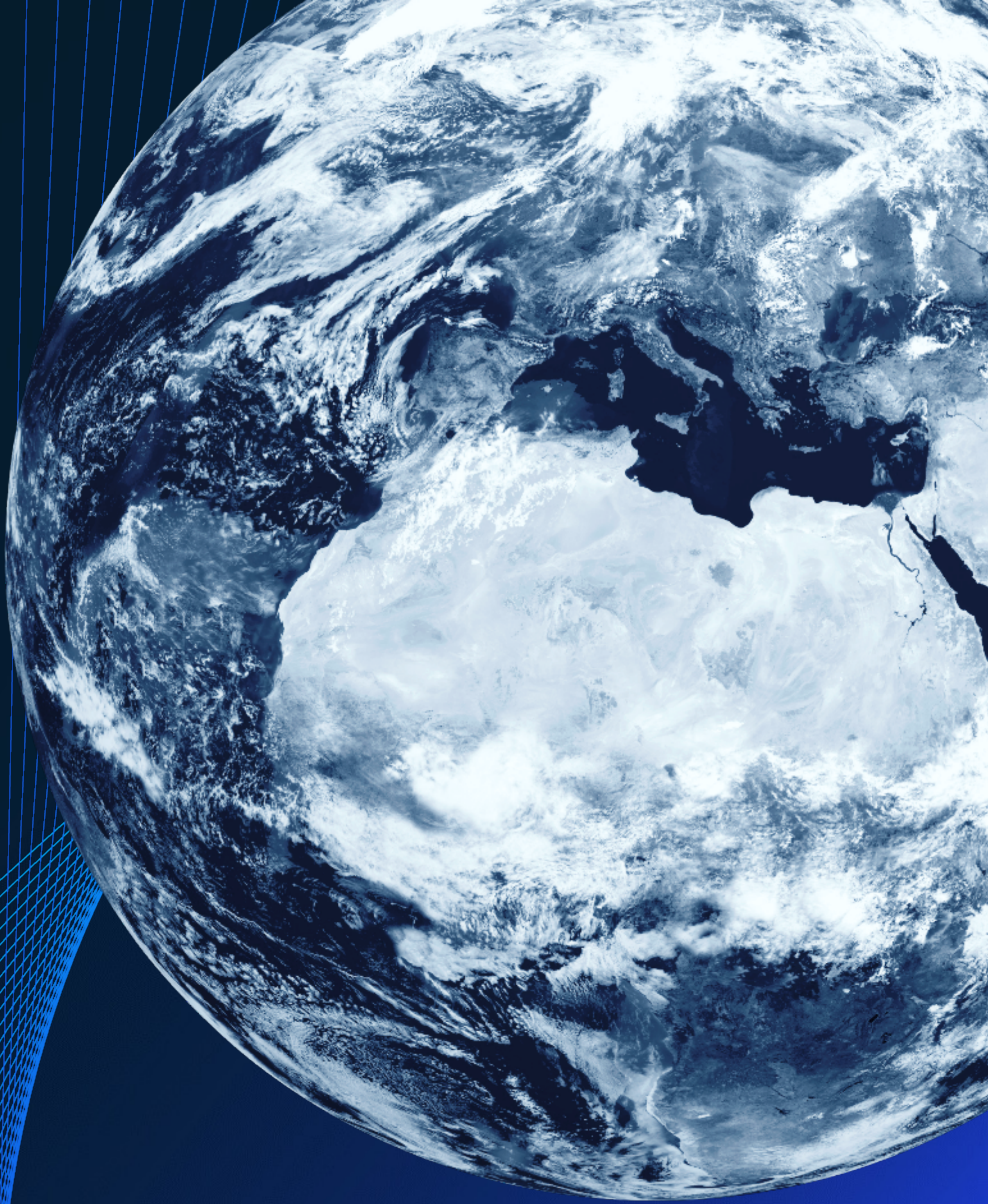
McKinsey & Company

Implications of the Global Energy Transition on critical materials in the long term

World Materials Forum | Nancy, 17-19 June 2021



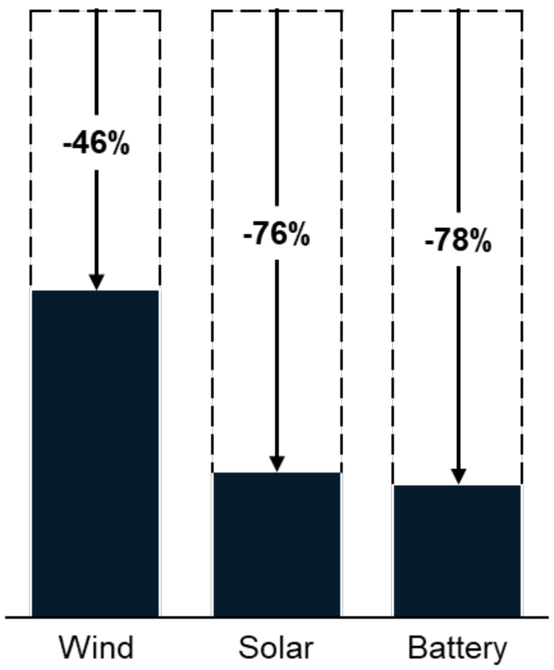
WORLD MATERIALS FORUM

The past decade brought fundamental changes to the global energy system

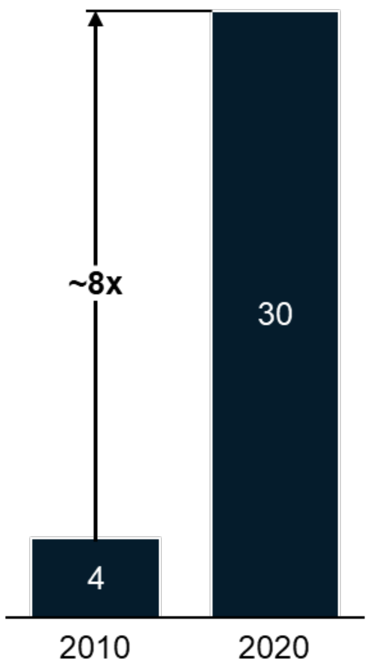
At the start of the 2020s, we look back at a decade of rapid technological and policy shifts in energy sectors

Examples of shifts in the global energy system

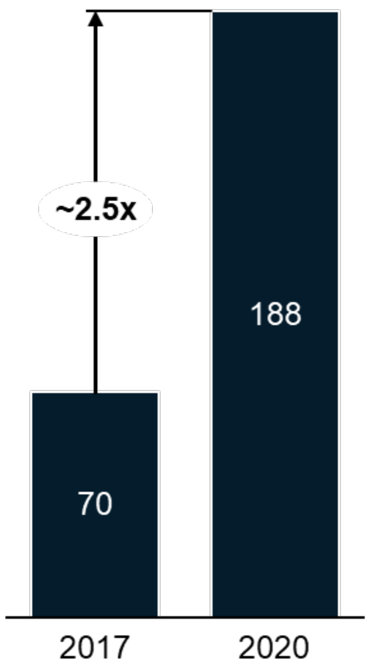
Technology cost,[1]
indexed 2010 = 100



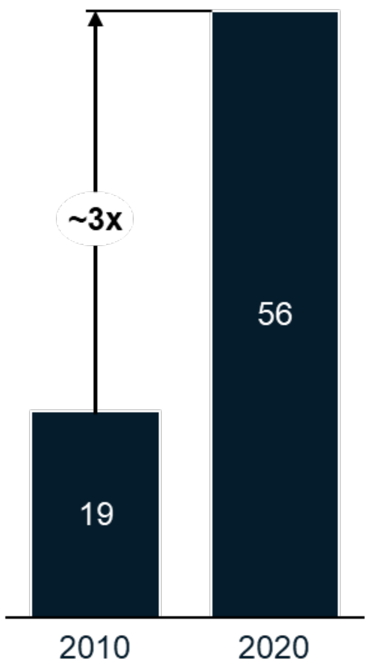
Total shale/tight oil and gas production,
MMb/d (gas in oil eq)



Announced 2030 ICE city access restrictions,
millions of citizens affected



National/regional carbon-pricing initiatives,
number of initiatives



1. Numbers represent global average

Source: McKinsey Energy Insights Global Energy Perspective 2021, December 2020

The McKinsey reference case considers a global warming by +2.5°C and is the basis for the energy perspective applied

Comparable scenarios

CO_2 price
USD/ t CO_2

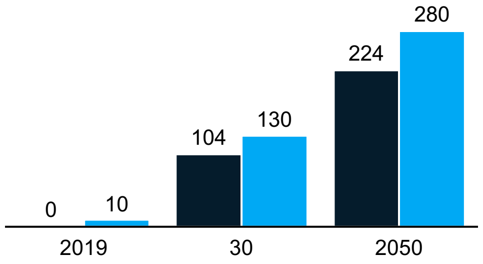
- Developing regions
- Developed regions

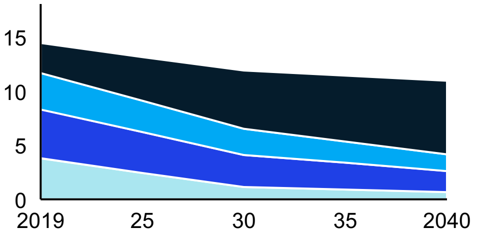
Energy mix
(Btoe)

- Other[2]
- Natural gas
- Oil
- Coal

+1.5°C scenario[1]

McKinsey – 1.5°C scenario

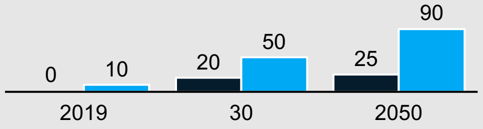


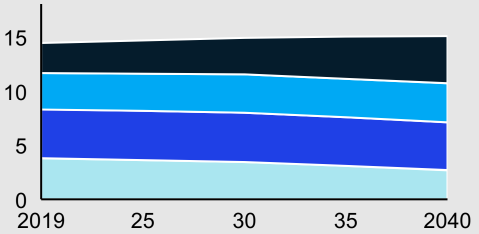


McKinsey's view of a pathway that limits global warming to 1.5ºC, across sectors and energy products, reflecting deep expertise to build technically viable decarbonization paths

+2.5°C scenario[1]

McKinsey – Reference case scenario



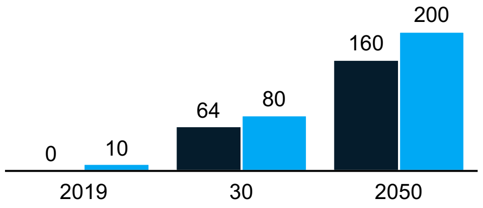


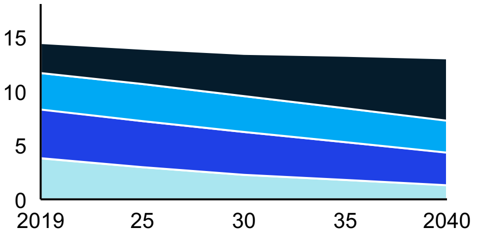
McKinsey's consensus view on our current path, combining more progressive views as well as views that question feasibility and actual realization. Reflects the latest perspectives on short-term COVID-19 impacts and long-term macro-economic outlooks, & expert views on cost trajectories for existing & novel technologies

SDS +1.7°C scenario[1]

Sustainable Development Scenario

IEA – SDS



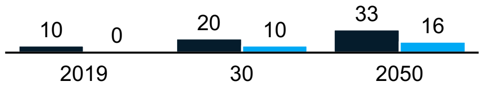


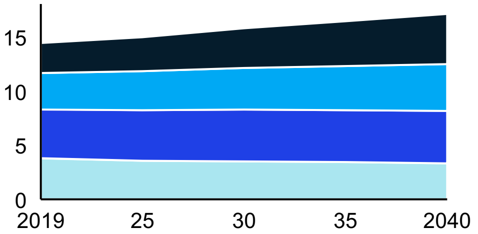
A surge in clean energy policies and investment puts the energy system on track to achieve sustainable energy objectives in full, including the Paris Agreement, energy access and air quality goals. The assumptions on public health and the economy are the same as in the STEPS

STEPS +2.7°C scenario[1]

Stated Policies Scenario

IEA – STEPS





COVID-19 is gradually brought under control in 2021 and the global economy returns to pre-crisis levels the same year. This scenario reflects all of today's announced policy intentions and targets, insofar as they are backed up by detailed measures for their realization

1. Global warming potential by 2100 ranges: for SDS between 1.7-1.8 °C and STEPS 2.5-3.0 °C
2. Solar, Wind, Hydro, Nuclear, Bioenergy, Other renewables

Source: Team analysis

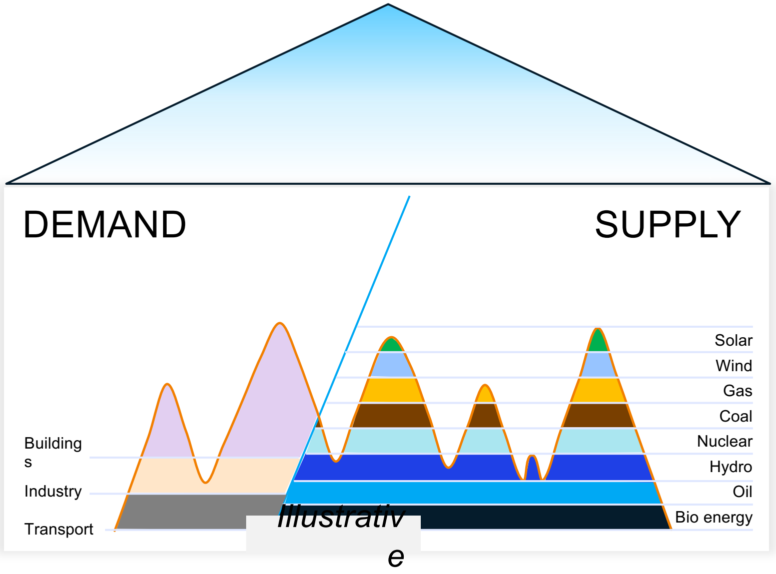
The McKinsey Global Power Model covers demand/supply dynamics on power markets in an integrated and granular approach

DEMAND

Sectors

- Buildings
- Industry
- Transport

GEP Power Model



Ensuring to deliver **power demand on an hourly level** from different sectors

Building the **system's cost-optimal capacity mix,** split into 41 technology classes, based on detailed inputs and constraints (e.g., existing fleet and local circumstance)

Dispatching capacity to create **cost-optimal generation mix**, considering country specific circumstances (e.g., cost and capacity factors)

SUPPLY[1]

Generation

- Solar
- Wind
- Gas
- Coal
- Nuclear
- Hydro
- Oil
- Bio energy
- Marine
- Geothermal

Flexibility

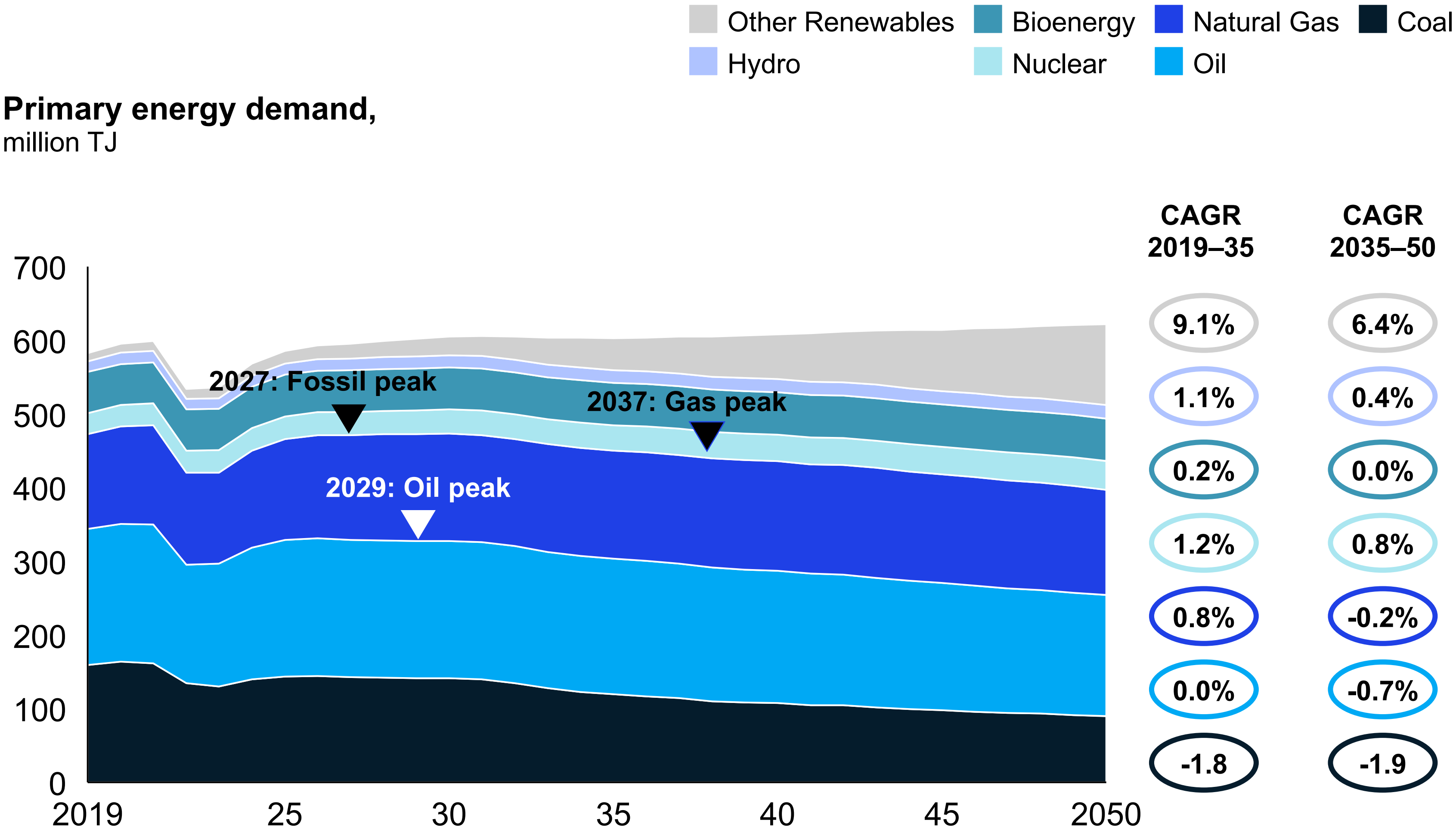
- Utility-scale batteries
- Distributed batteries
- Hydrogen
- Pumped hydro

1. Sub-technologies for different technology groups leads to total of 41 technology classes

Source: McKinsey Energy Insights' GEP Power Model

In the Reference Case, fossil fuels gradually get replaced by renewables but continue to play a role

Oil demand peaks in the late 2020s, gas in the 2030s, whereas coal declines steadily



Compared to 2019, by 2050 we will see:

>220% higher

renewable[2] demand

~5% higher

gas demand

>10% lower

oil demand

>40% lower

coal demand

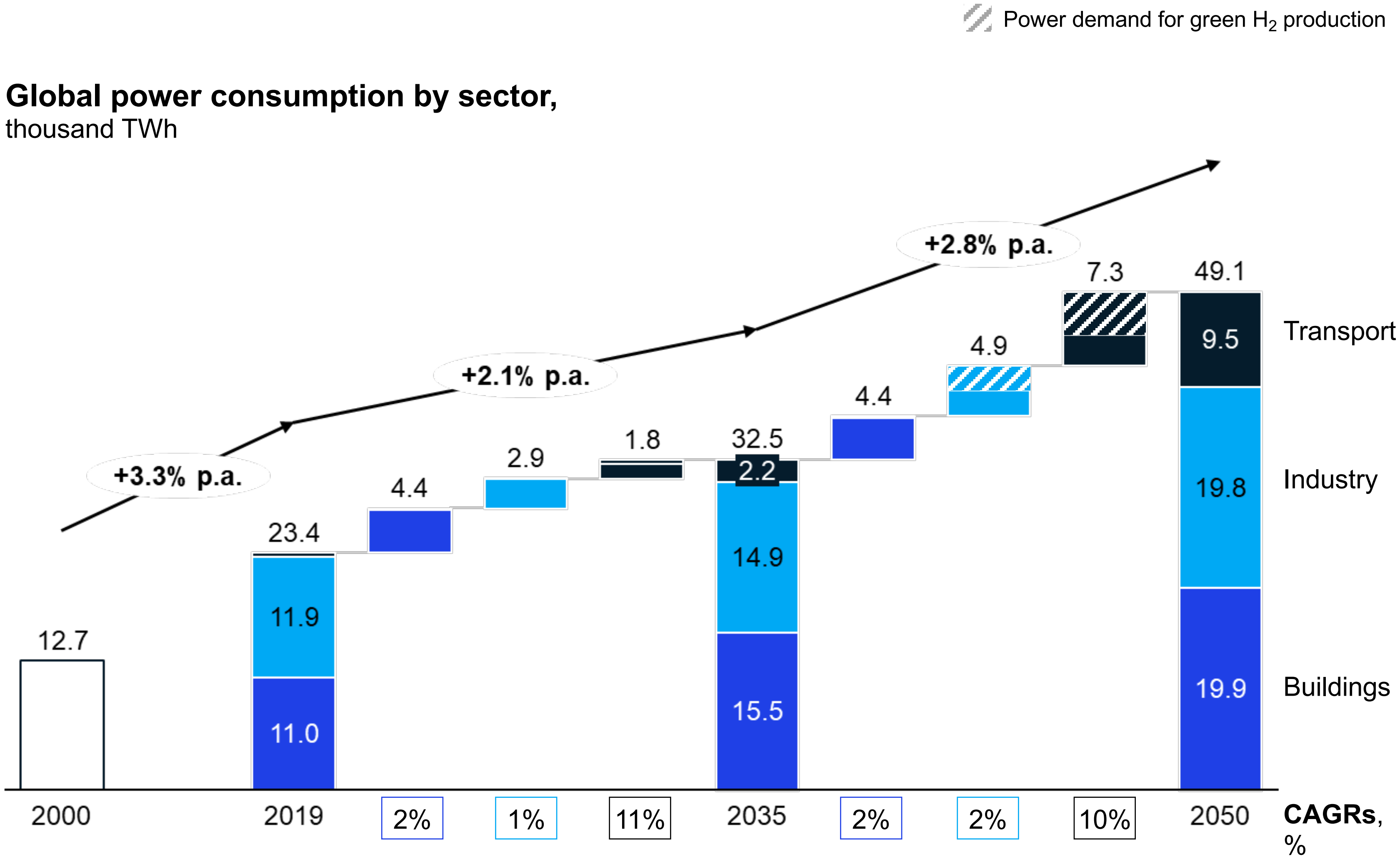
1. Compared to 2019 levels
2. Bioenergy, hydro, and other renewables

Source: McKinsey Energy Insights Global Energy Perspective 2021, December 2020

Doubling in power demand is driven by higher living standards, electrification, and hydrogen

Relative growth is largest in the transport sector

Global power consumption by sector, thousand TWh



Source: McKinsey Energy Insights Global Energy Perspective 2021, December 2020

2x higher

global electricity consumption by 2050

~30%

share of hydrogen in total electricity uptake until 2050

Ensuring global power supply going forward will rely on a complex landscape of power generation and energy storage technologies

Coal (13)1

Super- and sub-critical lignite

Sub-critical hard coal (x3)

Supercritical hard coal (x3)

Ultra-supercritical hard coal

IGCC

Co-fired (with biomass)

CCS super-critical hard coal

CHP

Fuels modelled as technologies for modelling simplicity

Gas (9)[1]

CCGT (x6)

OCGT (x2)

CHP

Hydro (2)

Run-of-river

Dam

Nuclear (1)

-

Limited to political/geo-graphical potential

Oil (1)

-

Wind (4)

Onshore2 (x3)

Offshore

Bio-energy (3)

Biomass

Waste

CHP

Solar (6)

Large-scale PV2 (x3)

Small-scale PV3 (x2)

Solar thermal

Geothermal (1)

-

Marine (1)

-

Storage (4)

Pumped hydro

Utility-scale batteries

Distributed batteries

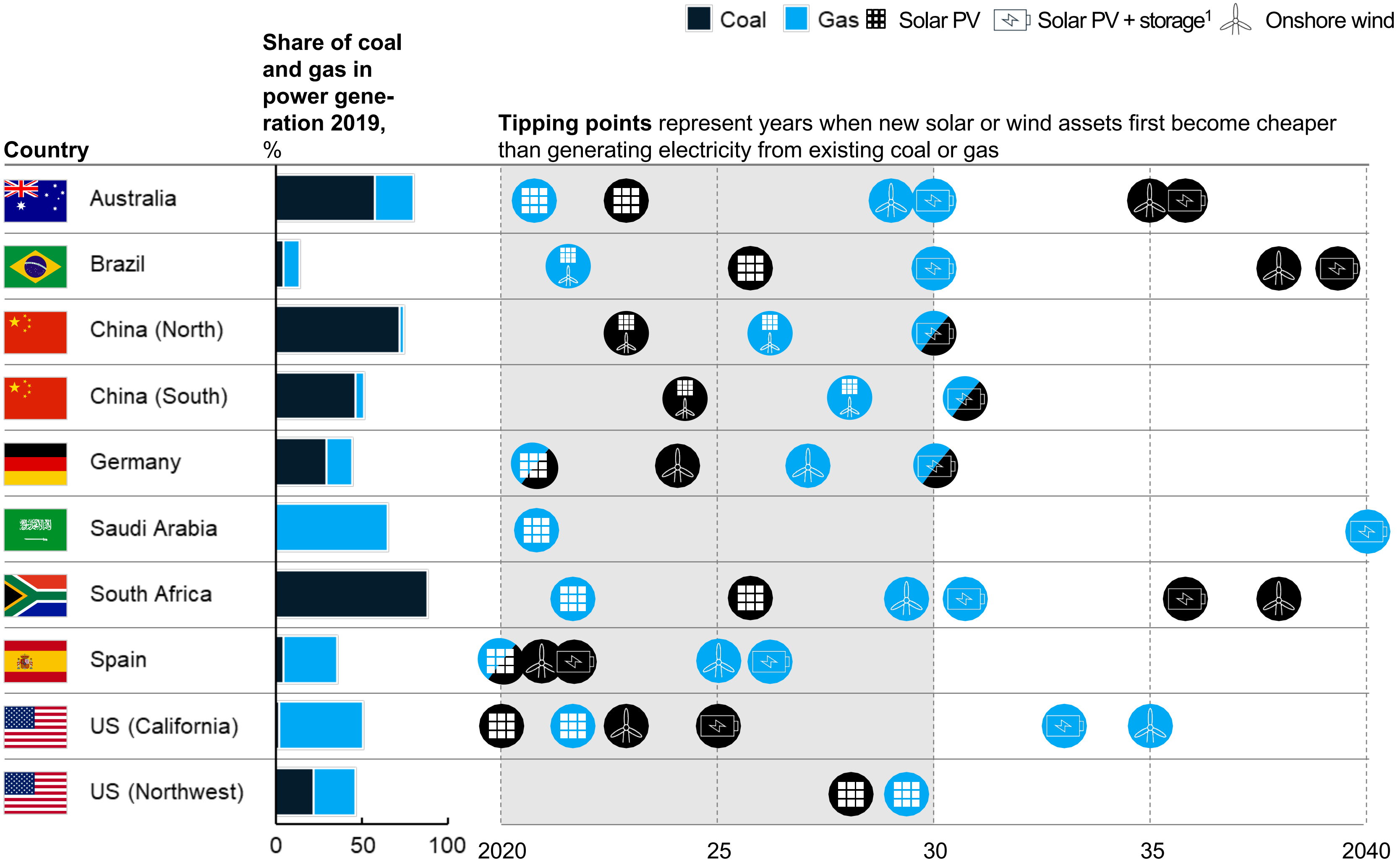
Hydrogen

1. Coal and gas technologies are split in subclasses based on percentile of plant-level efficiencies; 2. Includes subclasses for sites with high, medium and low capacity factors; 3. Residential and C&I, modelled exogenously based on consumer dynamics and retail tariffs

Source: McKinsey Energy Insights' GEP Power Model

Renewables become cheaper than existing fossil plants in most locations

New renewables can compete with the marginal cost of fossil power by 2030



1. CAPEX for buffer storage capacity etc. included

Source: McKinsey Energy Insights Global Energy Perspective 2021, December 2020; McKinsey Power Model

Late 2020s

New build renewables cost-competitive with existing assets n most countries

Solar PV

becomes economical first in all regions as a result of lower levelized cost of electricity

Energy transition toward renewables will boost Copper demand while its impact on PGMs will be more balanced

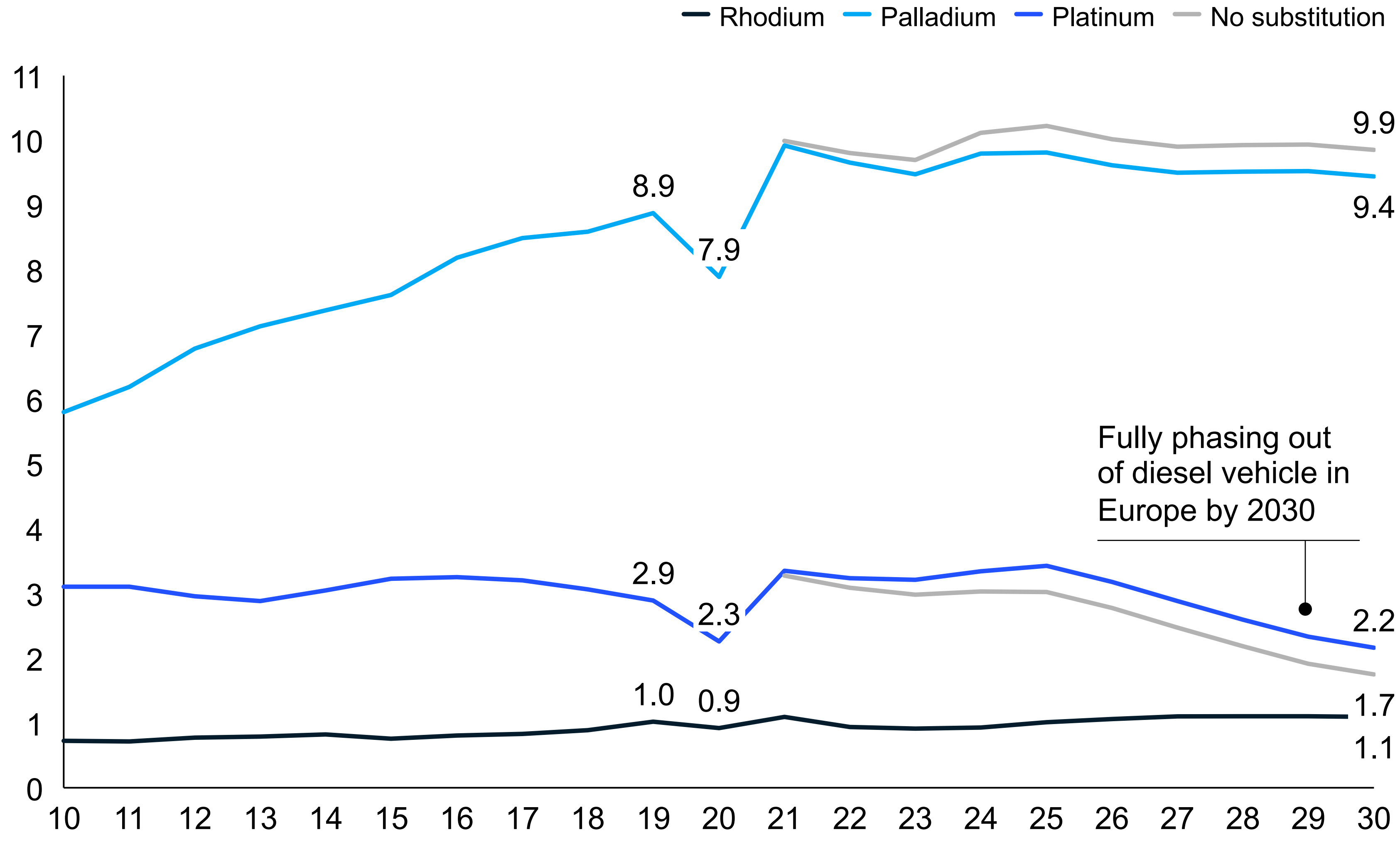
Very high degree of risk | Low probability of risk occurrence

	Mid- to long-term demand trends	Mid- to long-term supply trends	WMF criticality assessment
PGM	Rapid renewables EV adoption will negatively impact PGMs in auto catalysts Platinum-Palladium substitution and stricter emission loadings will largely offset this decline/change dynamics Platinum demand from FCEV and hydrogen production will be low by 2030, growing significantly after 2030	Mine supply has been flat since 2010, expected market conditions should incentivize up to 1Moz of Pt and 1.5Moz of Pd of new supply Current operations will decline, driven by aged South African western limb assets, which will impact rhodium supply Palladium supply has a stronger project outlook due to throughput improvements and expansions in Russia	45 Rh 102.096 **Rhodium** 46 Pd 106.420 **Palladium** 78 Pt 195.085 **Platinum**
Copper	Global copper demand is forecasted to grow at 3.1% p.a., above the historical long term rate of 2.5% (+9.1 Mt between 2019-30) driven by grid expansions and infrastructure modernization If the 'green shift' proceeds at pace, additional 5Mt of copper will be needed by 2030 for renewable power generation, grid storage and mass EV adoption	Supply growth will peak in 2026 at 23.8Mt; weak project pipeline over the second half of the 2020s Structural market deficit is expected after 2025 and will exceed 4.6Mt by 2030 unless projects are incentivized to advance and potential environmental risks of copper extraction get addressed Recycling will play a crucial role to close the supply gap	29 Cu 63.546 **Copper**

Source: WMF, McKinsey MineSpans

Demand for PGMs in auto catalysts to be impacted by both tailwinds and headwinds

Platinum[1] and palladium demand for auto catalysts, 2010-30, Moz



1. Excluding FCEV (hydrogen society); 665Koz Pt by 2030

Source: Metals Focus, McKinsey Center for Future Mobility, McKinsey PGM model

Headwinds:

City de-congestion and entry-bans, rapid adoption of electric vehicles, stricter emission standards, OEM thrifting to drive PGM demand in autocatalysts

2019-30 **light vehicle sales to be flat to marginal** growing reaching 87m – 97m units; 0%-1% CAGR – significantly less than previous estimates

BEV to account for 19% of light vehicles sales by 2030; ~16million vehicles

Tailwinds:

China's new emission standards, **China 6b, to be equivalent to the Euro 6** – PGM loadings to increase significantly, particularly Pd in ICE vehicles

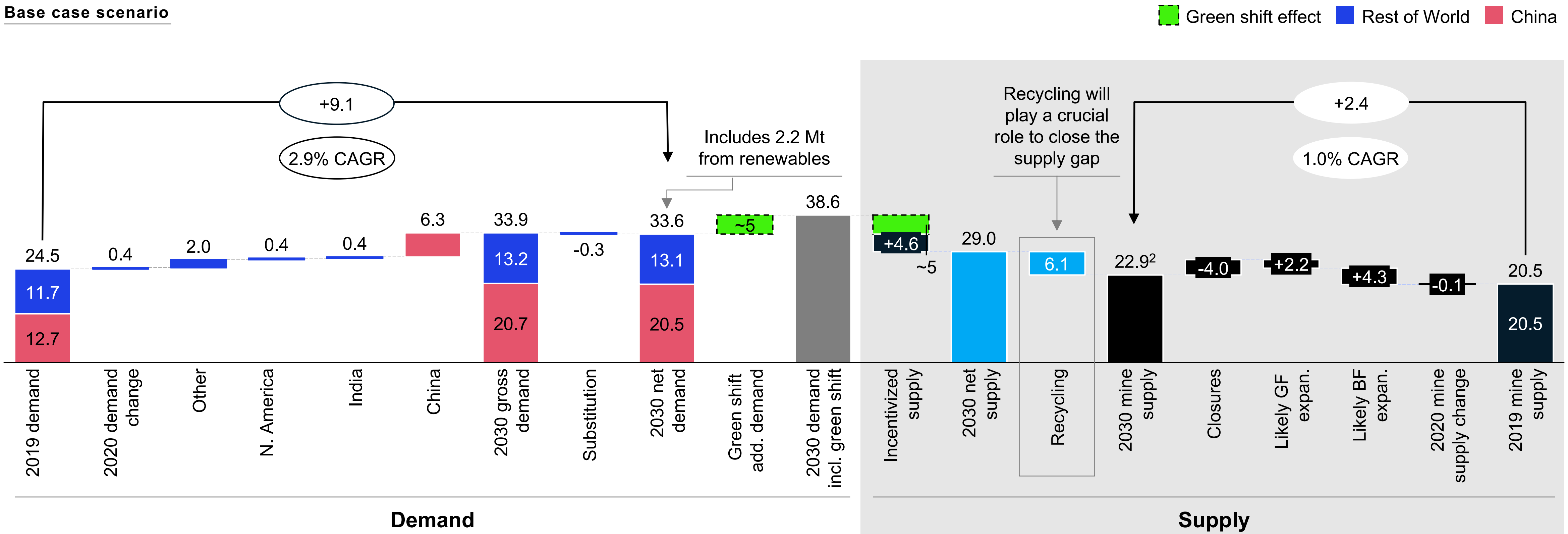
“” Platinum giants get lifeline as green economy boosts demand

Bloomberg

Copper demand is forecasted to grow by at least 9Mt between 2019 and 2030, current supply pipeline insufficient to meet demand

Copper mine supply[1] and refined copper demand, 2019-2030, Mt

Base case scenario



Additional supply uncertainties and risks

- Environmental risks related to copper extraction might harm chances or delay environmental permitting processes for new projects or require additional capex
- Political instabilities in main producing regions and changes to royalty schemes, e.g., in South America might limit willingness of investors to fund required greenfield projects

1. Including mill-head grade corrections
2. Full potential supply is 29.5Mt

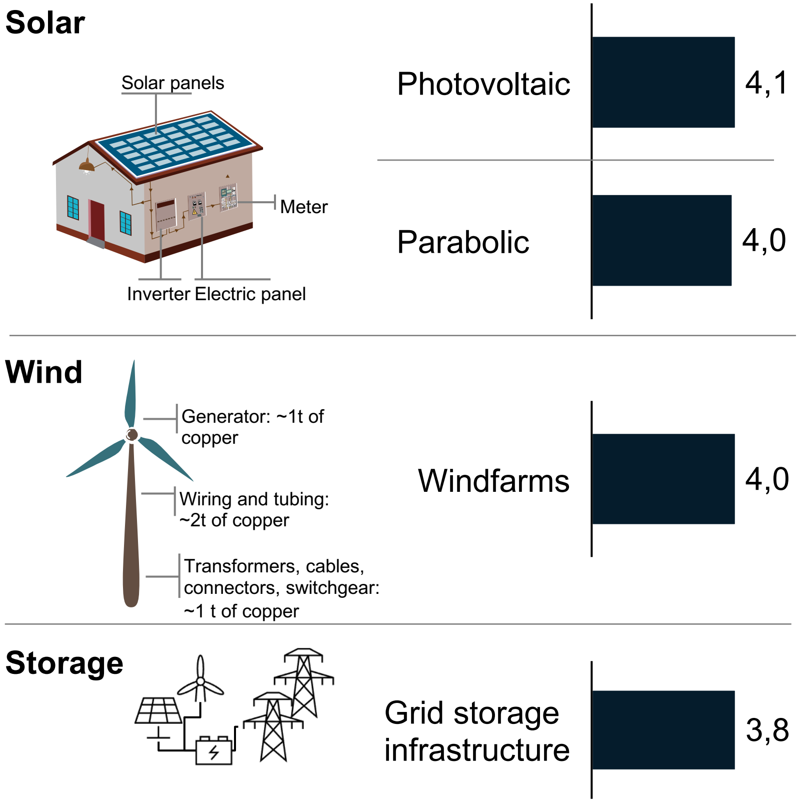
Source: MineSpans; McKinsey Copper Demand Model Q4 2020; International Copper Study Group

In a disruptive scenario copper demand from the renewable power sector could exceed our base case by 3x

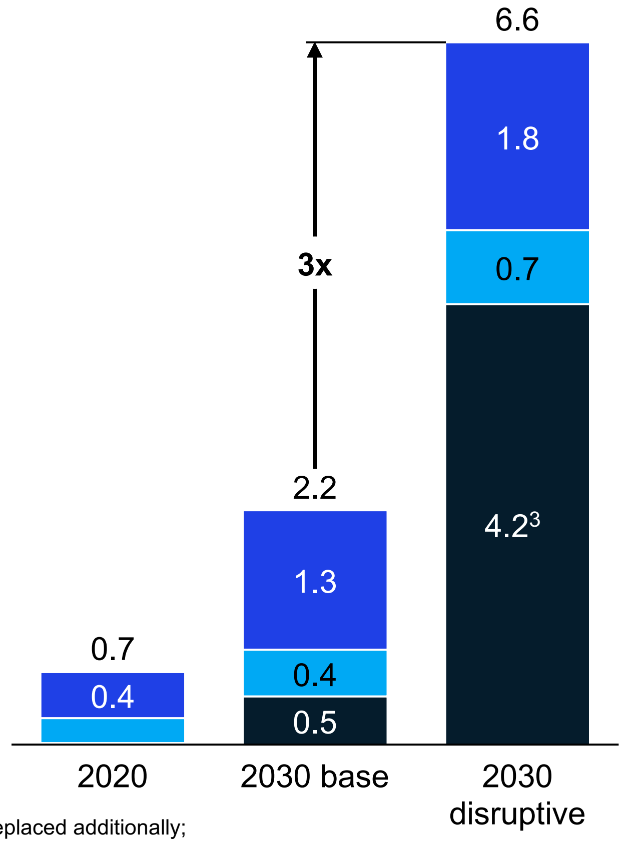
Disruptive case scenario

Solar Wind Storage

Copper intensities[1], t/MW



Annual Cu demand from renewables, 2020-30, Mt



What you need to believe

- Base scenario follows IEA's sustainable development scenario leading to a **copper demand from renewables and grid storage of ~2.2Mt in 2030**
- **China is a major driver for renewables** due to the country's decision to become carbon neutral by 2060
- ~2.5Mt of copper will be needed in 2030 for wind and solar power in the disruptive case
- Following Tesla's estimate on grid storage materializes in additional 4.2 Mt of copper, lifting total demand from the renewables sector to **6.6Mt in the disruptive case**

1. Includes grid connectors, transformers etc.
2. Solar/Wind - 50% of global coal capacities in IEA's sustainable development scenario are replaced additionally; Storage - Tesla's assumption on global grid storage is used as disruptive case
3. Tesla's scenario

Source: IEA, McKinsey Energy Insights, websearch