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# The Electrotech Revolution

## The shape of things to come

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Kingsmill Bond, CFA

**September, 2025**

# The Age of Electrotech

Humanity is graduating from burning fossil commodities to harnessing manufactured technologies—from hunting scarce fossils to farming the inexhaustible sun, from consuming Earth's resources to merely borrowing them.

This isn't a marginal climate substitution. It's an energy revolution.

The magnetic centre is the electron: we are revolutionising how we generate, use, and connect electrons. Solar and wind are conquering electricity supply. EVs, heat pumps, and AI are electrifying major new uses. Batteries and digitalisation are connecting supply and demand.

Three reinforcing shifts. One energy revolution. The electrotech revolution.

At its core, this revolution is driven by physics, economics, and geopolitics. After all, the arc of energy history bends towards solutions that are leaner, cheaper and more secure.

Short-terms setbacks matter, but fundamentals matter more. And the fundamentals are stacked in electrotech's favour.

Physics. Electrotech makes a mockery of setting fossils on fire and losing two-thirds of the energy to heat. Electrotech is three times as efficient.

Economics. Technologies get cheaper with scale. Commodities get more expensive the deeper you dig.

Geopolitics. Three quarters of the world is dependent on fossil imports. 92% of countries have renewables potential over 10x their current demand.

Electrotech has grown exponentially for decades. The difference today is that it's too cheap to contain and too big to ignore. If current exponentials hold for five more years, global fossil demand will fall off its plateau.

Welcome to the Age of Electrotech.

**Daan Walter, Sam Butler-Sloss, Kingsmill Bond**



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# Chapter 1
# A New Perspective: The Electrotech Revolution

## 01

### Electrotech is a better way to explain reality

Most of the debate on the future of energy is between fossil gradualists and net zero advocates. We propose a third approach — the electrotech revolution — which better explains the extraordinary changes taking place in the energy system today.

## 02

### Electrotech is electricity technology

Electrotech describes exponential energy technologies revolutionising how we generate, connect and use electrons – technologies enjoying learning curves and rapid growth, such as solar, wind, batteries, and digital solutions.

## 03

### Electrotech releases 100x more energy

Electrotech enables us to harness the sun's enormous energy resources. The sun supplies Earth with as much energy every five days as all fossil fuel reserves combined. This makes possible a new energy era.

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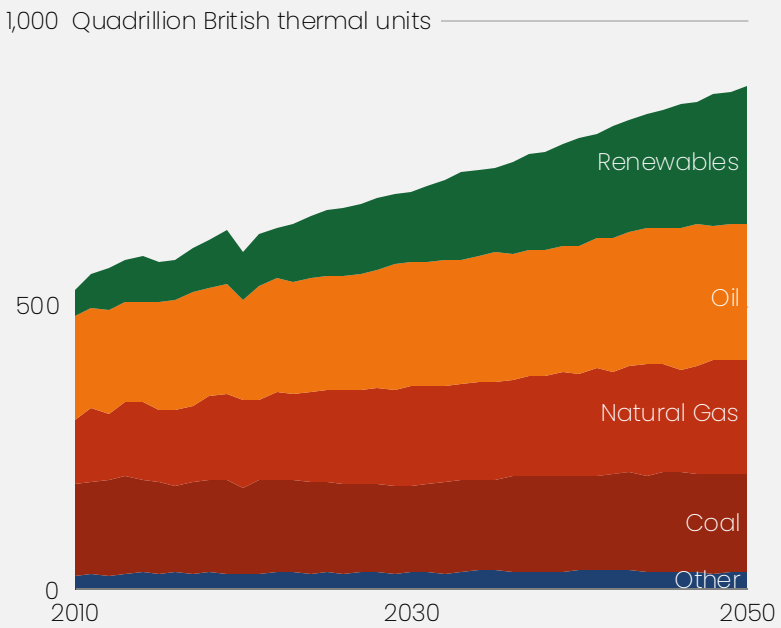
# Two views on energy dominate the conversation. We propose a third

## The dominant energy views in the energy debate today

### The incumbent energy view, centred on fossil fuels, slow change and business-as-usual

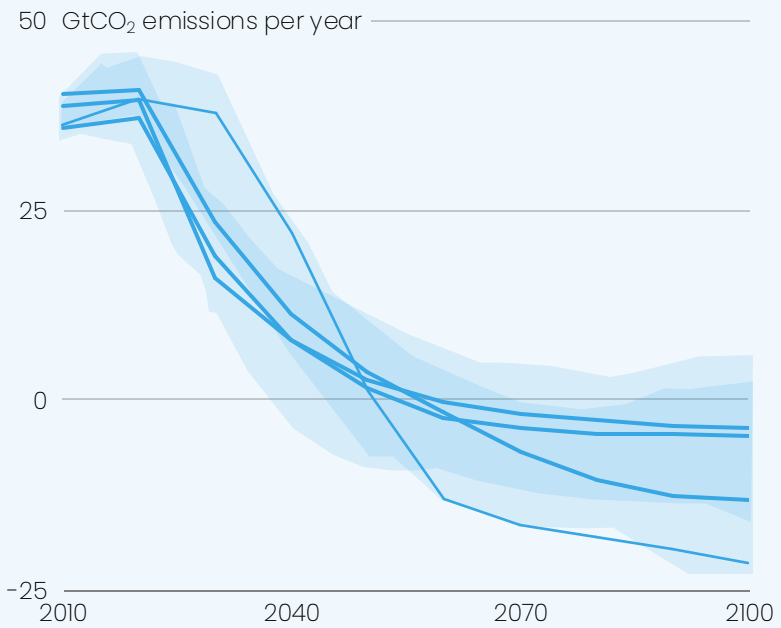
**EIA – Primary energy supply**




Source: Energy information Administration

### The climate view, centred on emissions, policy targets and the moral obligation to fix climate change

**IPCC – Pathways to net zero emissions**

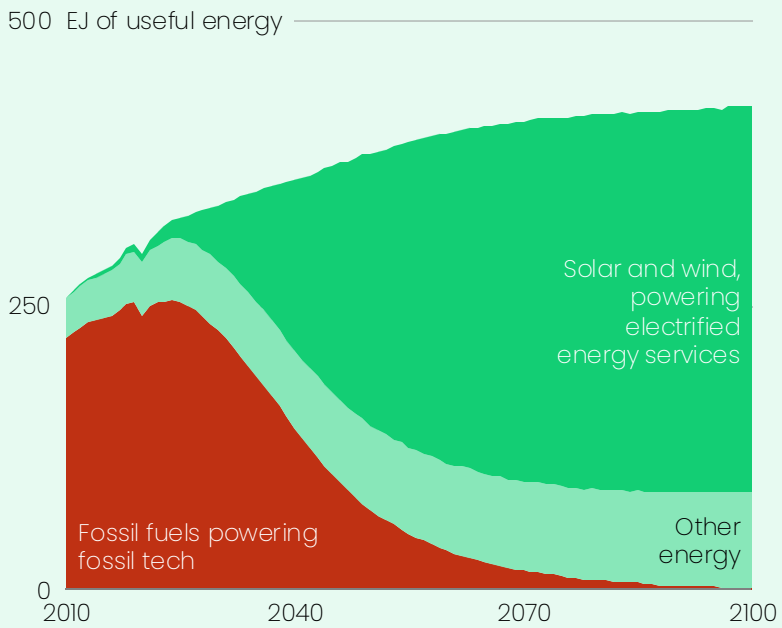



Source: Intergovernmental Panel on Climate Change (IPCC)

## A third way: the electrotech view

### The new electrotech view, centred on growth and innovation

**Rystad – Global useful energy demand**




Source: Rystad Energy



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# This is a technology revolution in energy

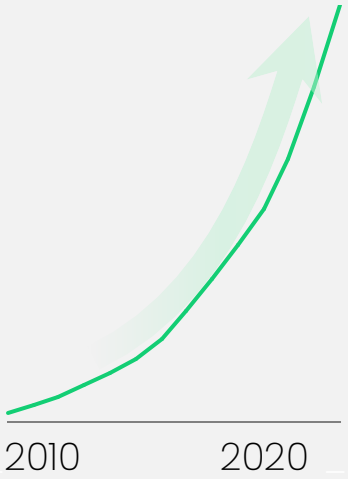
Electrotech is technology that revolutionises the supply, connection and demand of electricity

## Supply

### New ways to generate electricity

**Renewables** as vectors of change

**Solar PV**
deployment (GW)



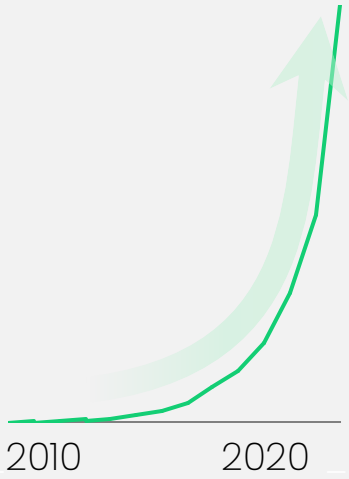

**Wind**
deployment (GW)


## Connections

### New ways to transport and store electricity

**Flextech/gridtech** as vectors of change

**Battery storage**
deployment



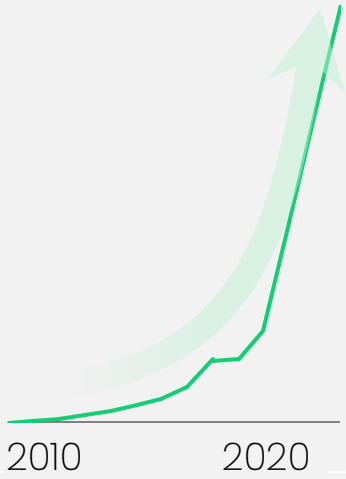

**HVDC lines**
deployment (km)


## Demand

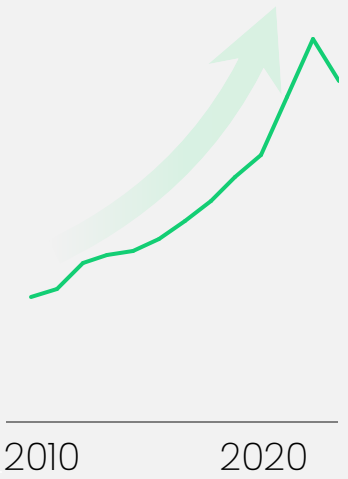
### New ways to use electricity

**Electrification** as vector of change

**EV**
sales




**Heat pumps**
sales






Sources: Ember, IEA, RMI, Thunder Said

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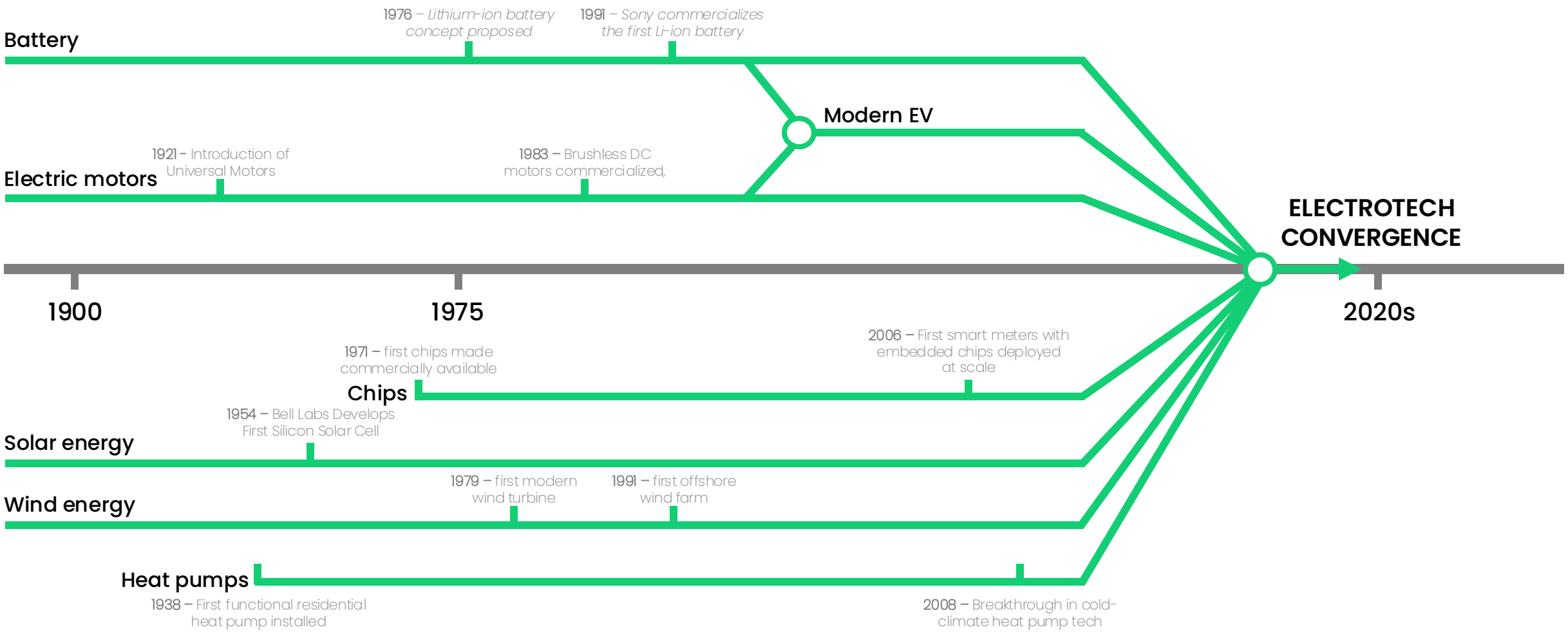
# A century of evolution is converging into a decade of revolution

The 2020s mark a great technology convergence

ILLUSTRATIVE






Source: Ember

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# This is the age of electrotech

It is the latest in a long line of technology shifts

**Industrial Revolution**
1st wave

Iron
Waterpower
Mechanisation

**Age of steam and rail**
2nd wave

Steam engines
Steam power
Rail

**Age of steel and electricity**
3rd wave

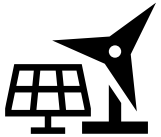
Electricity
Steel
Heavy engineering

**Age of oil and mass production**
4th wave

Mass-produced automobiles
Cheap oil
Petrochem

**Digital Age**
5th wave

Information technologies
Telecoms
Software



**Electrotech Age**
6th wave

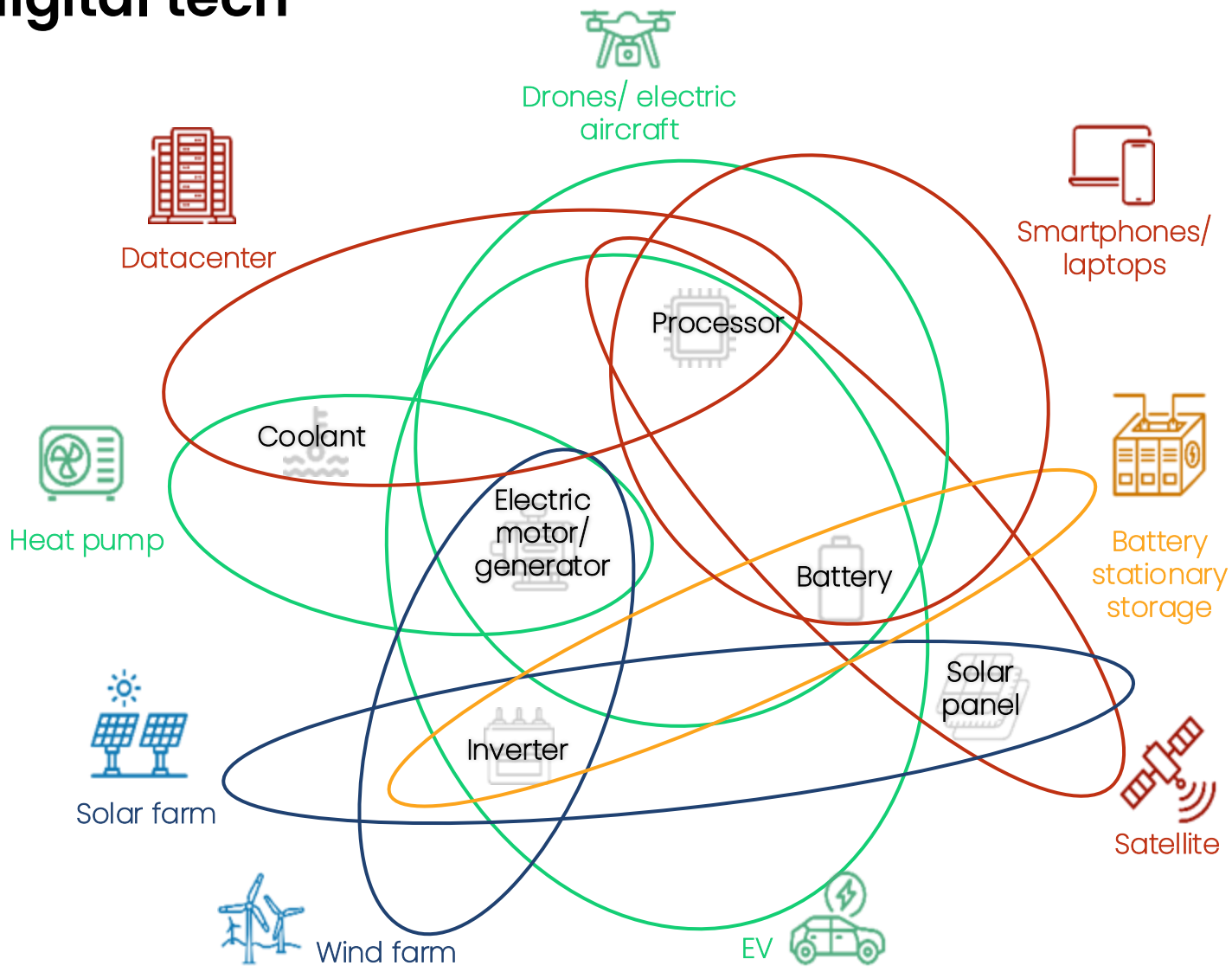
Renewable energy
Electrification
AI



Sources: Carlota Perez (first five waves), Ember Futures (6th wave)

# Electrotech is the child of digital tech

**Electrotech is made of the same components as digital tech, and inherits its momentum**



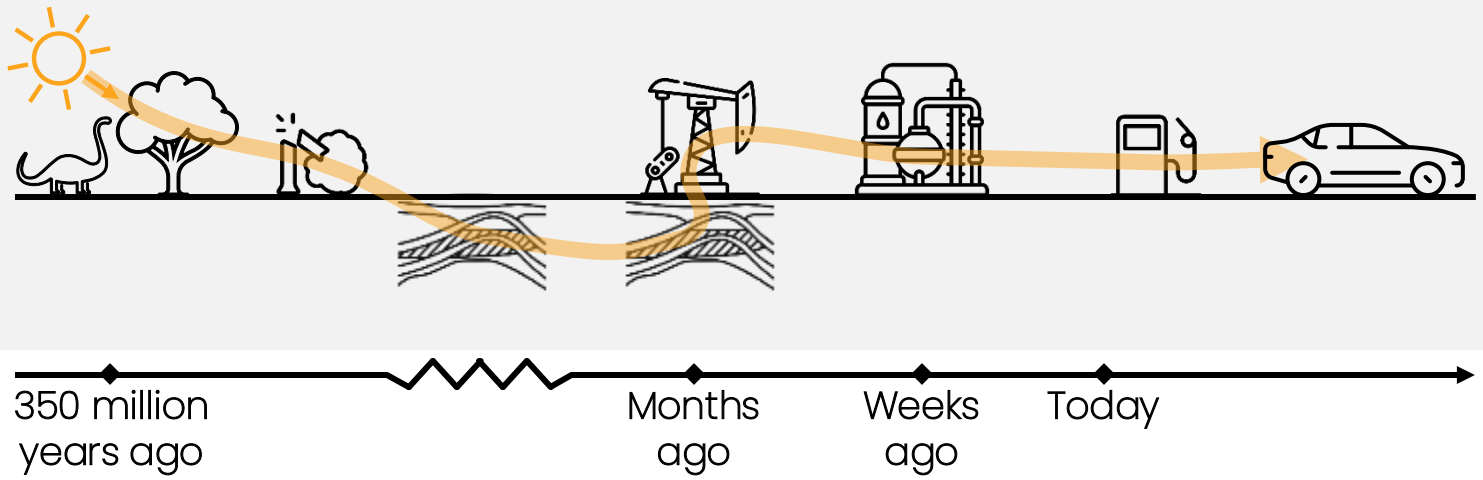



Source: Ember analysis

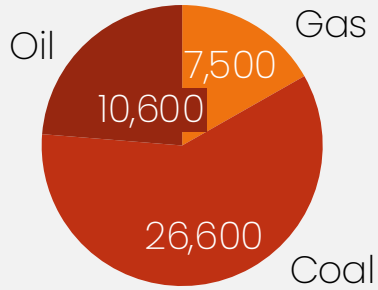
# From burning old sunshine to using it real-time

The sun supplies more energy to Earth every 5 days than all fossil fuel reserves

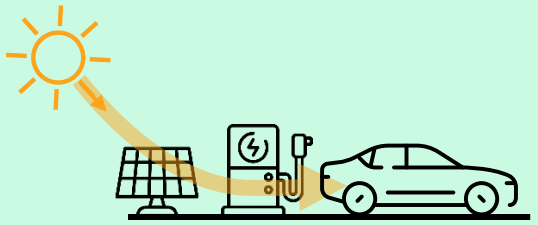
Fossil fuels



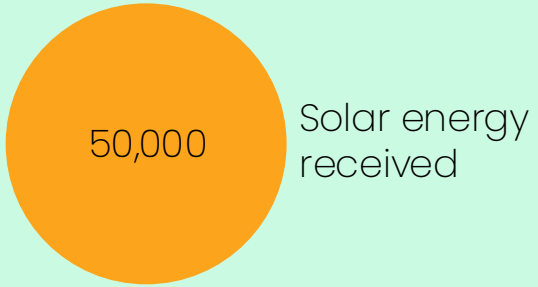

**Total terrestrial energy reserves for the rest of time, current estimates, global, EJ**




Electrotech – solar



**Solar energy received from the sun every 5 days, EJ**






Sources: EI; Ember analysis. Note this is all solar energy received by the earth. We only need to extract a small fraction of it.

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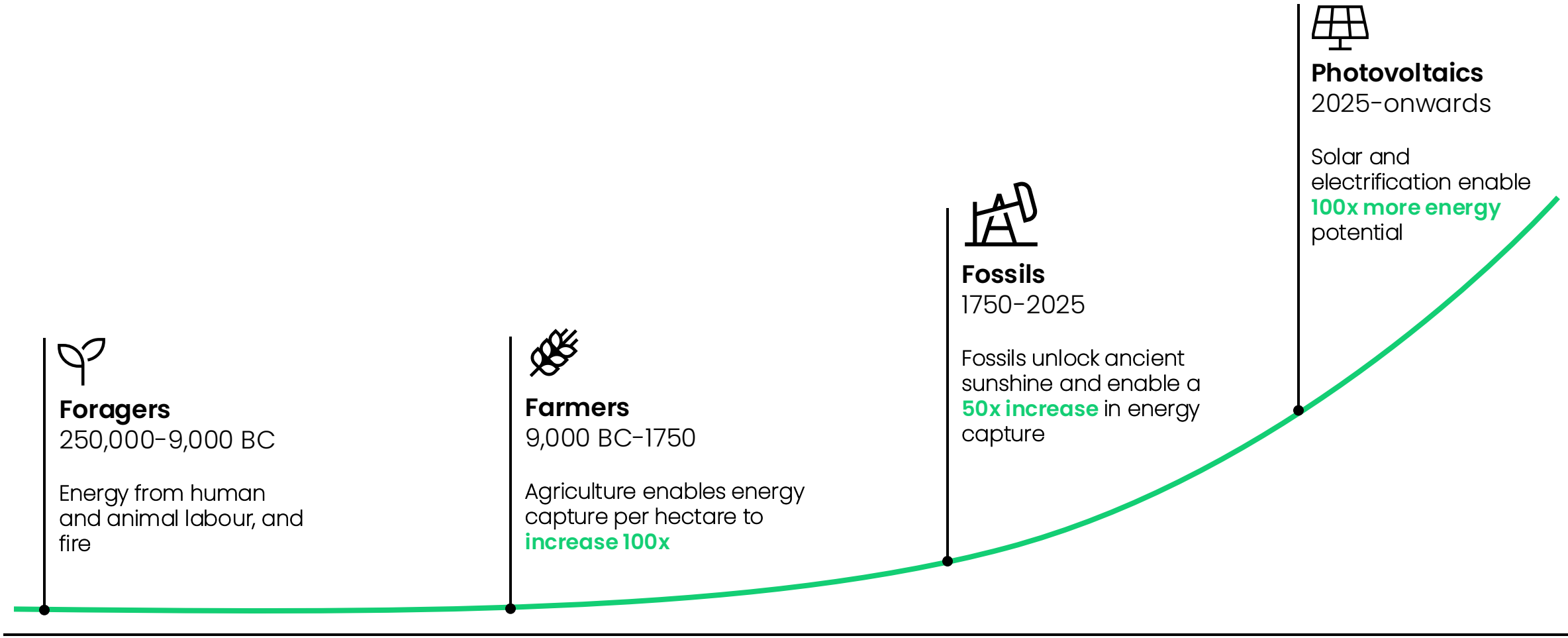
# Foragers, Farmers, Fossils, Photovoltaics

Electrotech enables another 100x leap in energy abundance






Sources: Ian Morris: Foragers, Farmers and Fossil fuels; Carbon Tracker: The Sky's the limit; Ember framing.

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# Chapter 2
# The rise of electrotech

## 01

### Electrotech costs have fallen fast

Electrotech costs have been falling for decades on established learning curves of around 20% for every doubling in deployment. They now challenge fossil fuels on cost, with Dolphin EVs retailing in China below $10,000 and solar-plus-storage in India at $40 per MWh. As a result, capital is shifting, and two-thirds of energy expenditure is going into electrotech.

## 02

### Growth has been exponential

Key electrotech technologies have enjoyed exponential growth. We see this for generation (solar and wind), connections (batteries and software) and usage (EV and heat pumps). Change is led by China, and is now cascading into the emerging markets. ASEAN, for example, leapfrogged the US in electrification in 2023.

## 03

### The ceiling of the possible is high above us

We already know how to get solar and wind to 70-80% of generation at a cost comparable with fossil fuels and how to electrify around 75% of end demand. So we can more than triple renewables and electrification.

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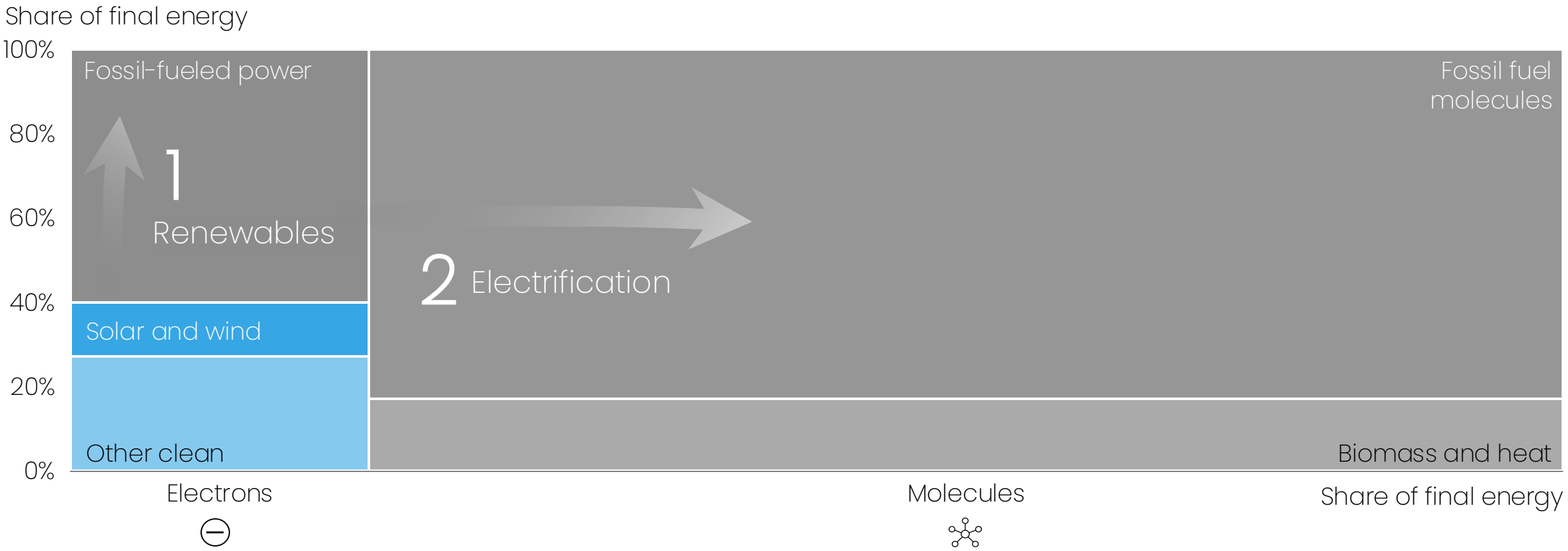
# The two vectors of the energy transition

Renewables replace fossil electricity; electrification replaces fossil molecules

## Global final energy demand in 2023






Sources: IEA WEO 2024; Ember analysis. Other clean electrons are mainly nuclear and hydro.

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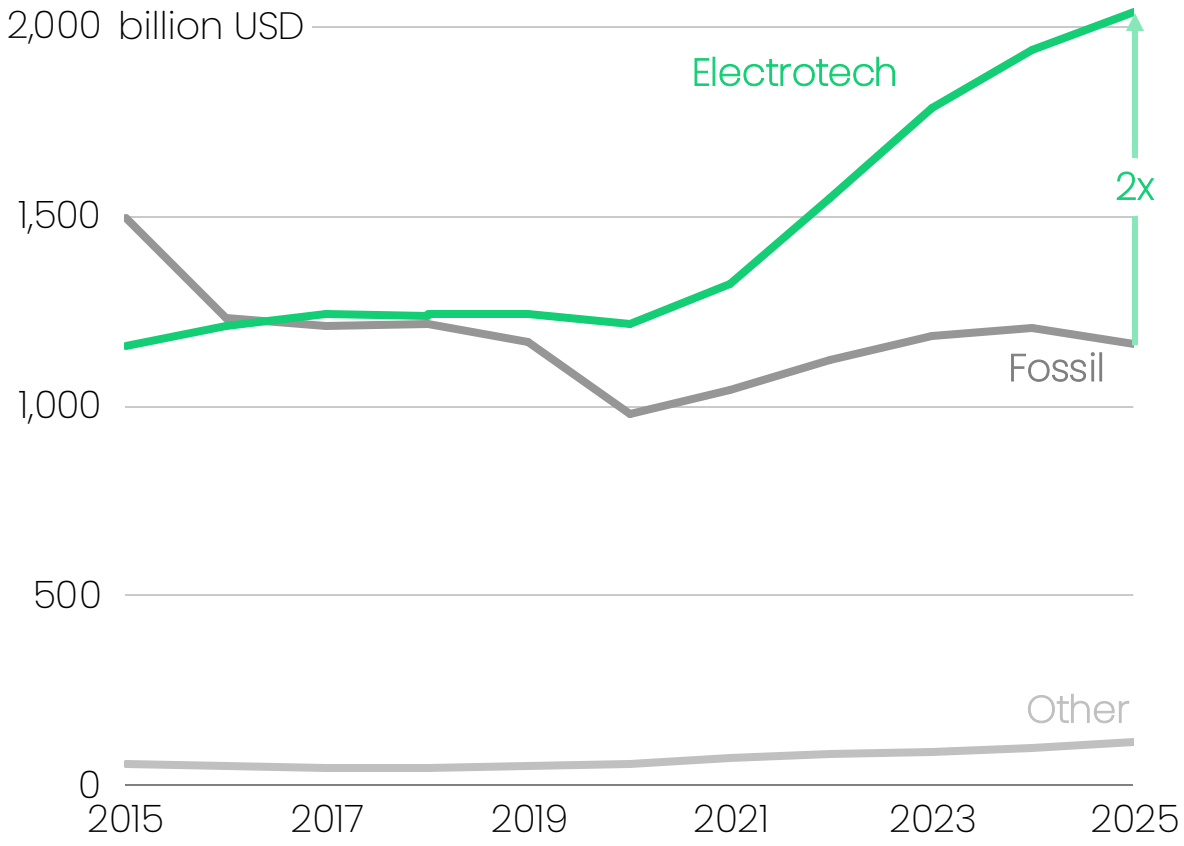
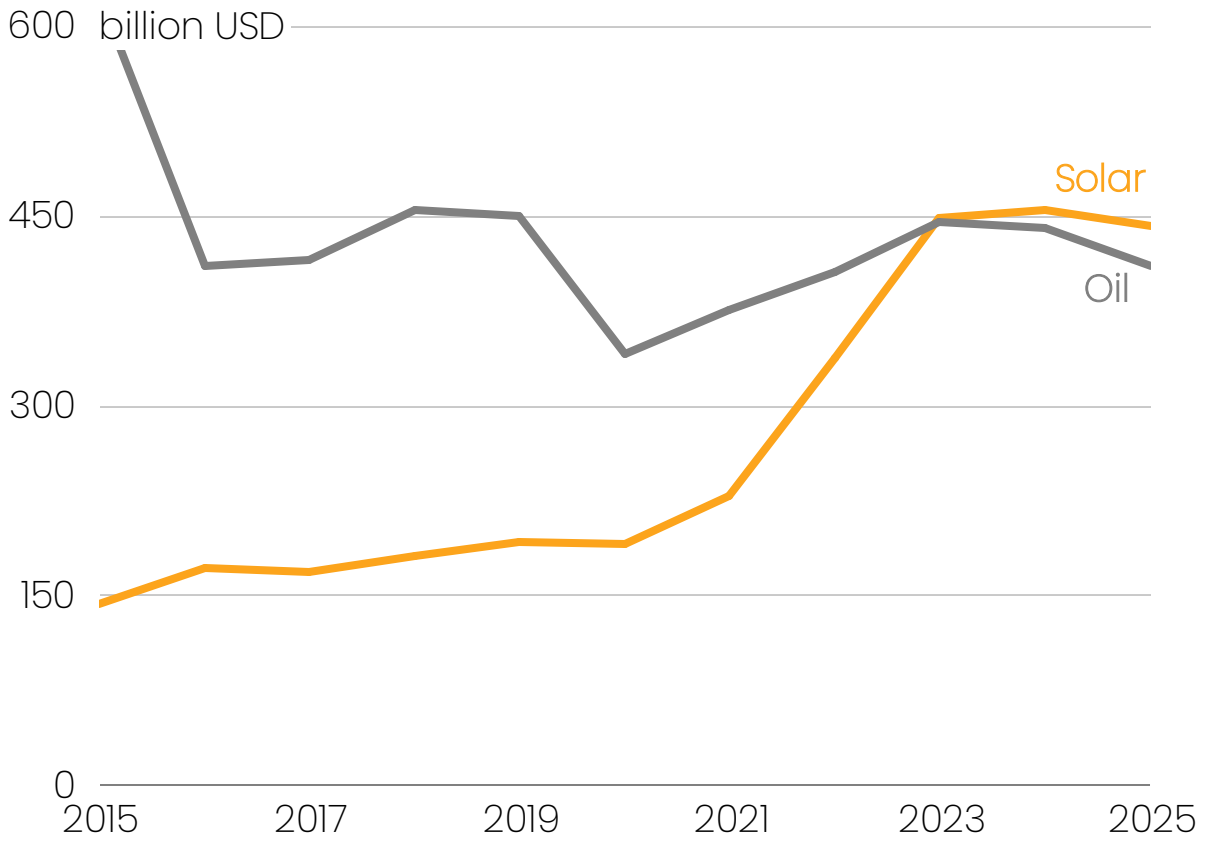
# Electrotech investment is twice as big as fossils

And we spend more on solar capex than on oil

## Energy investment by category




## Solar and oil investment






Sources: IEA WEI, Ember analysis – Note: Oil investment on the right hand side is upstream investment

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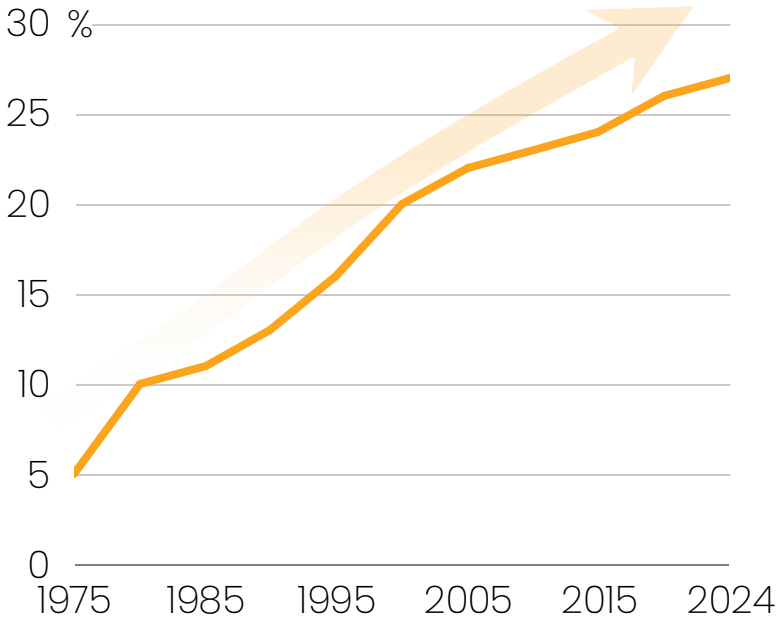
# Electrotech keeps getting better

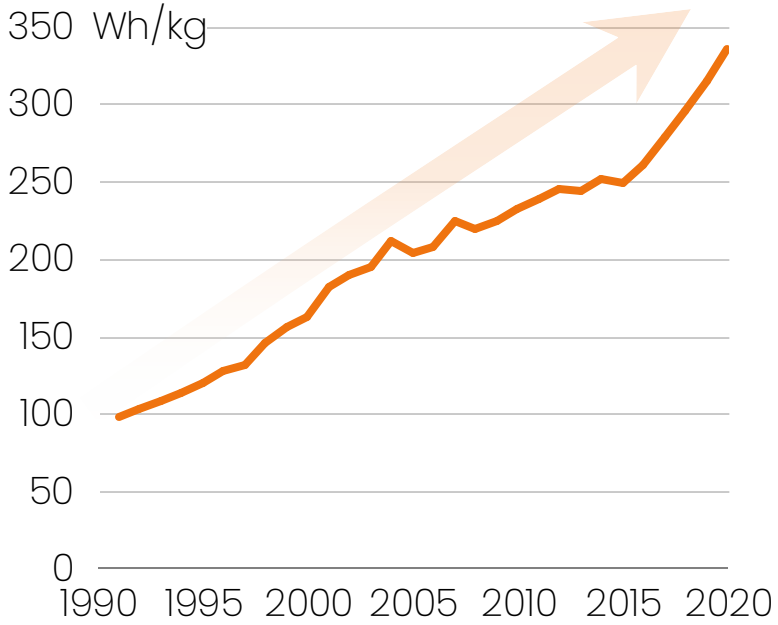
Decade after decade of innovation raises the ceiling of the possible

## Solar cell efficiency



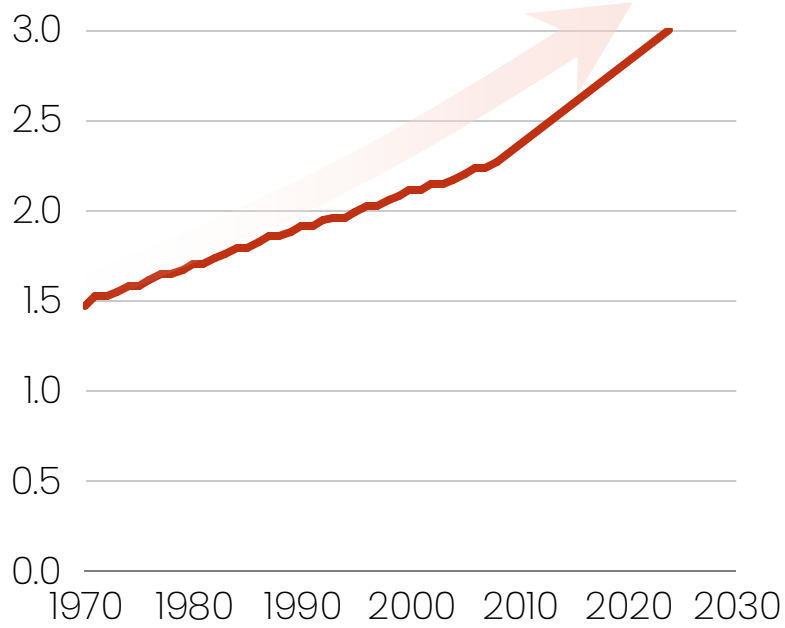

More efficient solar cells mean more space and material efficiency and lower cost

## Top-tier battery cell density




Denser batteries mean longer EV ranges; new EV applications opening up and more material efficiency

## Heat pump coefficient of performance, US sales average




Higher COP means a more efficient and powerful heating system



Sources: RMI X-Change Batteries, US DOE, US NREL; Ember analysis

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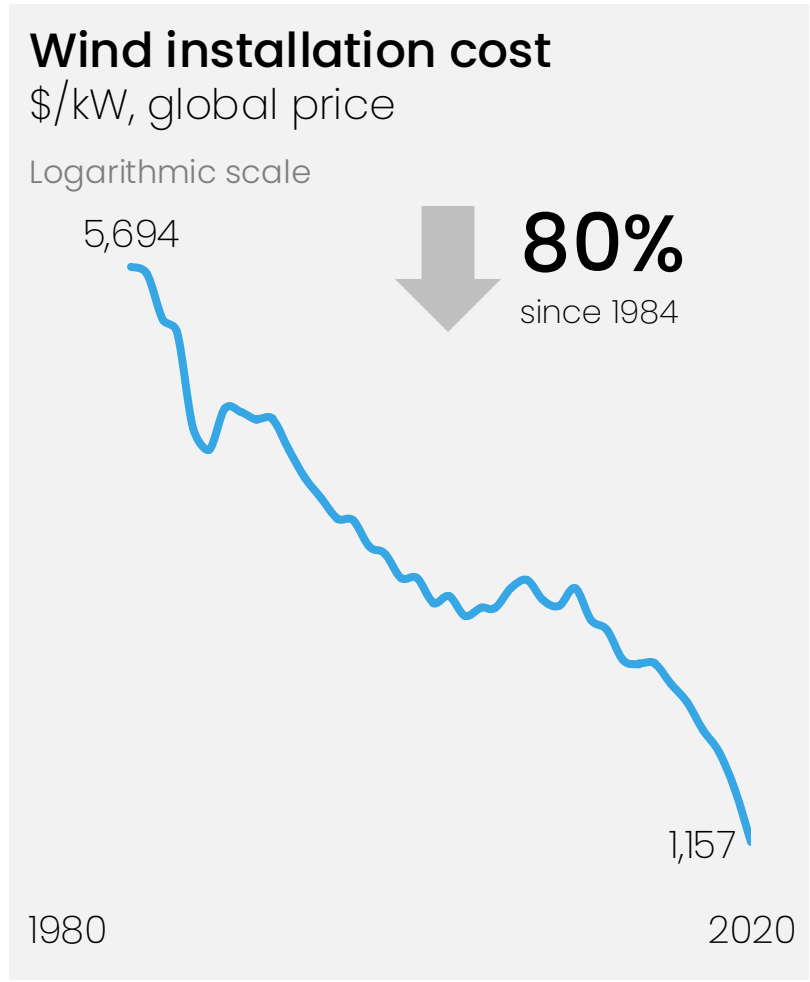
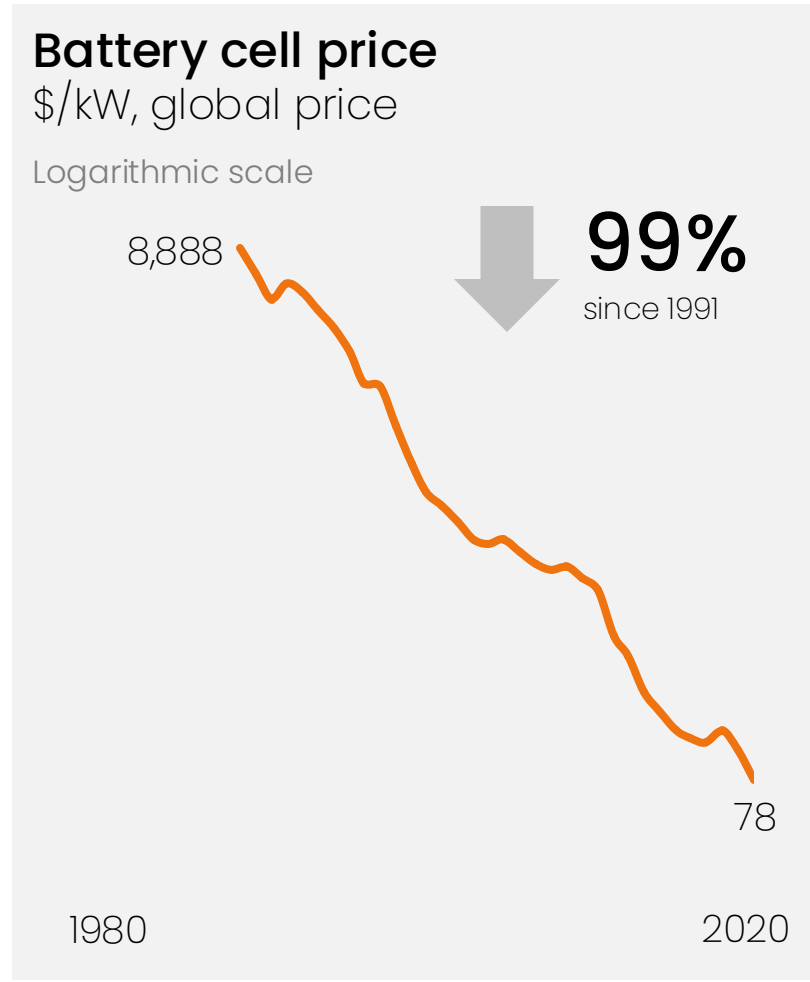
# Costs have been falling for decades on learning curves

Decades of steady cost innovation improved electrotech economics

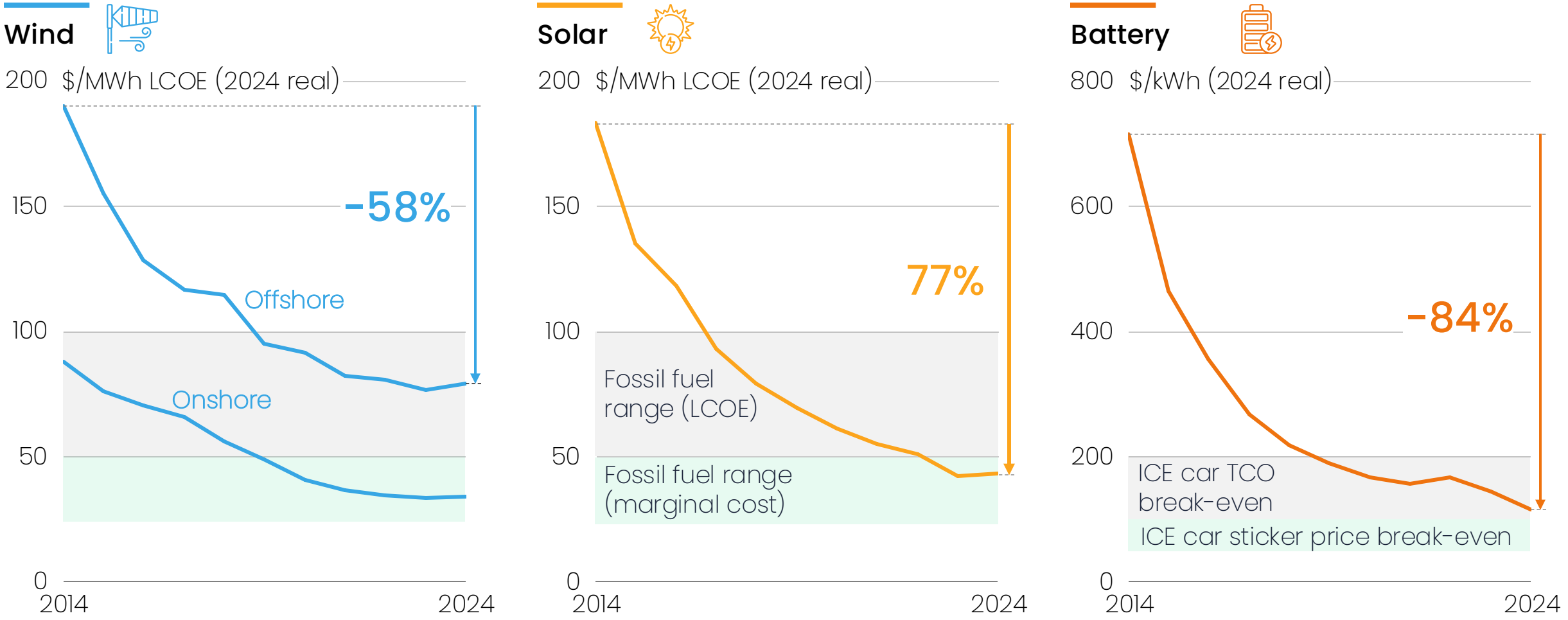






Sources: OWID; IRENA; BNEF/Avicenne

# Cheap enough to challenge incumbents

After decades of cost innovation electrotech is now cheaper than fossils






Sources: IRENA, BNEF (Batteries), Ember

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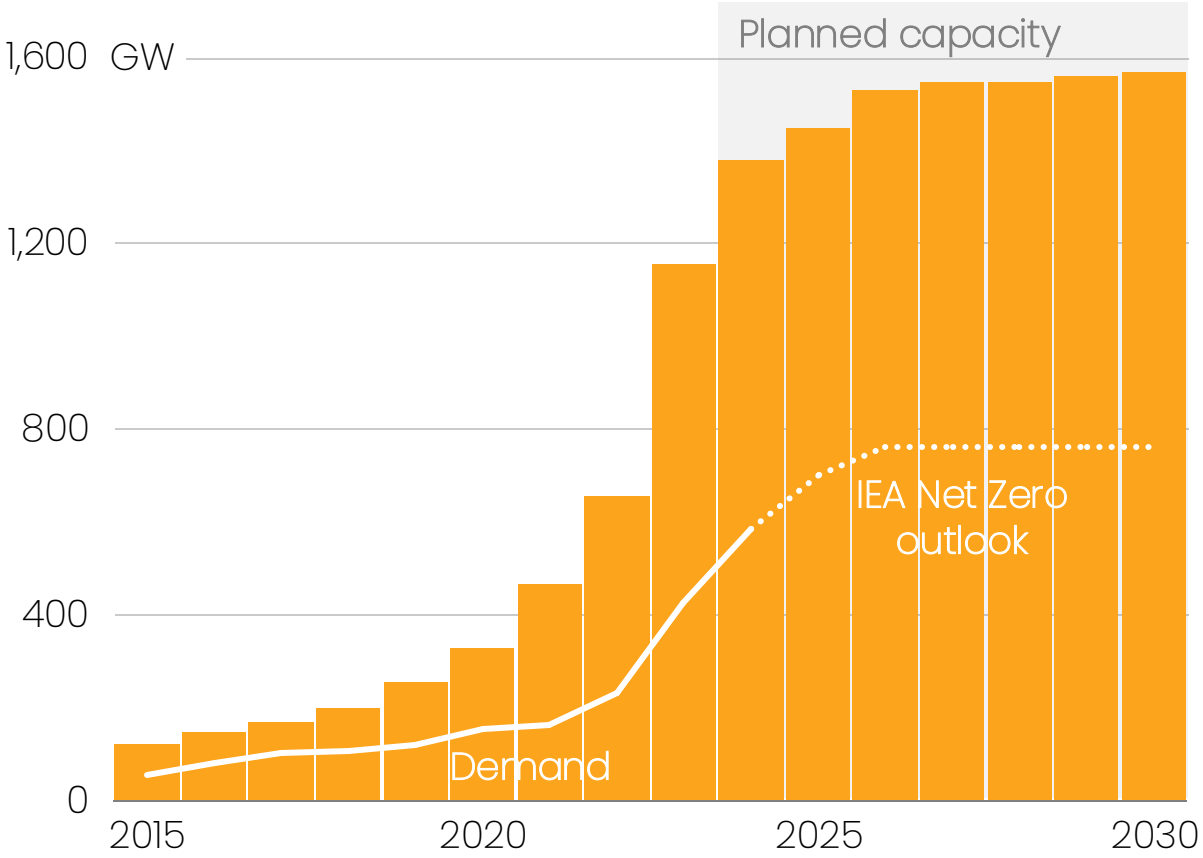
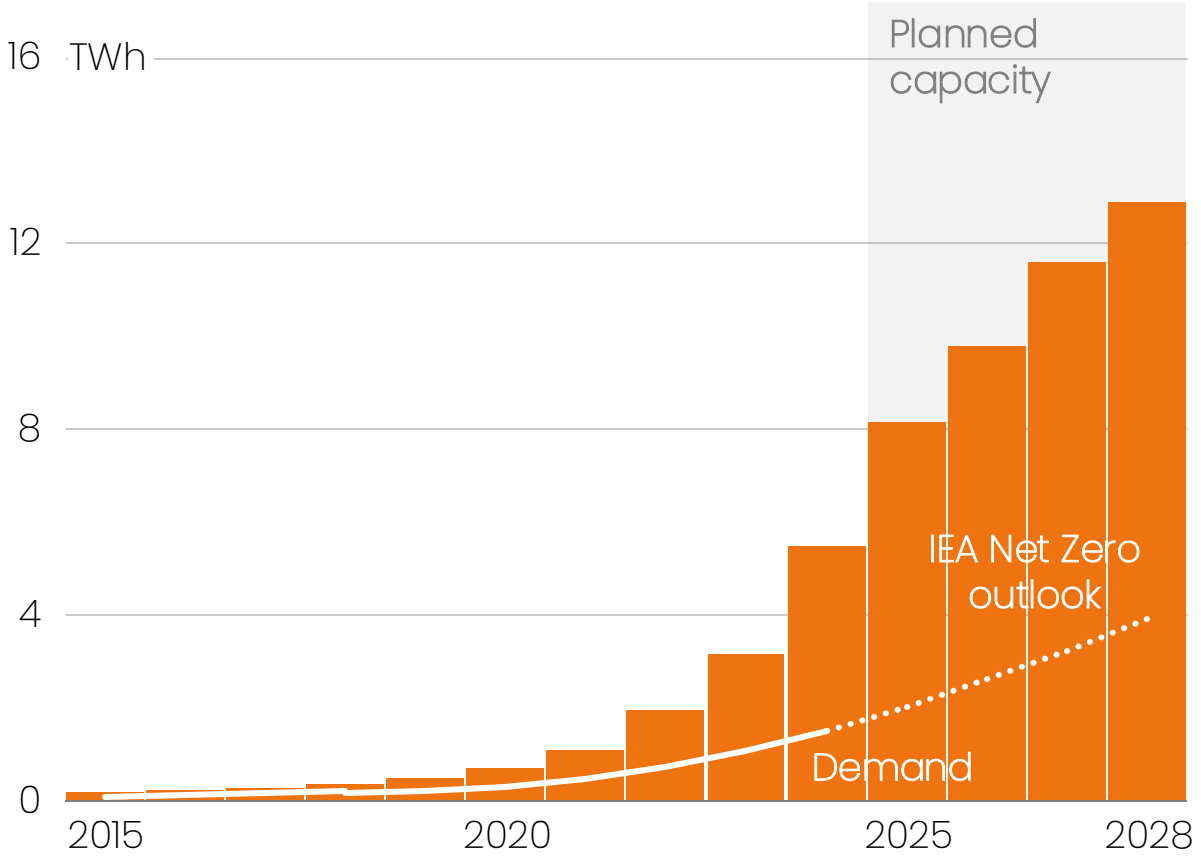
# The manufacturing capacity is in place

Outpacing projected demand of even net zero scenarios

## Solar PV manufacturing capacity




## Battery manufacturing capacity






Sources: IEA; Ember analysis. The IEA net zero outlook is chosen as an illustration that capacity is above even this level.

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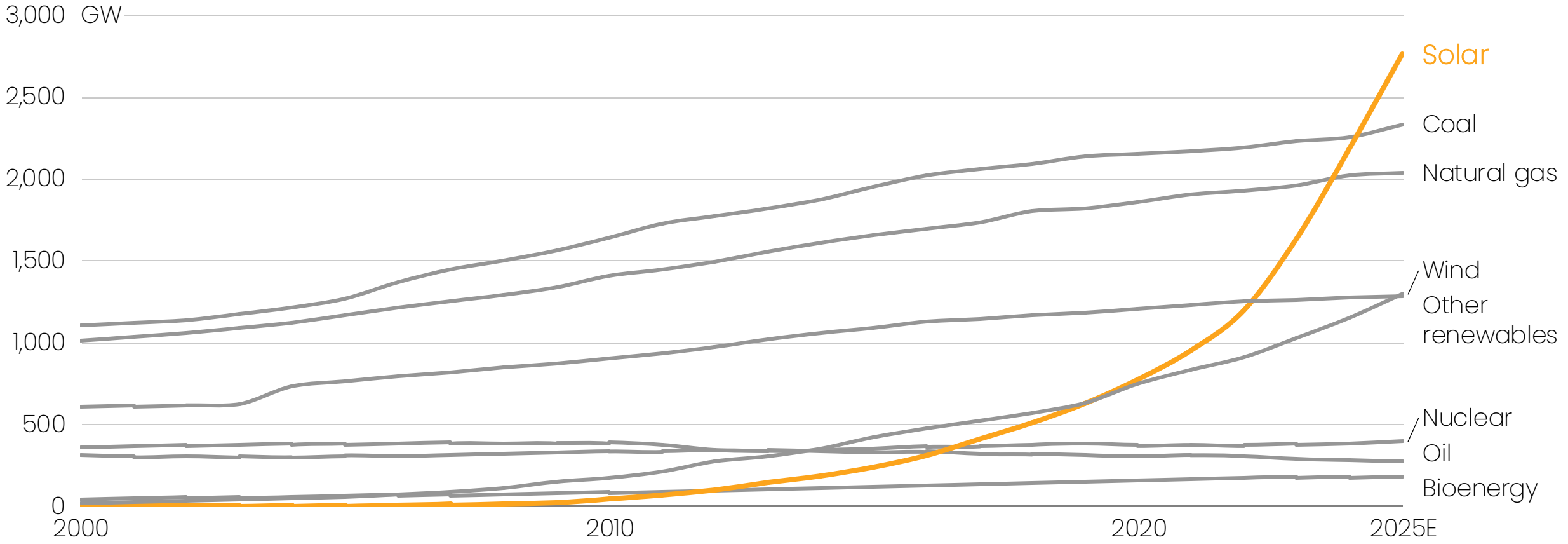
# Sunrise

Solar has gone from smallest to largest source of capacity in 15 years

## Global installed electricity capacity






Sources: BNEF

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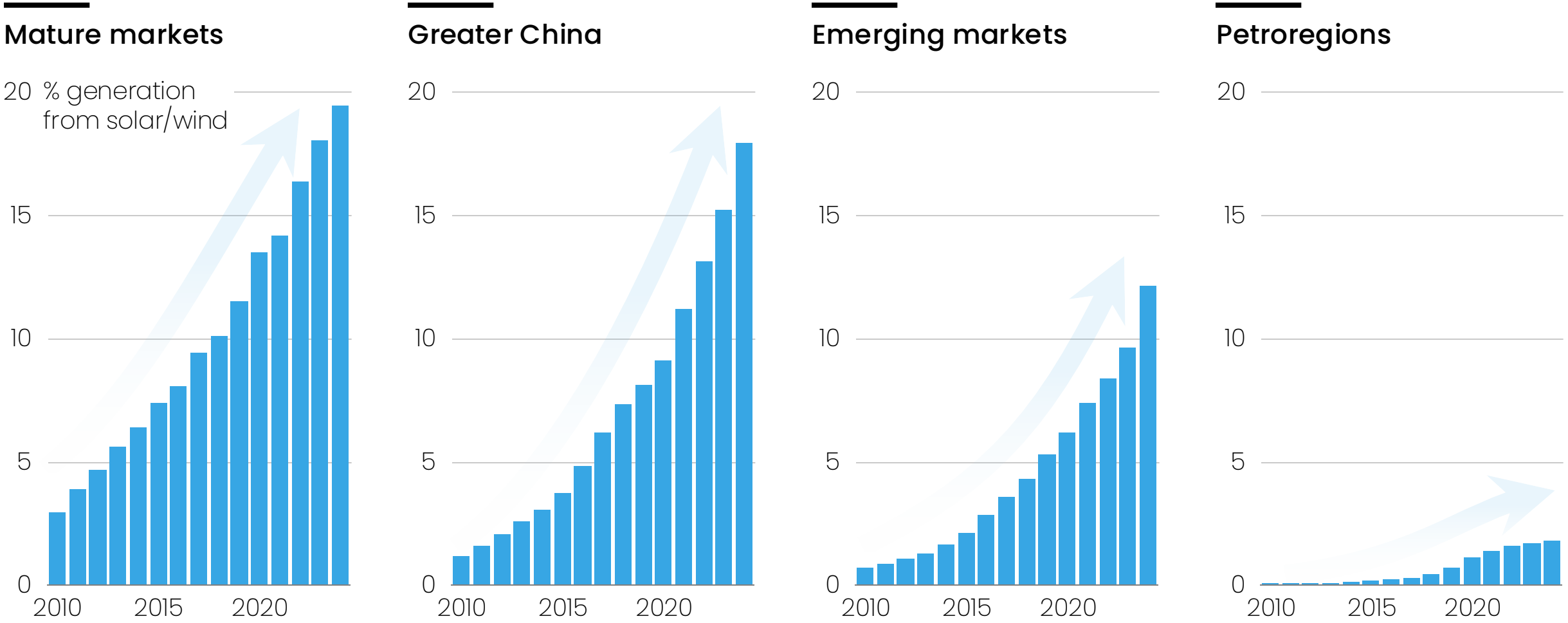
# Solar and wind deployment is a global story

From mature economies to emerging markets




Sources: Ember. Note: Emerging markets include Latin America, Africa, South Asia and Southeast Asia; Petroregions include the Middle East and Eurasia.



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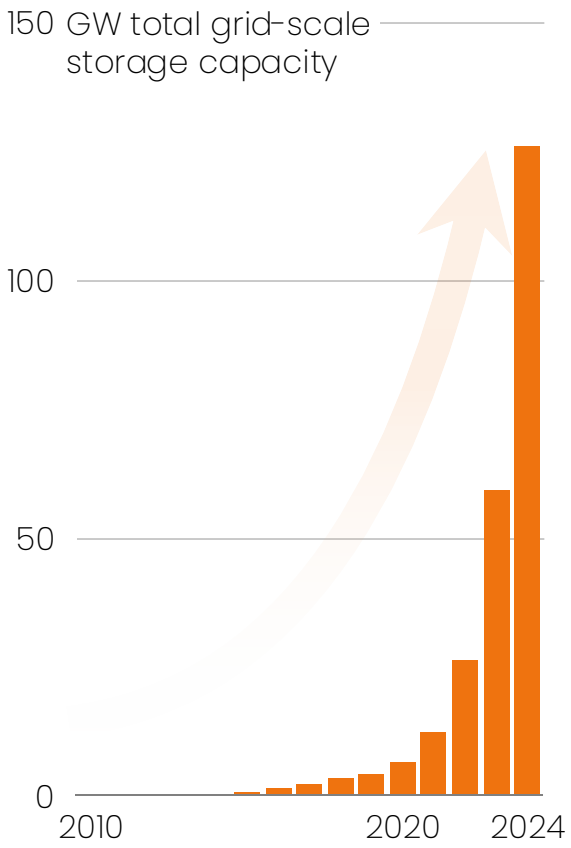
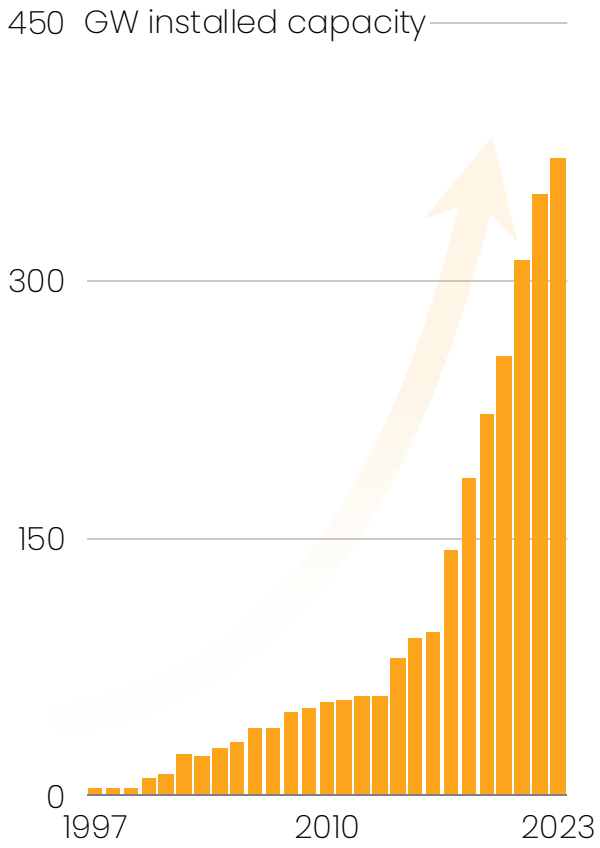
# The rise of new connections

Flextech and gridtech smartly connect supply and demand

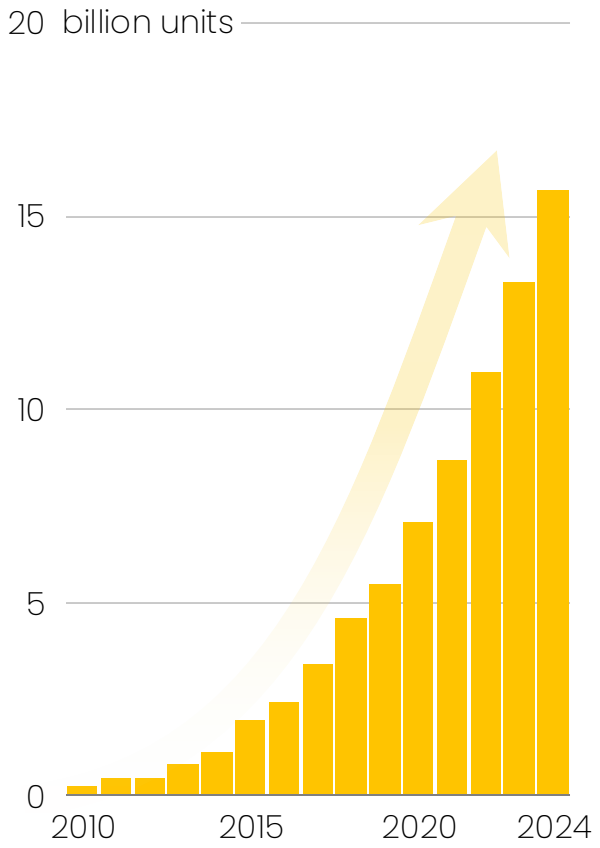
## Battery storage capacity



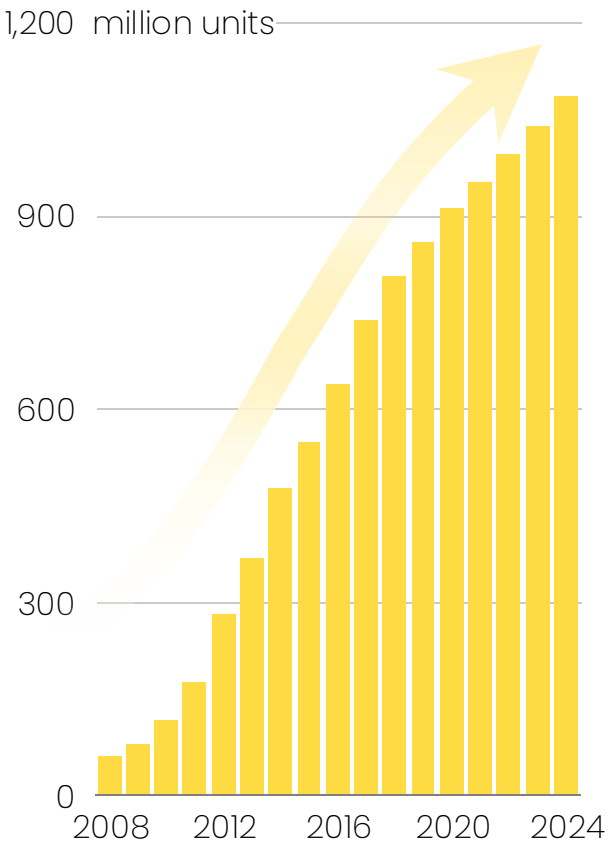

## High voltage DC transmission




## Internet connected devices




## Smart meters installed






Sources: Energy Institute, IEA; Thunder Said; Ember analysis

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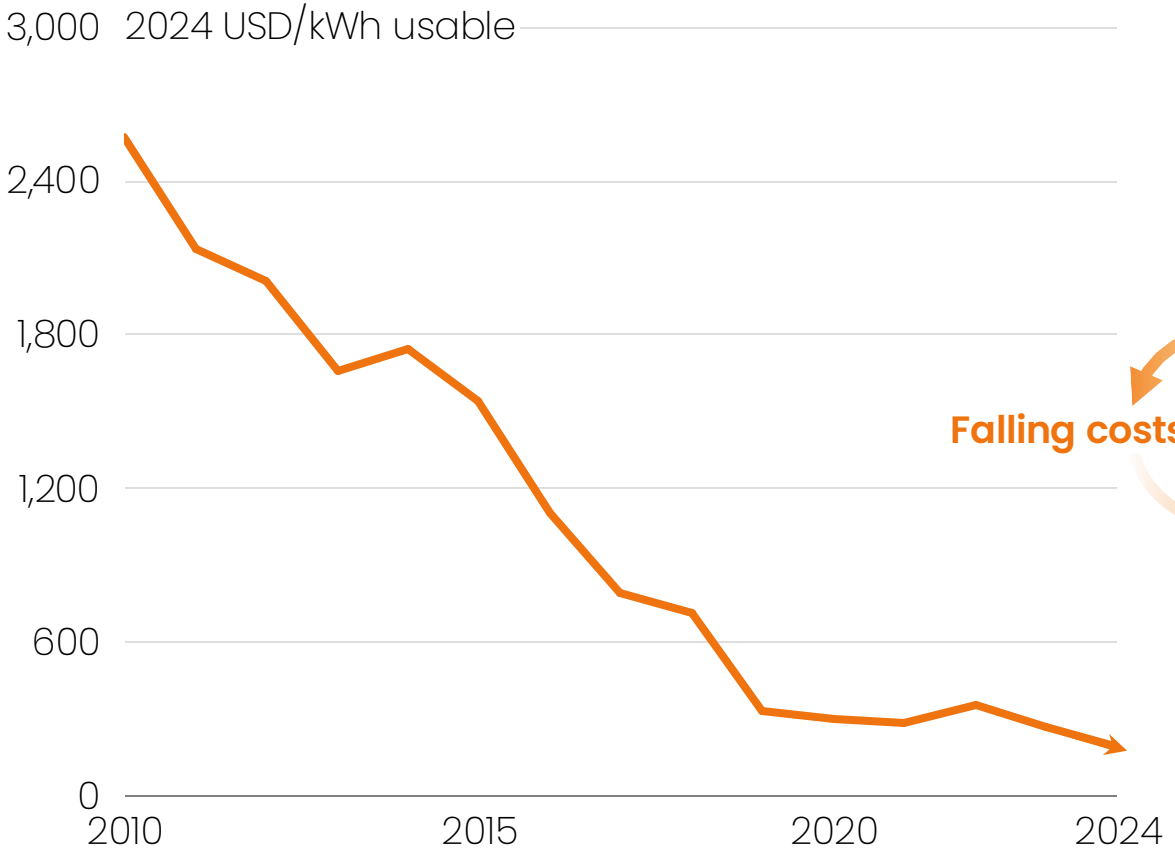
# The cheaper it gets, the faster it goes

The virtuous cycle between cost and volume is self-sustaining

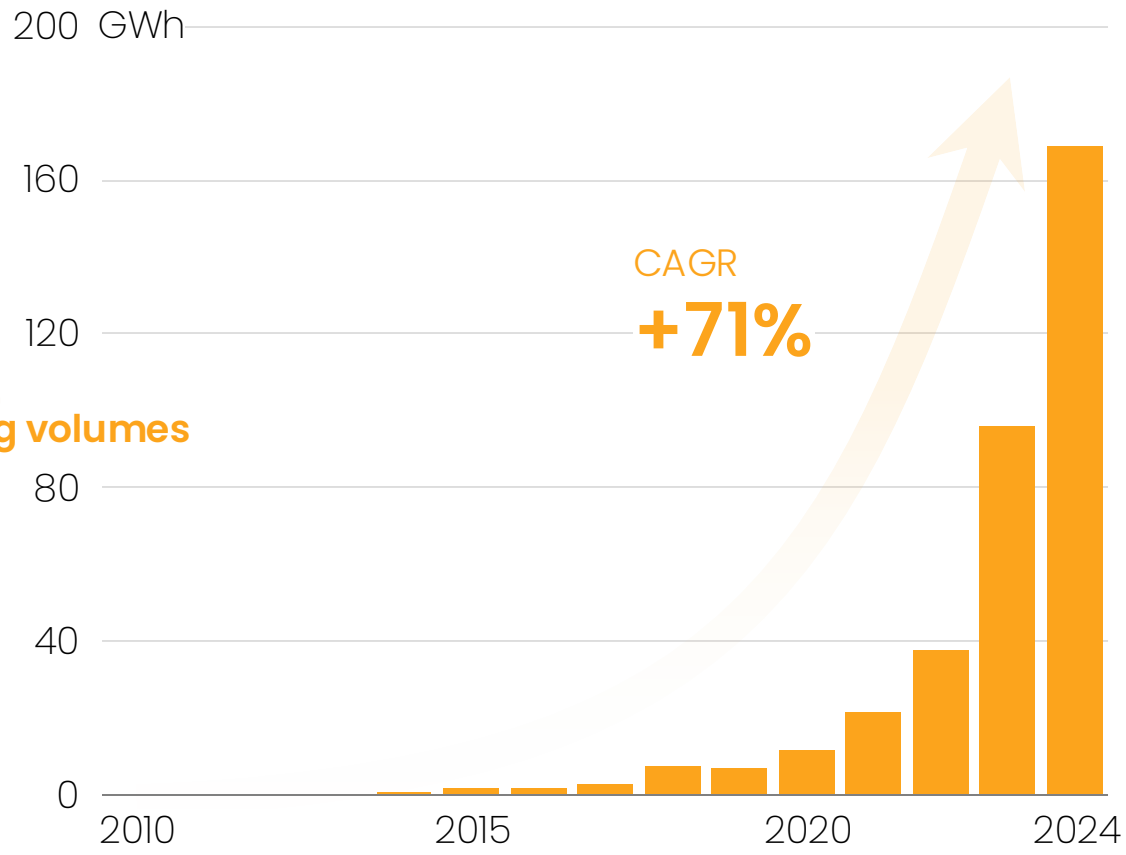
## Utility-scale energy storage cost, global




Falling costs

Rising volumes

## Utility-scale energy storage sales, global






Sources: IRENA, Ember

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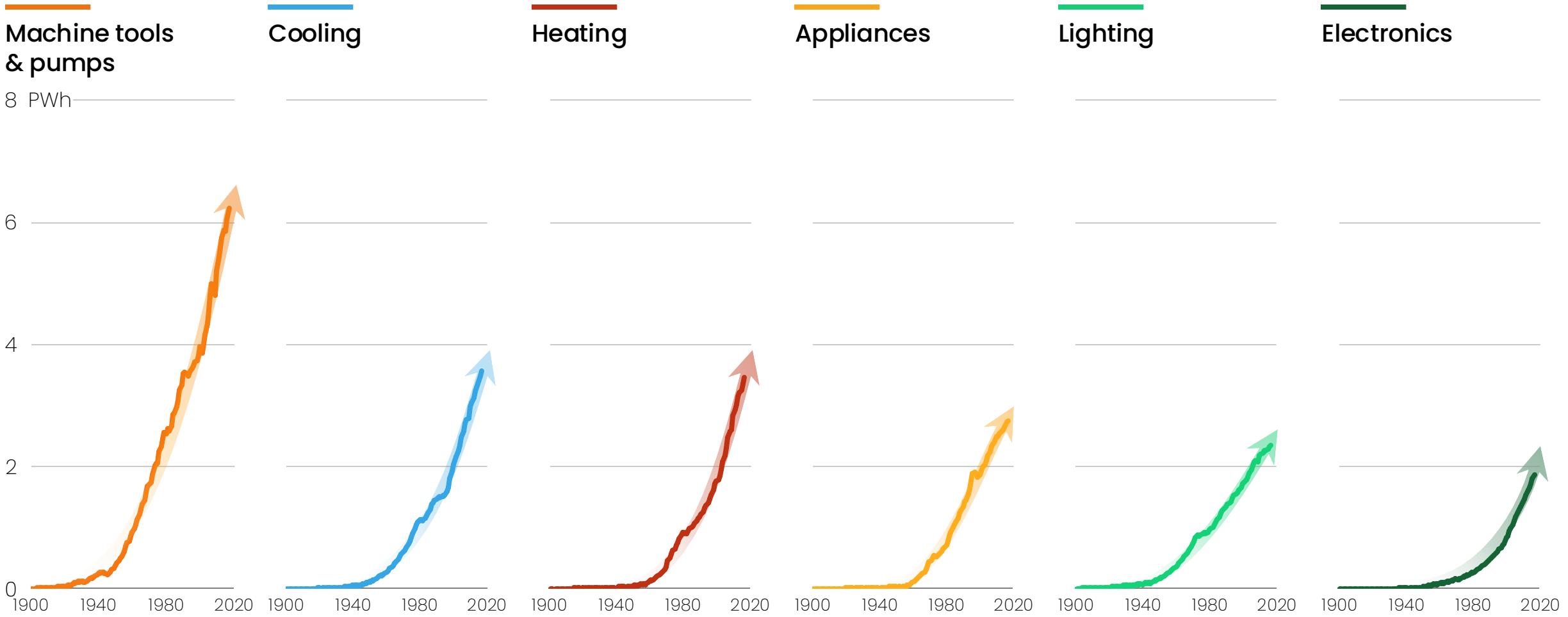
# The long march of electrification

We've been electrifying the global economy for over a century






Sources: Pinto et al, 2023; Ember analysis. Electricity consumption by end-uses.

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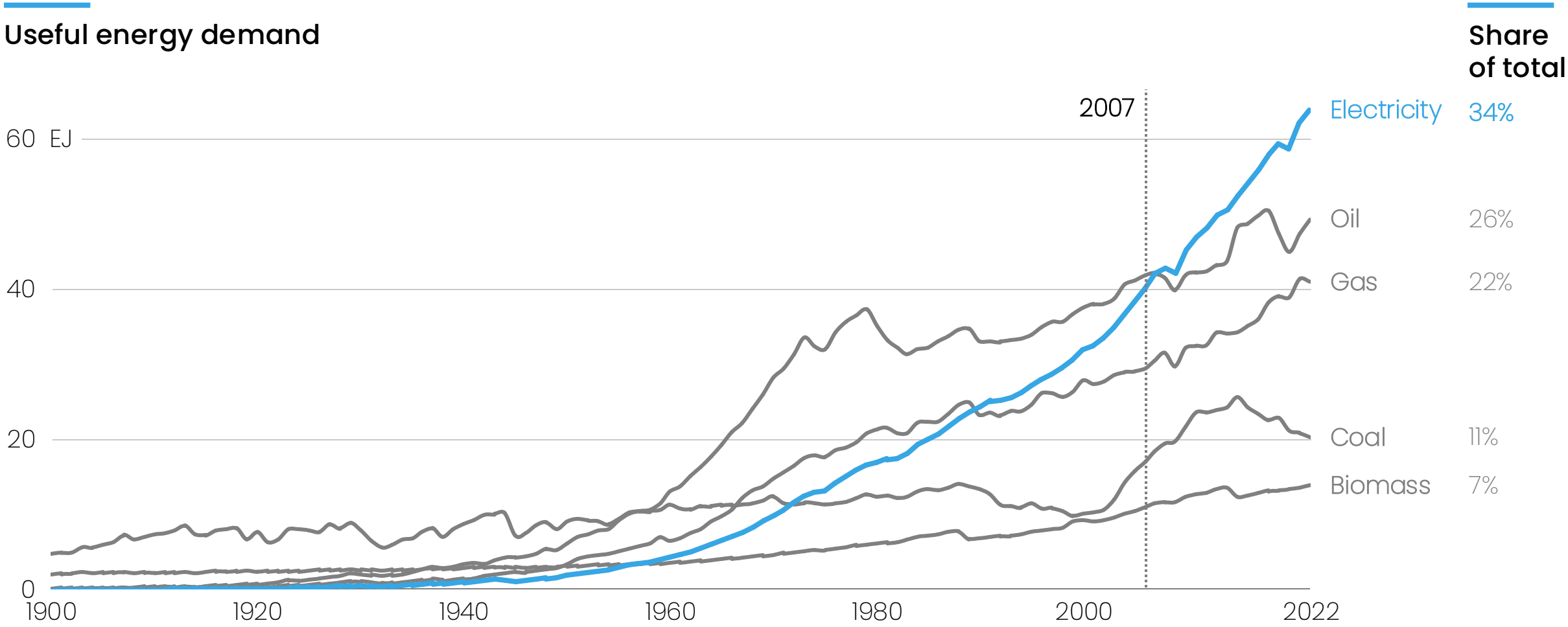
# Electricity is the king of energy

Electricity overtook oil as largest supplier of useful energy in 2007




Sources: IIASA, IEA, Ember analysis. All figures exclude feedstock use. Useful energy demand refers to the amount of energy used to perform a specific task, after accounting for energy losses in the process



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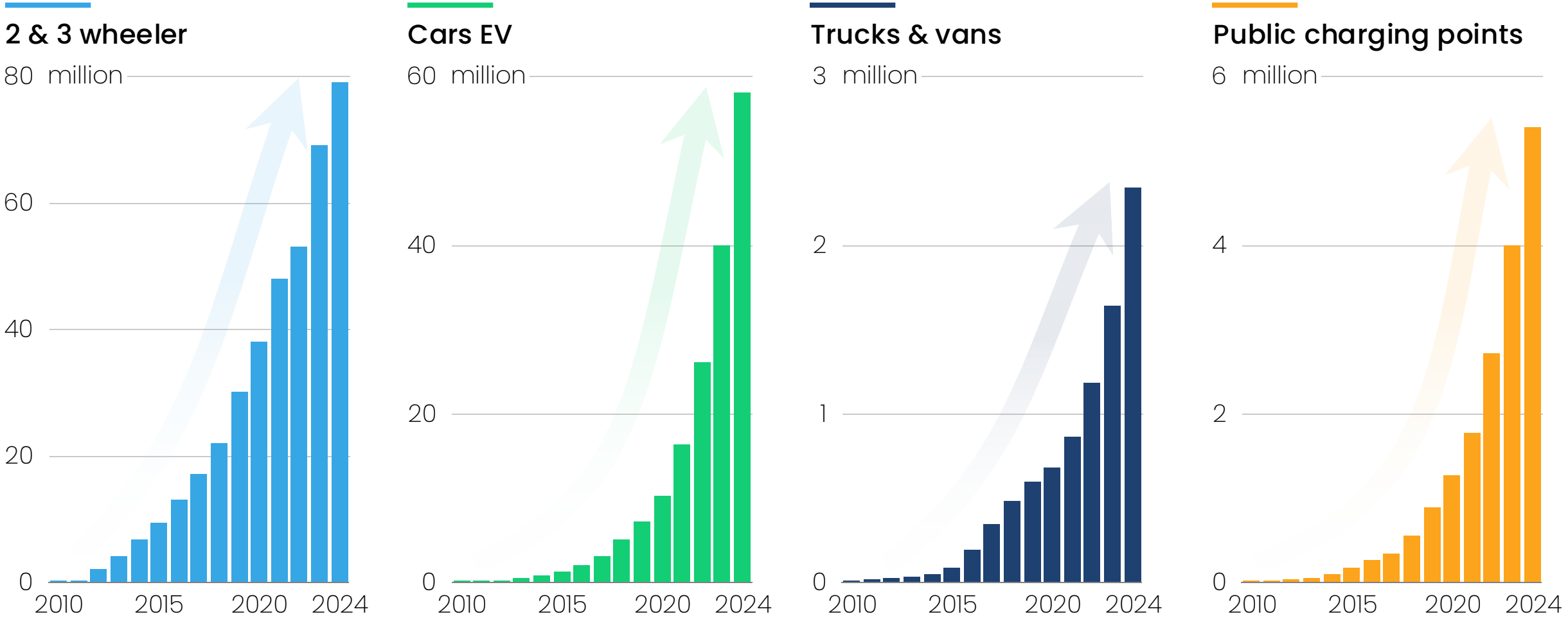
# The EV revolution is taking off

Electric mobility is growing exponentially across vehicle sizes






Sources: IEA. Note these figures are for the size of the fleet

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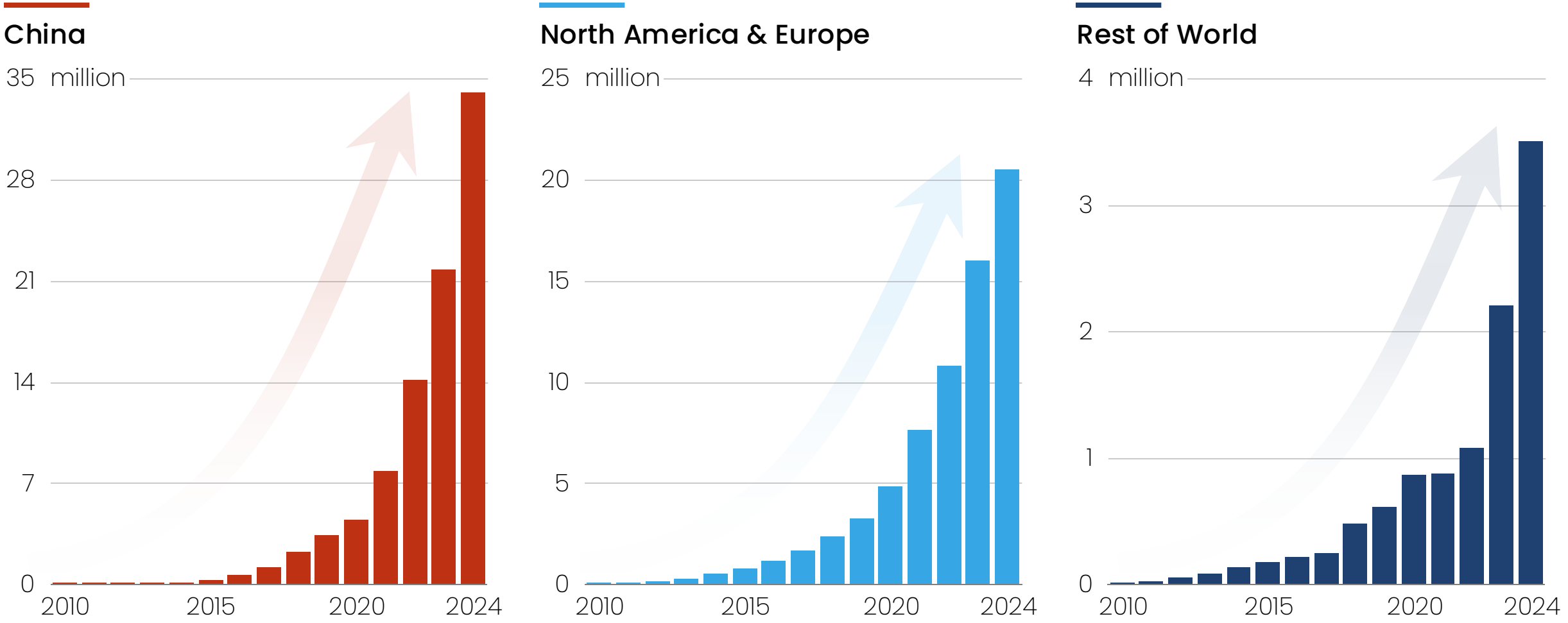
# EV deployment is growing exponentially

Double digit growth across the world






Sources: IEA, Ember analysis – Note: showing total fleet numbers for cars

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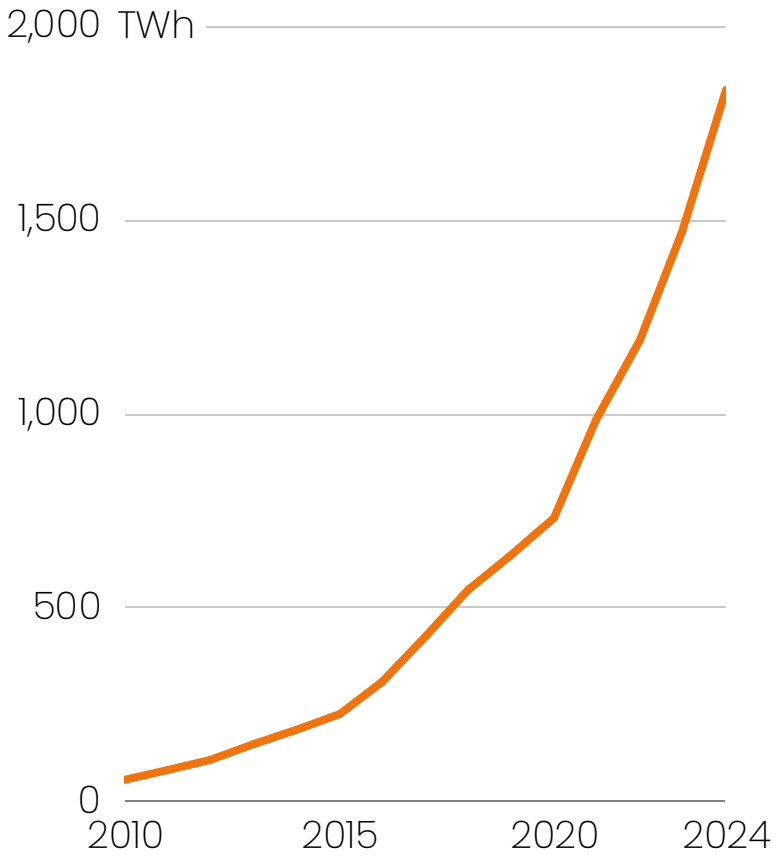
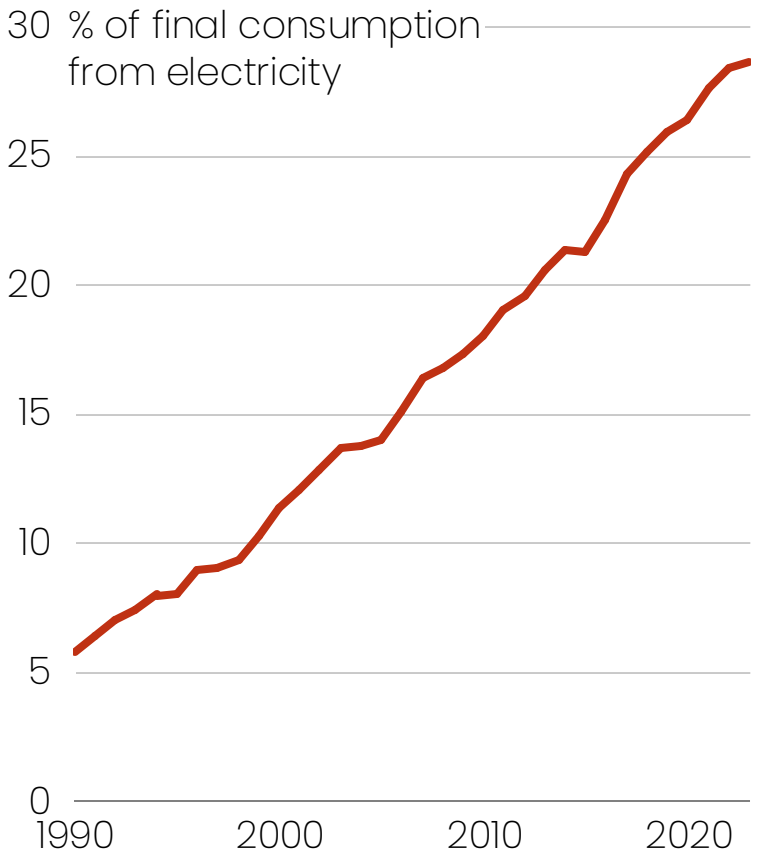
# China is moving at lightning speed

Across renewables and electrification

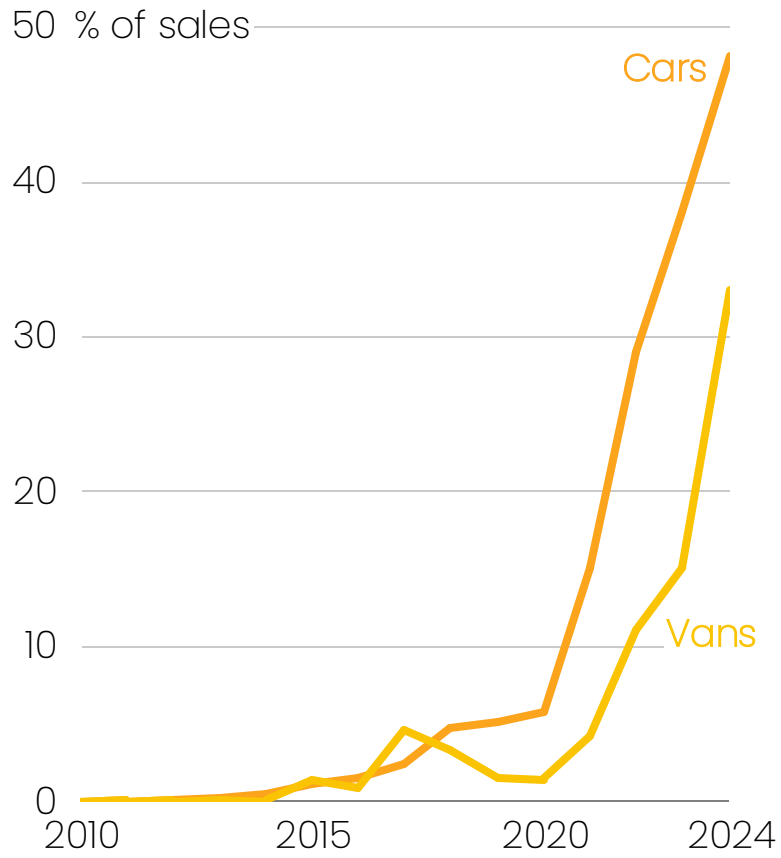
## Solar and wind generation




## Electrification




## Electric vehicles






Sources: Ember, IEA

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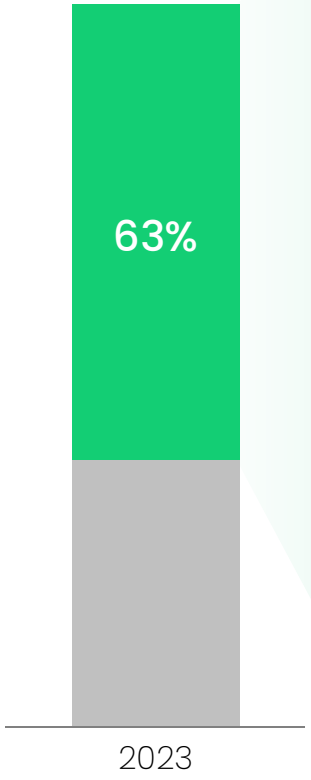
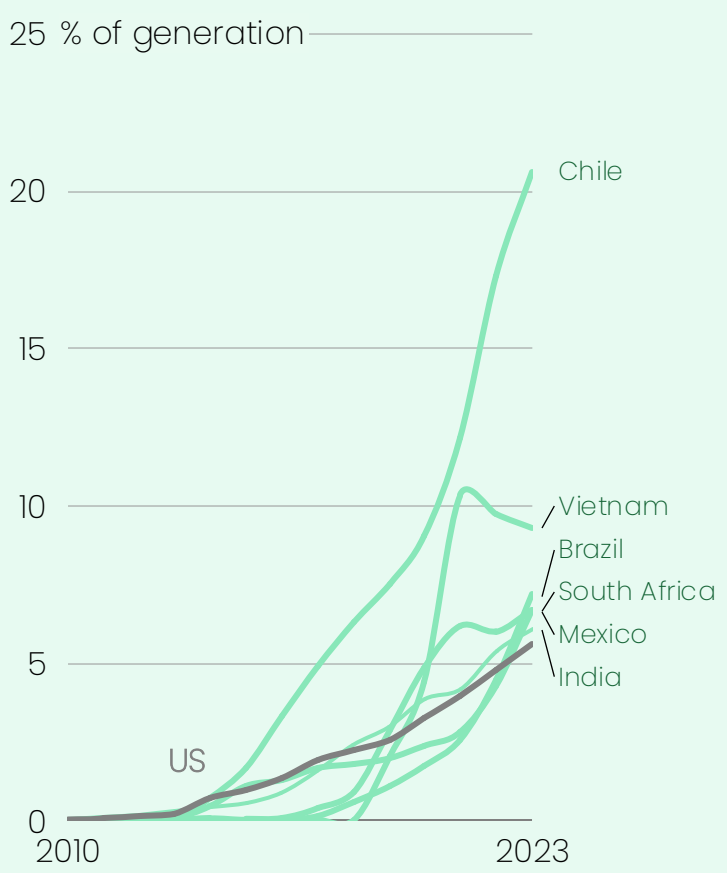
# Emerging markets are leapfrogging

Two thirds are ahead of the US in solar deployment and a quarter in electrification

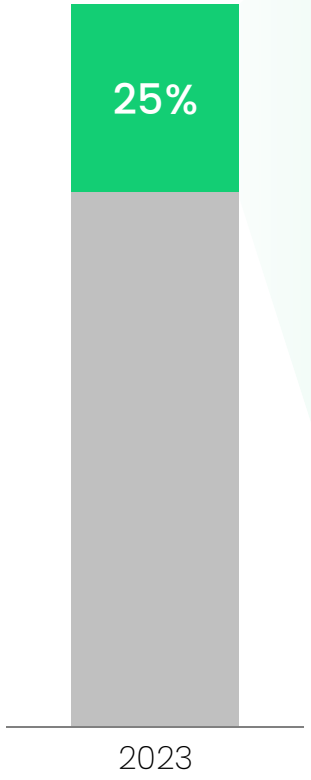
**Share of EM ahead of US in solar uptake**



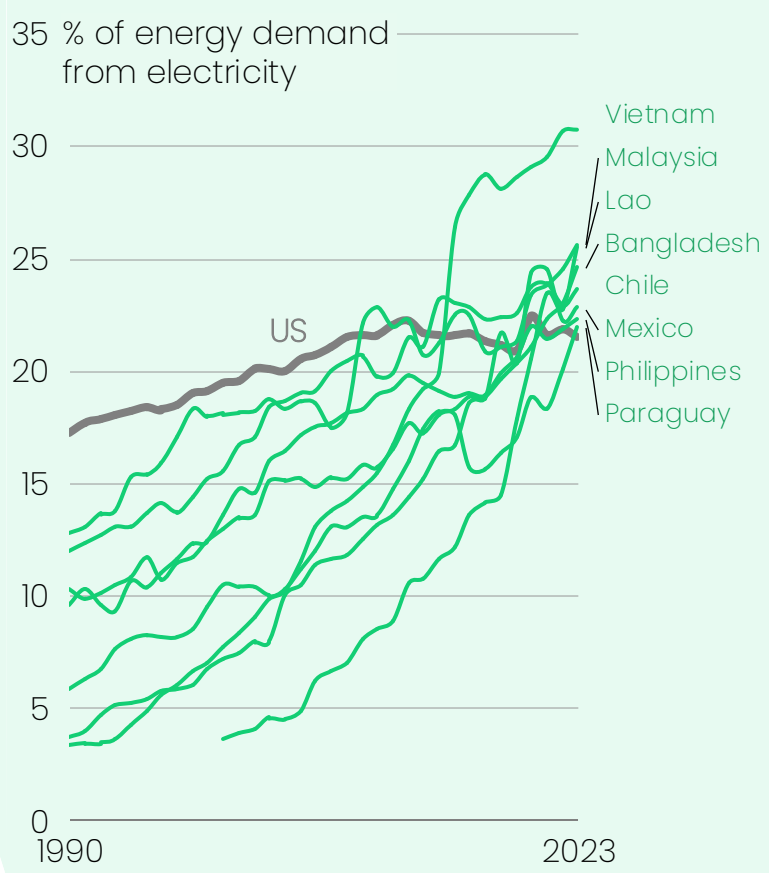

**Example countries**




**Share of EM ahead of US electrification**




**Example countries**




Sources: IEA; Ember analysis – Emerging markets (EM) defined as Latin America, Africa, South Asia and Southeast Asia and do not include the petroregions. Share of emerging markets is a share of electricity demand (l) and energy demand (r).



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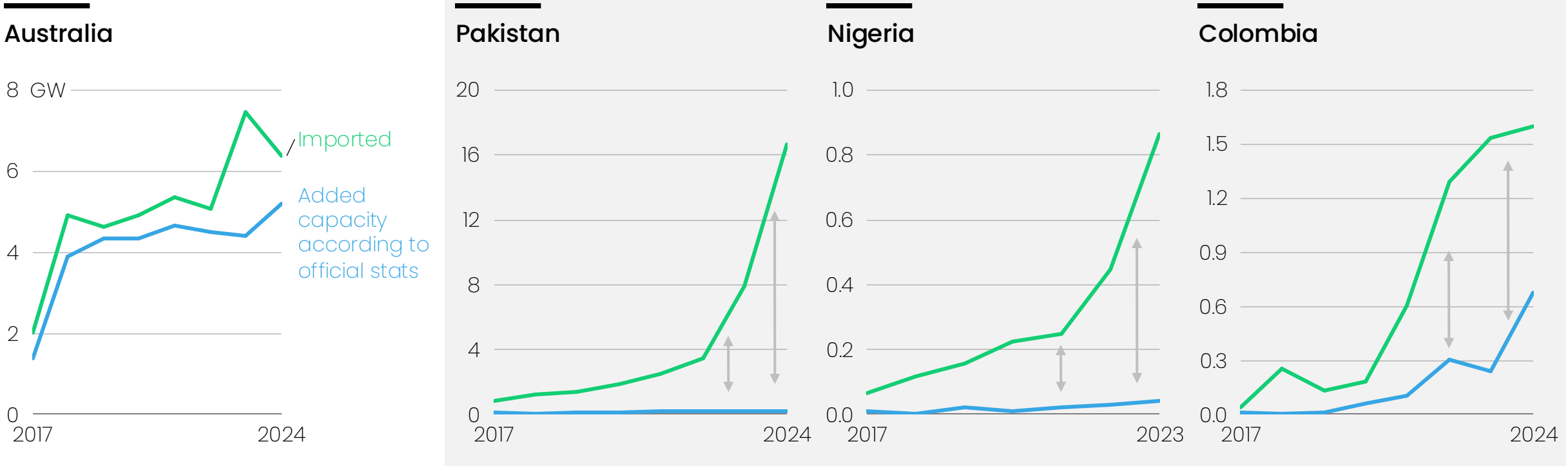
# Change is happening faster than it can be recorded

Central grid statistics cannot keep up with what is happening on the ground

## Solar capacity imported/installed

Imports generally convert to reported installed capacity within a year or so.

Across emerging markets, there is a growing gap between official statistics and import figures, which implies imported solar panels are not centrally connected and counted but installed decentrally.




Sources: Ember data; Ember analysis • Notes: Imported statistics are in DC, while reported capacity is in AC. They should match within the expected inverter clipping ratio.

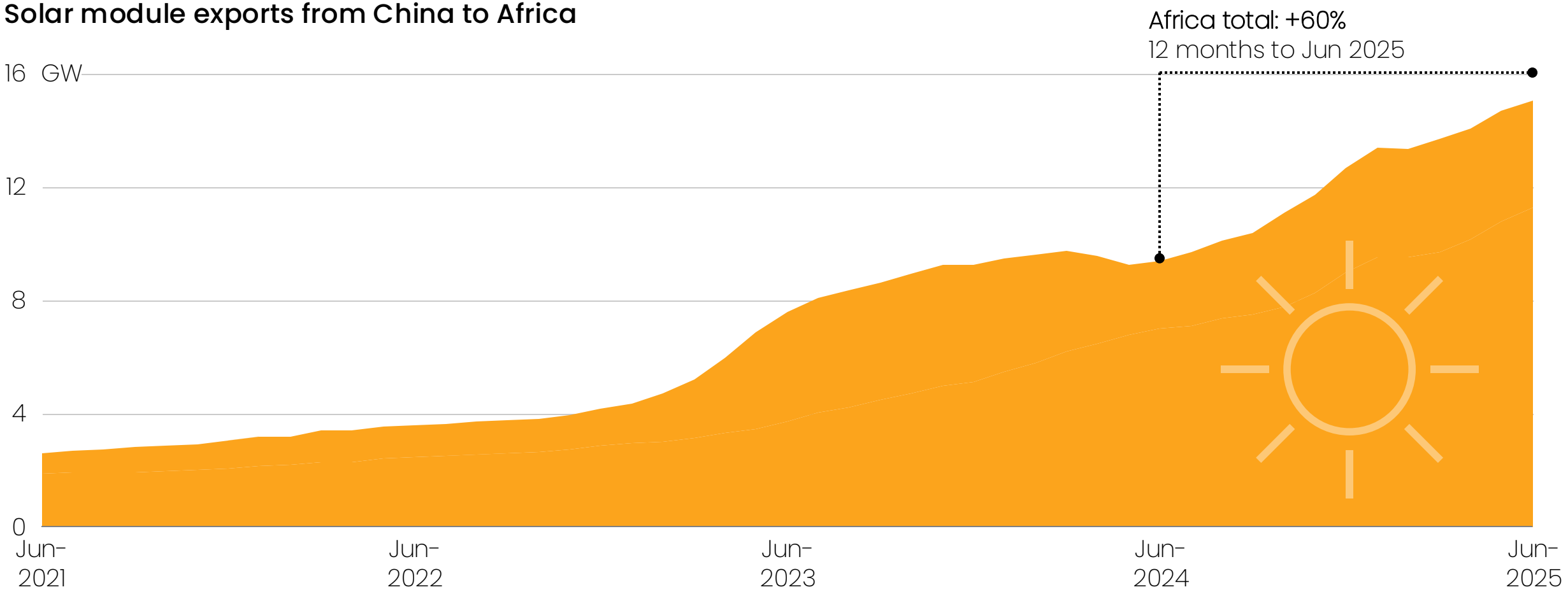


EMBER

# Africa is turning to the sun

Solar imports are up by 60% in the last 12 months

## Solar module exports from China to Africa





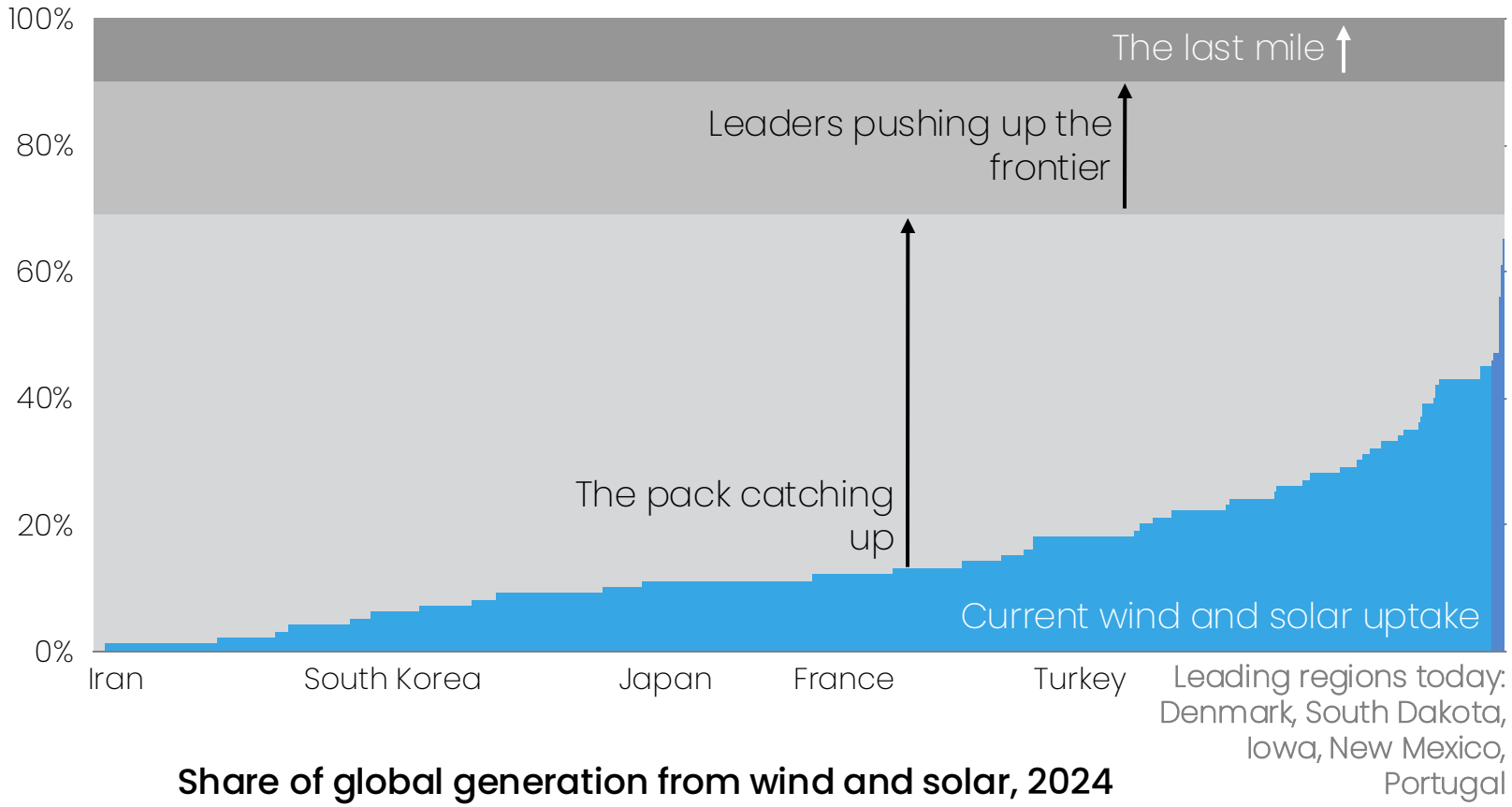

Sources: Ember China Solar Export Explorer

EMBER

# The renewables ceiling is high and rising

Some 70-80% penetration from solar and wind is within our reach today

## Wind and solar share of generation




**Share of global generation from wind and solar, 2024**

## 6 solutions to manage variability

- Demand side flexibility
- Flexible generation
- Smarter grids
- Bigger grids
- Energy storage
- Overbuild solar & wind

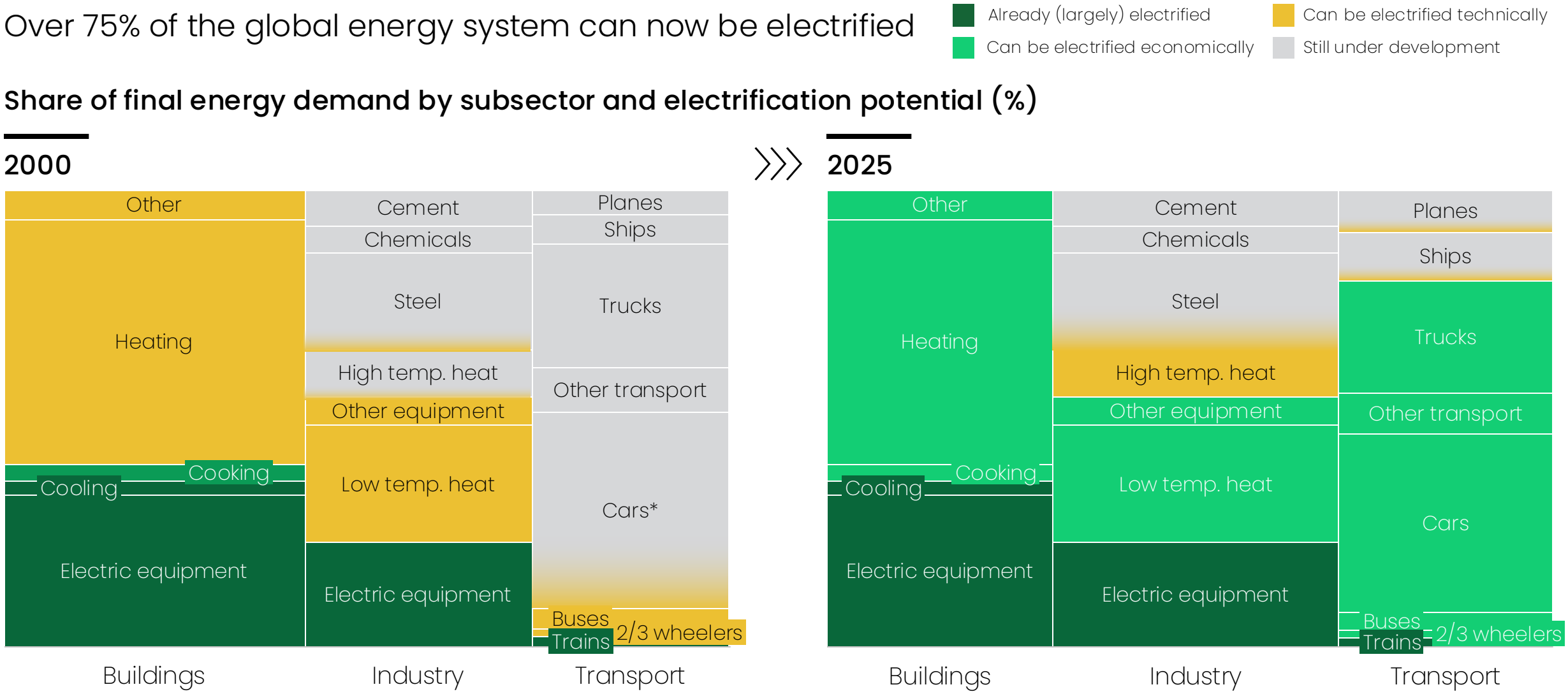


Sources: Ember analysis; ETC – Power Systems transformation

EMBER

# The electrification ceiling is high and rising

Over 75% of the global energy system can now be electrified



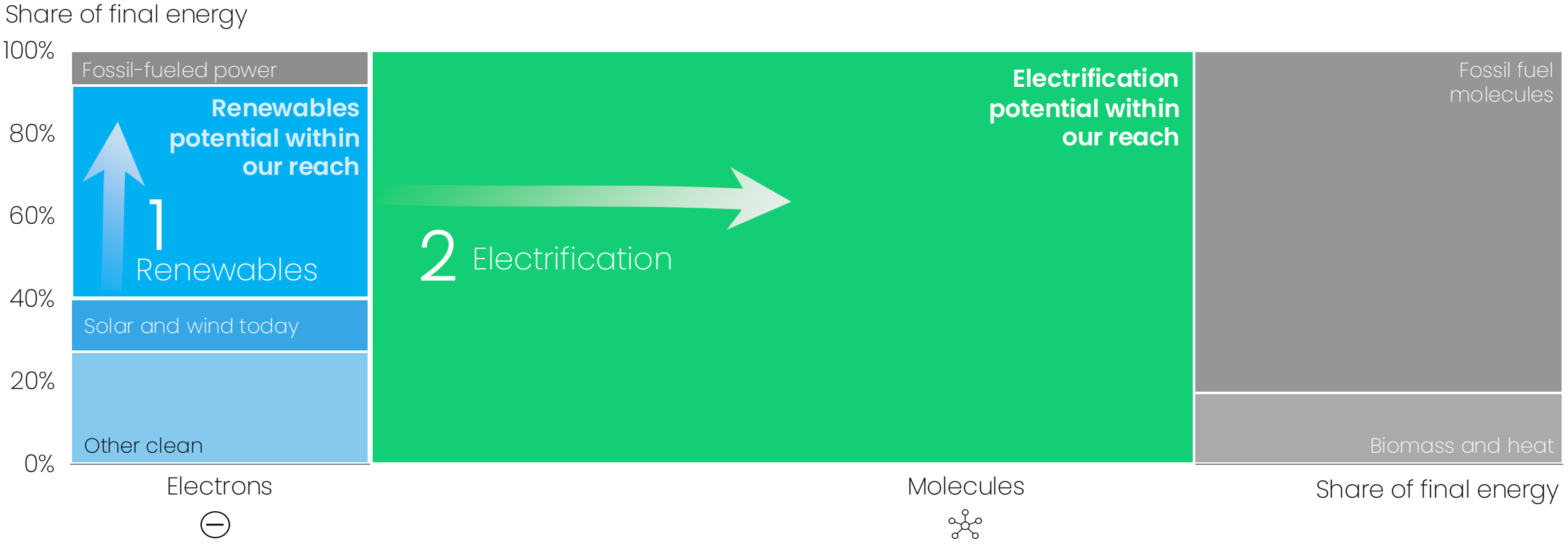



Sources: IIASA; IEA; BNEF; Ember analysis • Note: excluding feedstock *Technologies available for subset of total end-use with a clear path to expansion

# The majority of the energy system is within reach

Renewables and electrification can triple

## Global final energy demand in 2023






Sources: IEA, Ember – Note: Renewables potential includes solar and wind as well as other sources

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# Chapter 3
# Peak fossil demand

## 01

### Peak fossil demand for electricity

The rapid growth of solar and wind enables them to take a rising share of the growth in electricity demand, with 64% of the growth since 2018. In half of the world we have already seen peak fossil fuels for electricity, and initial indications for the first half of 2025 are that China has also peaked.

## 02

### Peak fossil demand for final energy

Peaks are cascading from one area to the next. Fossil demand has been flat for industrial energy since 2014, for buildings since 2018, and for road transport since 2019

Meanwhile two thirds of the world has already seen peak fossil demand for final energy.

## 03

### Peak China means peak global fossil demand

Fossil demand for final energy reached a peak in China in industry in 2012, in buildings in 2017, in transport in 2021, and in electricity in H1 2025. As a result total emissions are down by 1% year on year. Meanwhile, China is the pivot nation, as it accounted for 95% of the net growth in fossil fuel demand since 2018. As a result, a Chinese peak implies a global peak.

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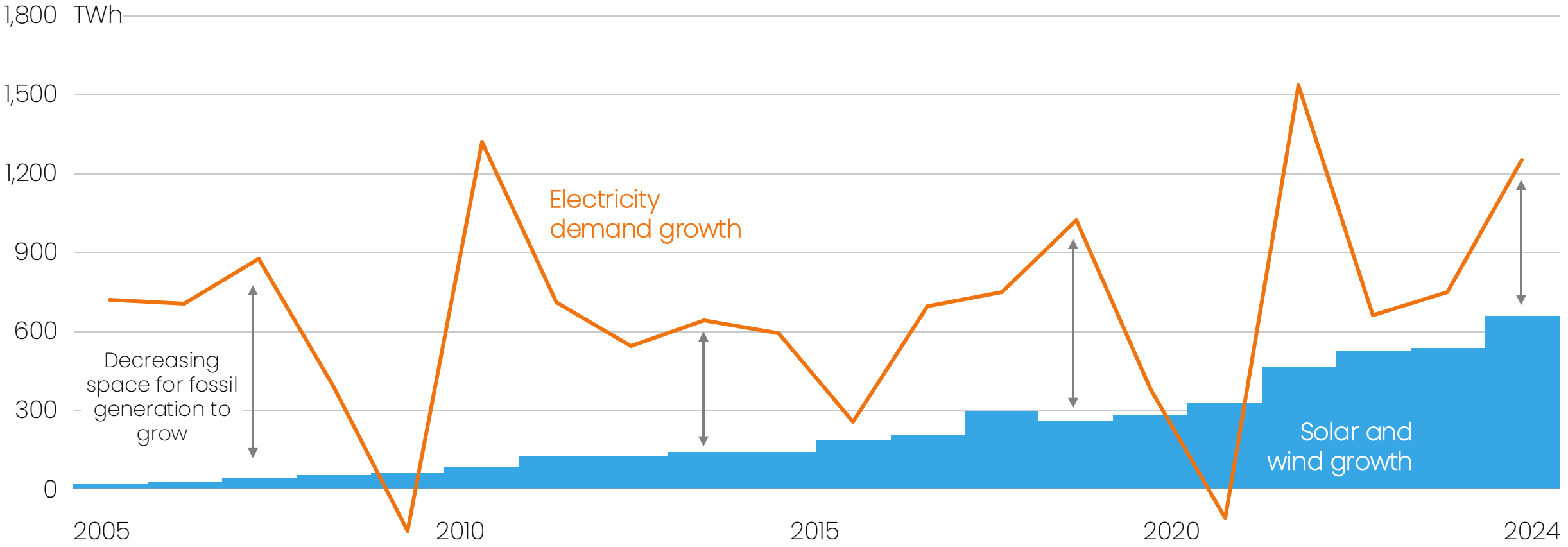
# No space for fossils to grow in electricity

Solar and wind are about to take all the growth

## Annual change in electricity generation






Source: Ember

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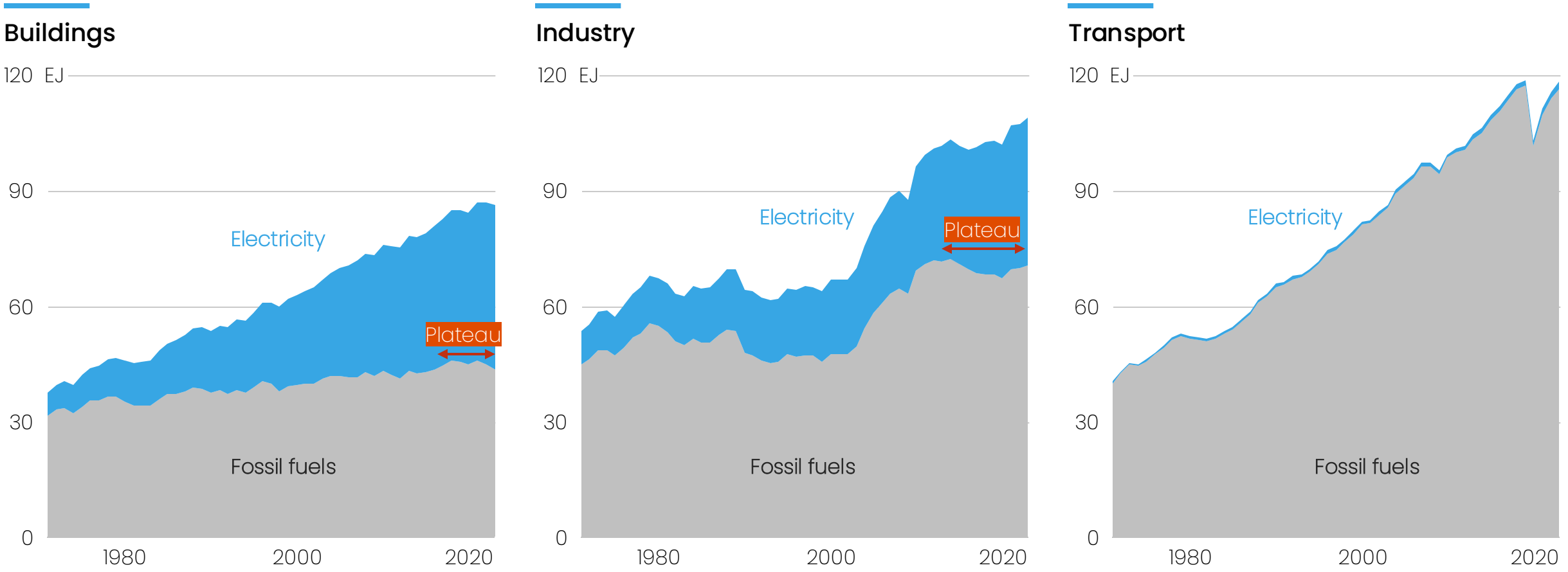
# Electricity is taking all the growth in final demand

Peak fossils in industry was 2014 and in buildings was 2018

## Final energy demand by sector






Sources: IEA WEB; Ember analysis. Note non-energy demand (42 EJ with growth of 1-2% pa) sits outside of industry in IEA WEB.

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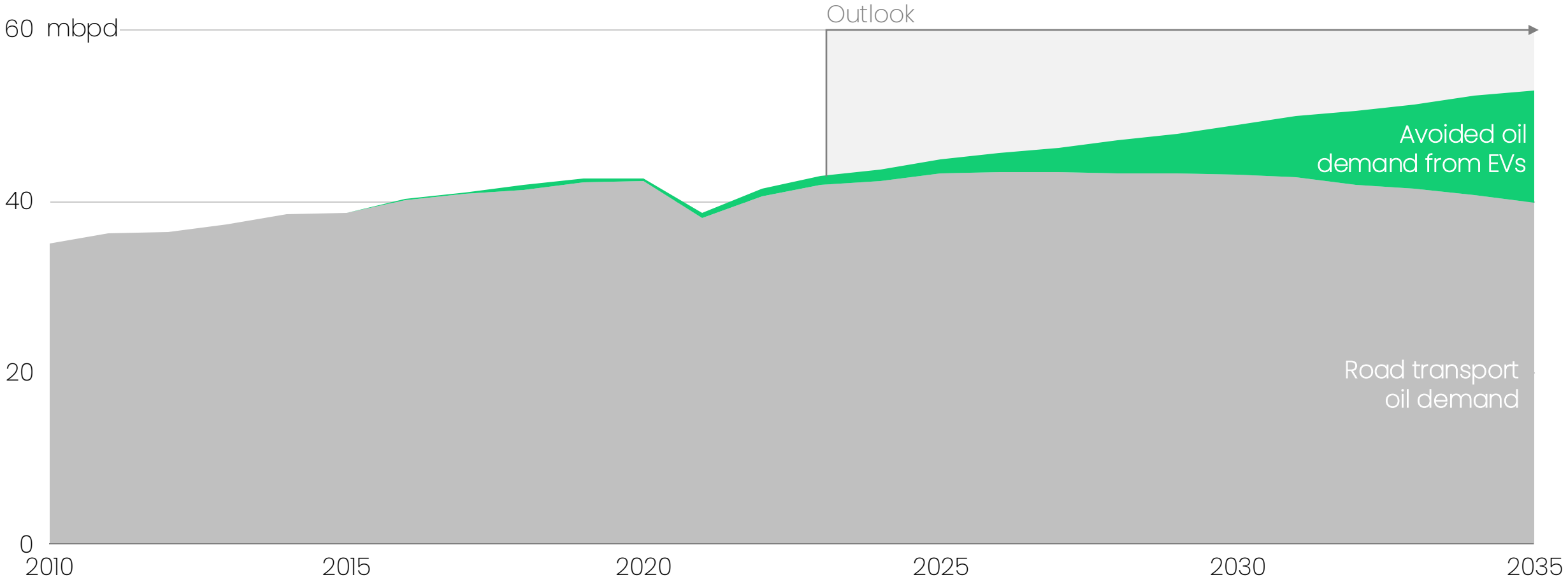
# EVs are driving a plateau in road transport

And road transport is 75% of transport energy demand

**Oil demand in road transport in the IEA STEPS scenario and savings from EVs, 2010-2035**






Sources: IEA WEO 2024 STEPS scenario – Note: STEPS is the IEA's most conservative scenario

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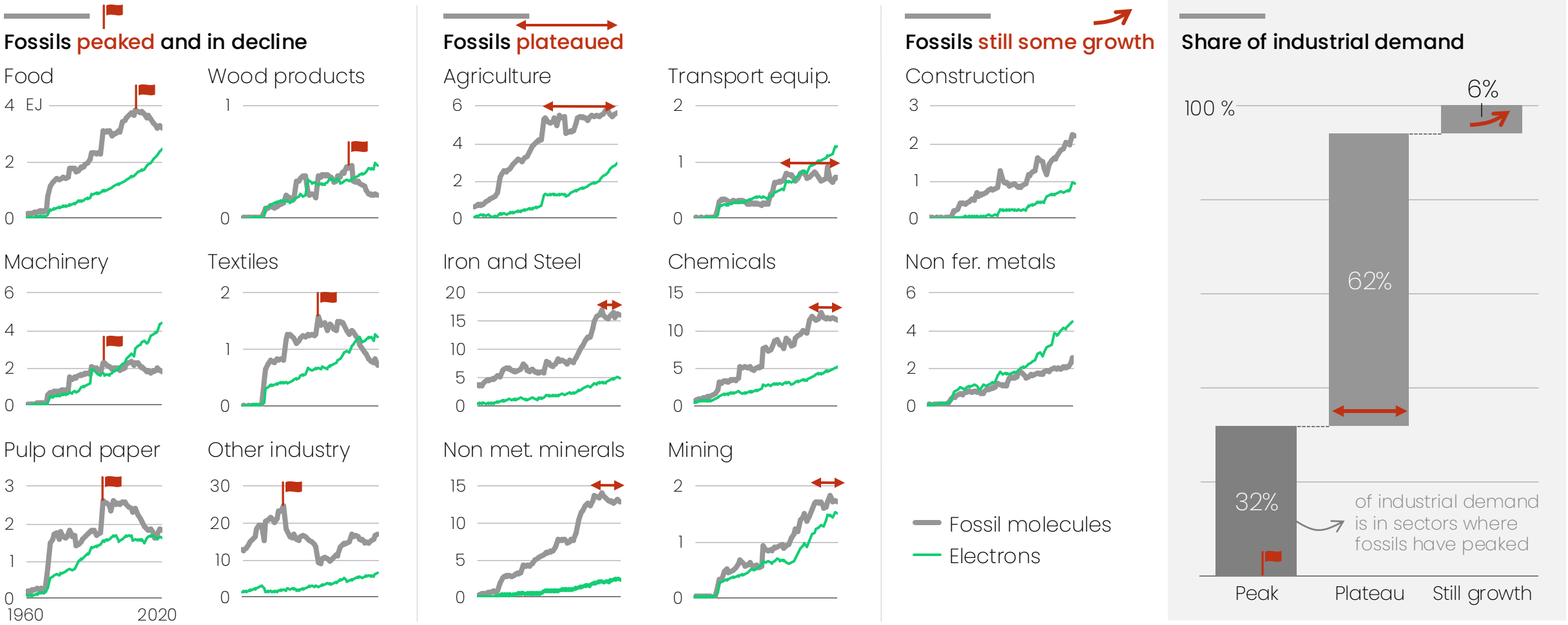
# Industrial peaks everywhere

Only 6% of energy demand comes from sectors which still have structural fossil growth






Sources: IEA WEB; Ember analysis. Note: Feedstock demand of 42 EJ is not included in the industrial sector in IEA WEB

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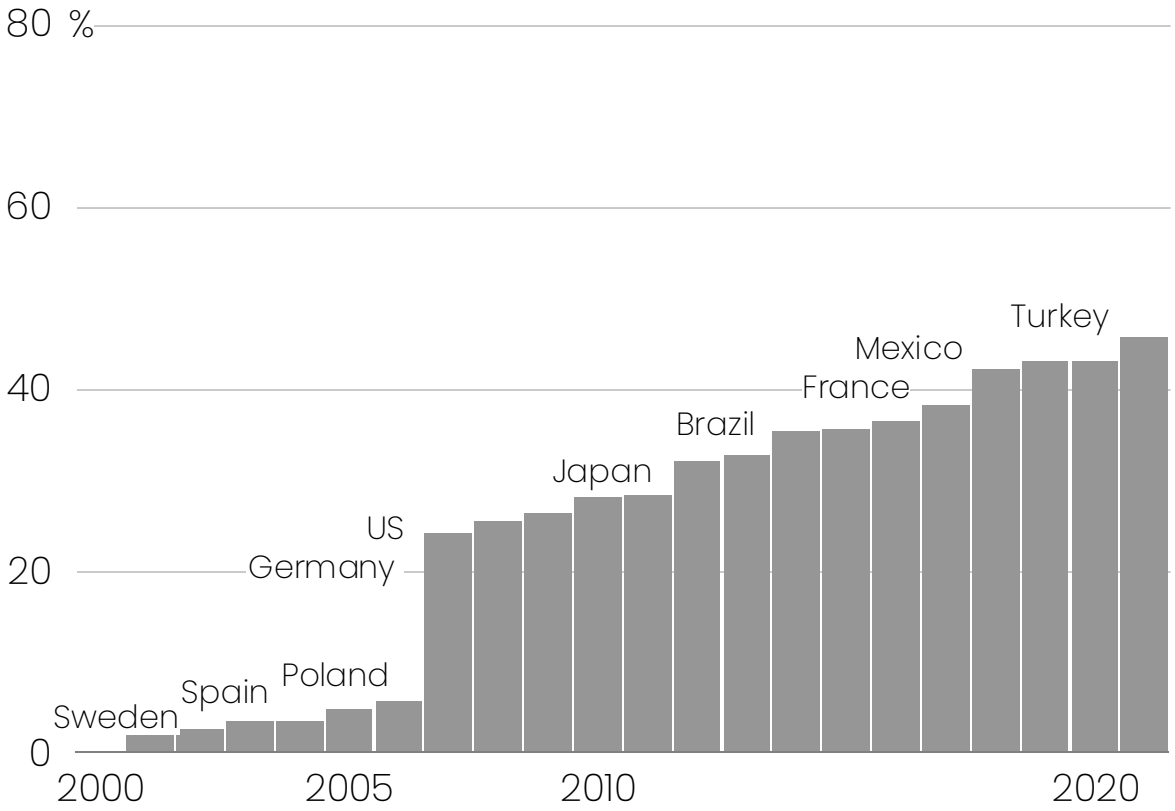
# Most of the world is past peak fossil fuels

Two-thirds of the world is past peak fossils in final energy and nearly half in power generation

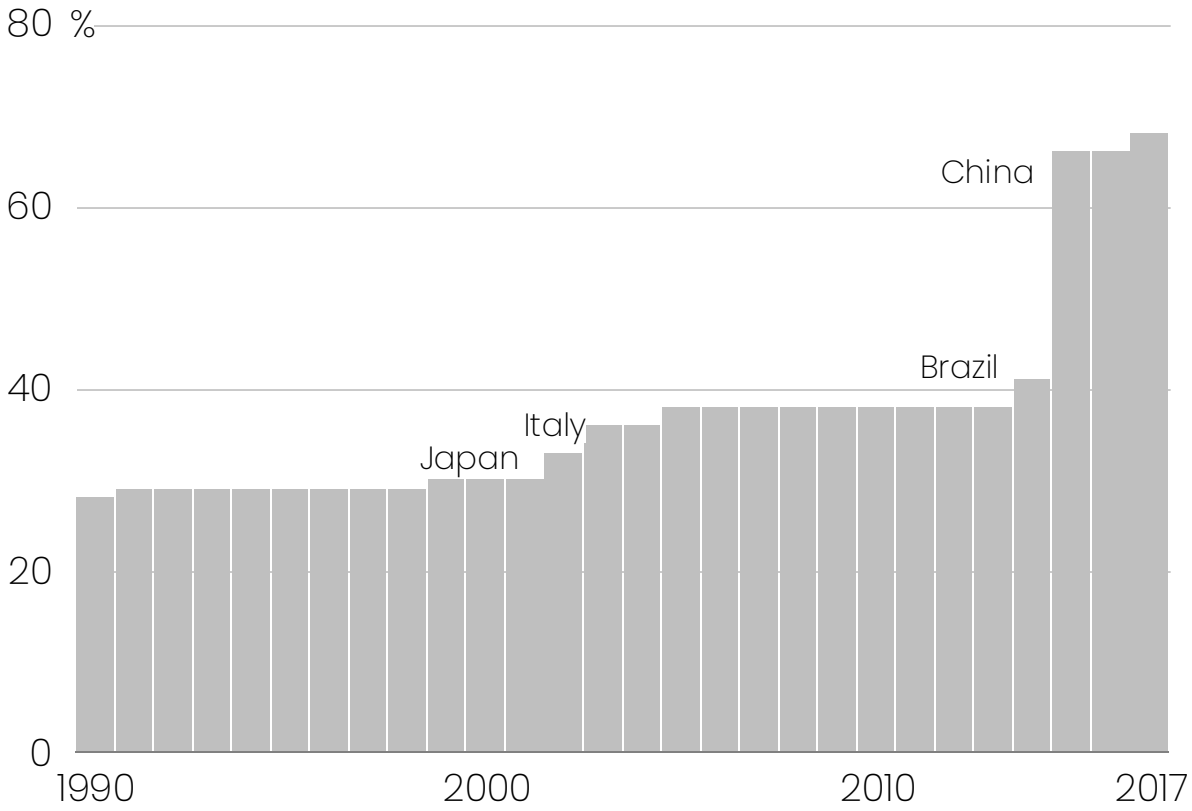
**Share of the world past peak fossil demand for electricity**

Driven by clean power and efficiency




**Share of the world past peak final fossil energy demand**

Driven by efficiency and electrification






Sources: Ember. Share of world measured in 2023 energy. Final energy excludes non-energy.

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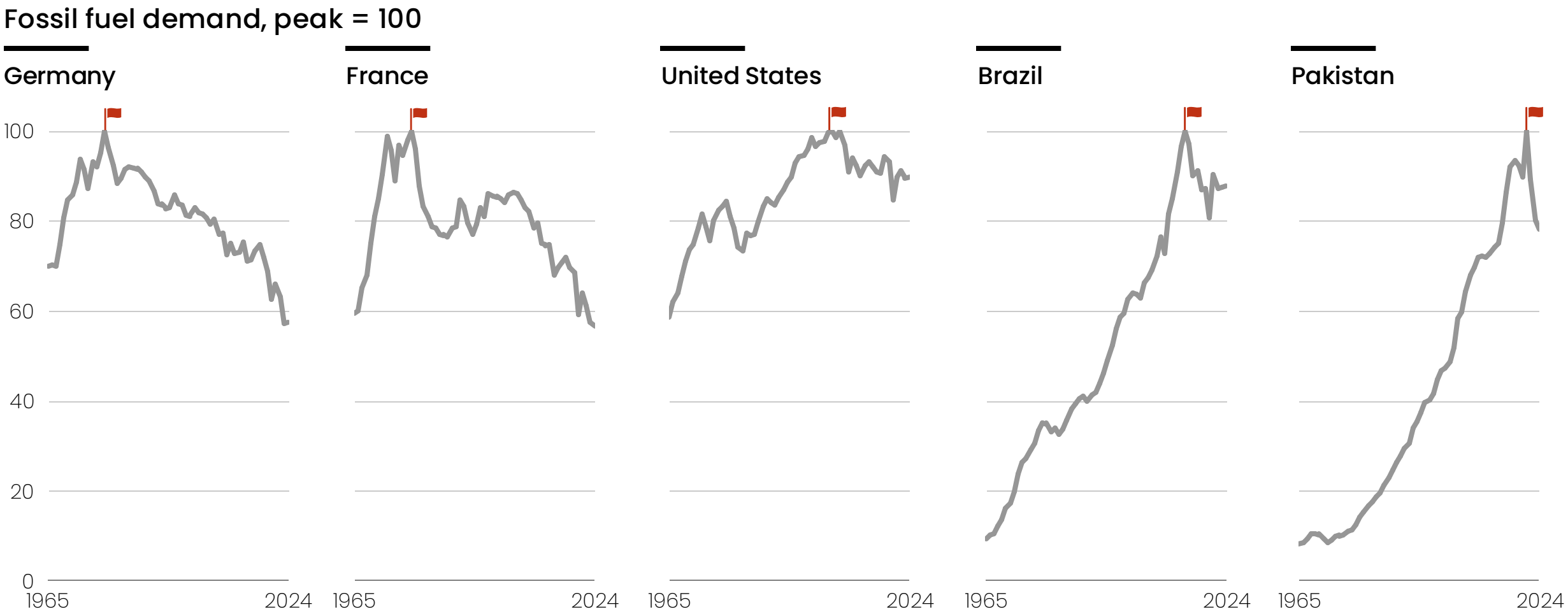
# After the peak comes the fall

Countries don't have long plateaus although the world does





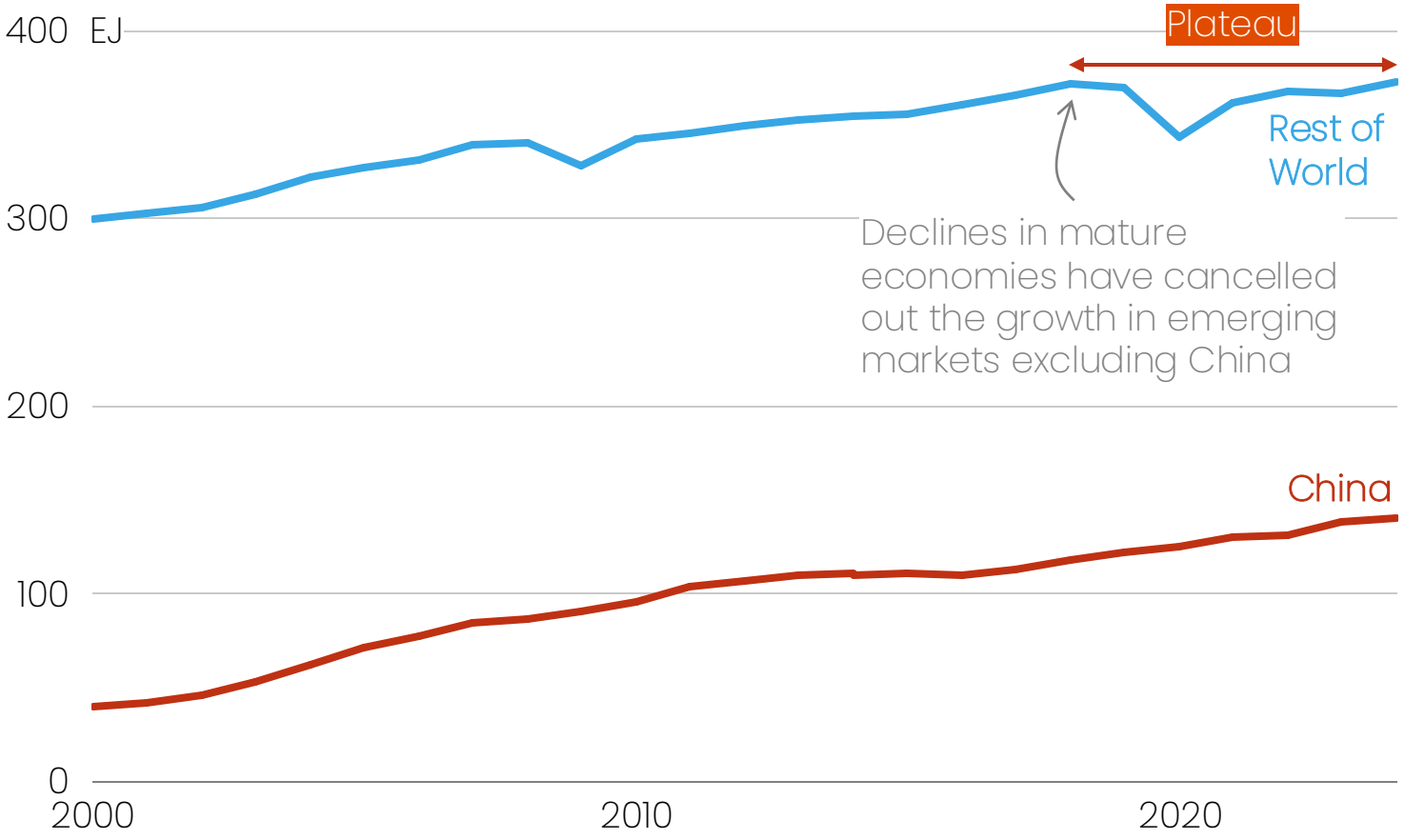

Sources: Energy Institute; Ember analysis

EMBER

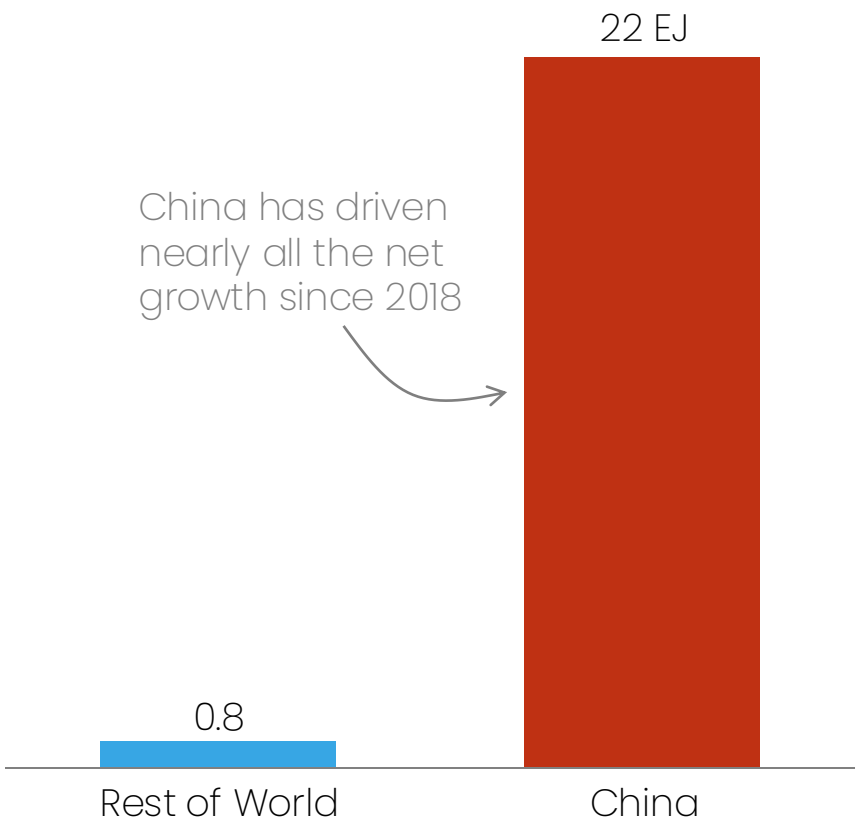
# China is the pivot nation

Fossil fuel demand has already reached a plateau outside China

## Primary fossil fuel demand




## Change in fossil fuel demand 2018-2024





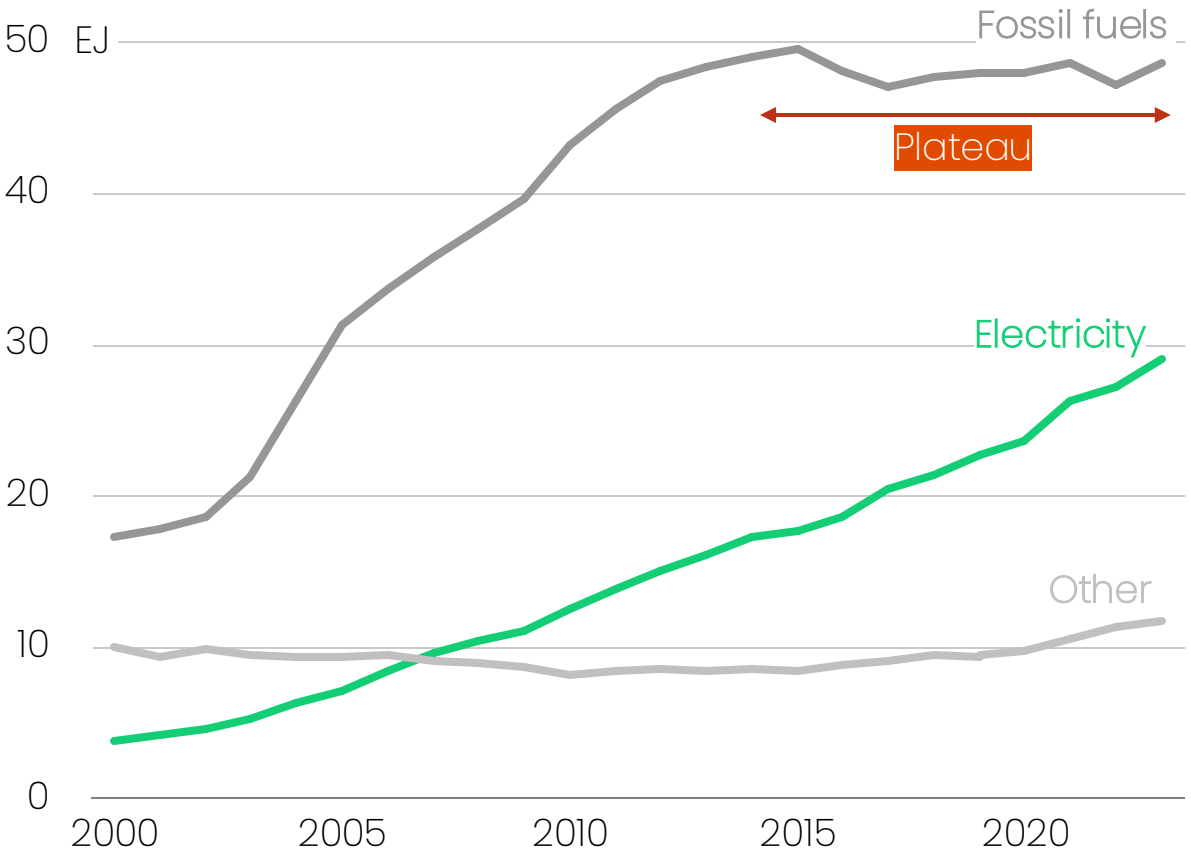

Sources: Energy Institute, Ember analysis

EMBER

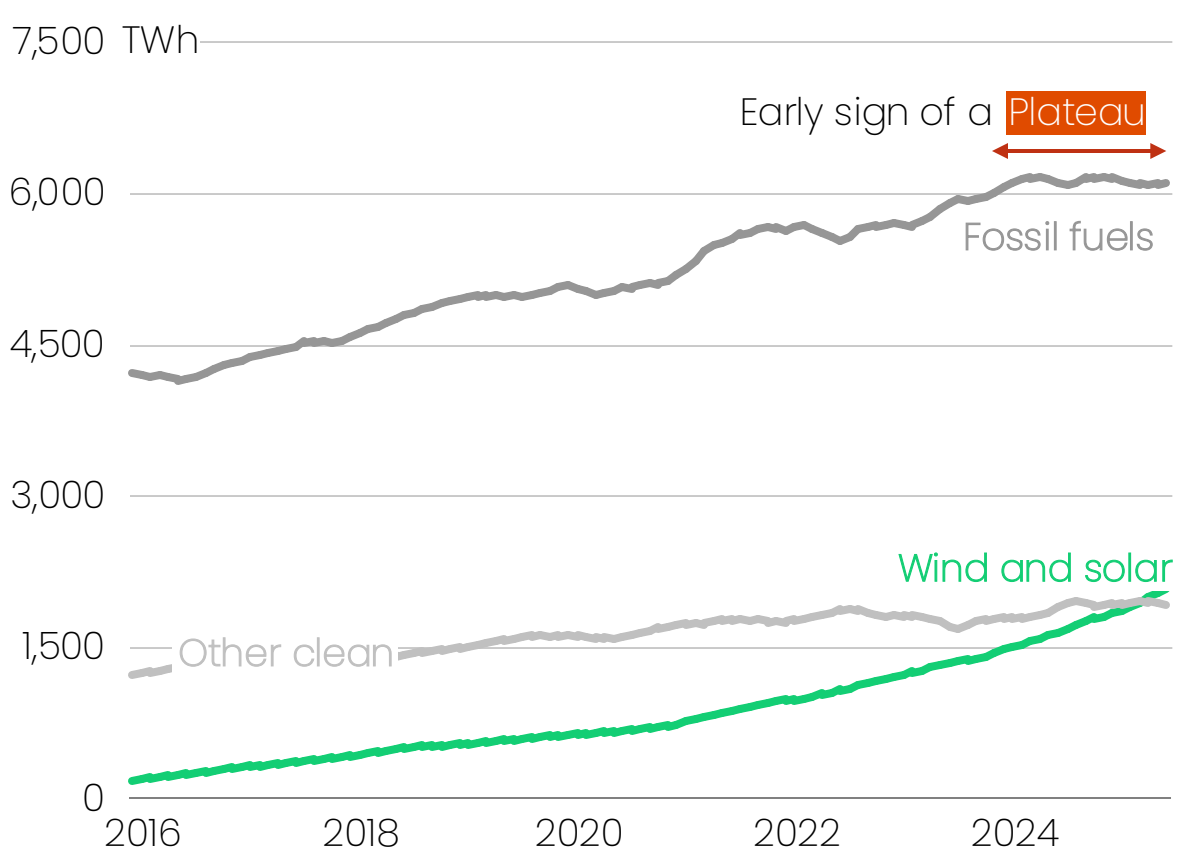
# Fossil fuel demand is peaking in China

Final fossil demand stopped growing in 2014 and fossil electricity in H1-2025

## Final energy consumption




## Electricity generation, 12-month rolling sum






Sources: IEA WEB; Monthly electricity data, Ember. Note: final energy excludes non-energy.

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## Chapter 4
# Three fundamental drivers of change

## Physics
Electrotech is more efficient than alternatives

## Economics
Electrotech as a technology has learning curves and growth curves

## Geopolitics
Electrotech is a key tool of energy security

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# Chapter 4.1
# The physics of change

## 01

### Fossil fuels are very inefficient

The fossil fuel system wastes two thirds of its primary energy. $4.6 trillion a year goes up in smoke, and this sets up a very attractive environment for more efficient solutions.

## 02

### Electrotech is three times more efficient

Electrotech is three times more efficient than fossil tech in sectors that make up two thirds of fossil fuel demand: electricity; road transport; and low temperature heat. Fossil fuels have to be burnt, requiring 17,000 million tonnes (mt) a year to be shipped around the world. Electrotech needs annual deployment of under 300 mt to build out the infrastructure required to harness the sun and wind.

## 03

### Electrotech beats the rest of cleantech

Electrotech is far more efficient than other cleantech solutions like CCS, biomass or hydrogen.

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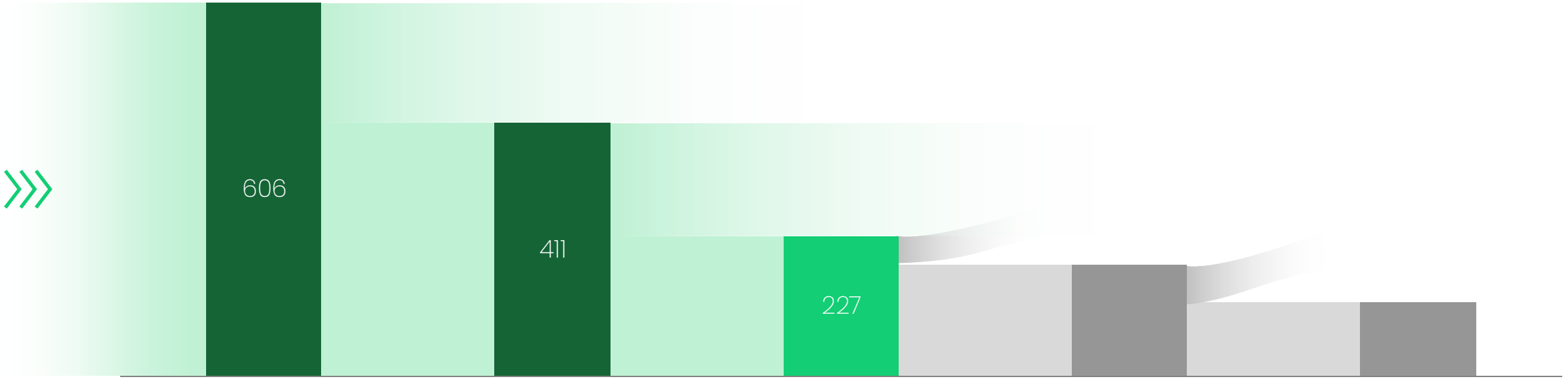
# Energy is all about efficiency

At its core, the energy system is about converting energy into useful forms as efficiently as possible




| | **Primary energy** Energy going into the global energy system | **Final energy** Energy delivered to consumers | **Useful energy** Energy turned into functional forms | **Energy services** Useful energy turned into activities | **Prosperity** Activities turned into value |
|---|---|---|---|---|---|
| **Examples** | e.g., crude oil, coal | e.g., gasoline, electricity | e.g., hot water, vehicular motion | e.g., goods transported, ton steel produced | e.g., wealth, satisfaction, happiness |

**WHAT EVERYONE TALKS ABOUT** | **WHY WE ACTUALLY CARE ABOUT ENERGY**



Sources: RMI

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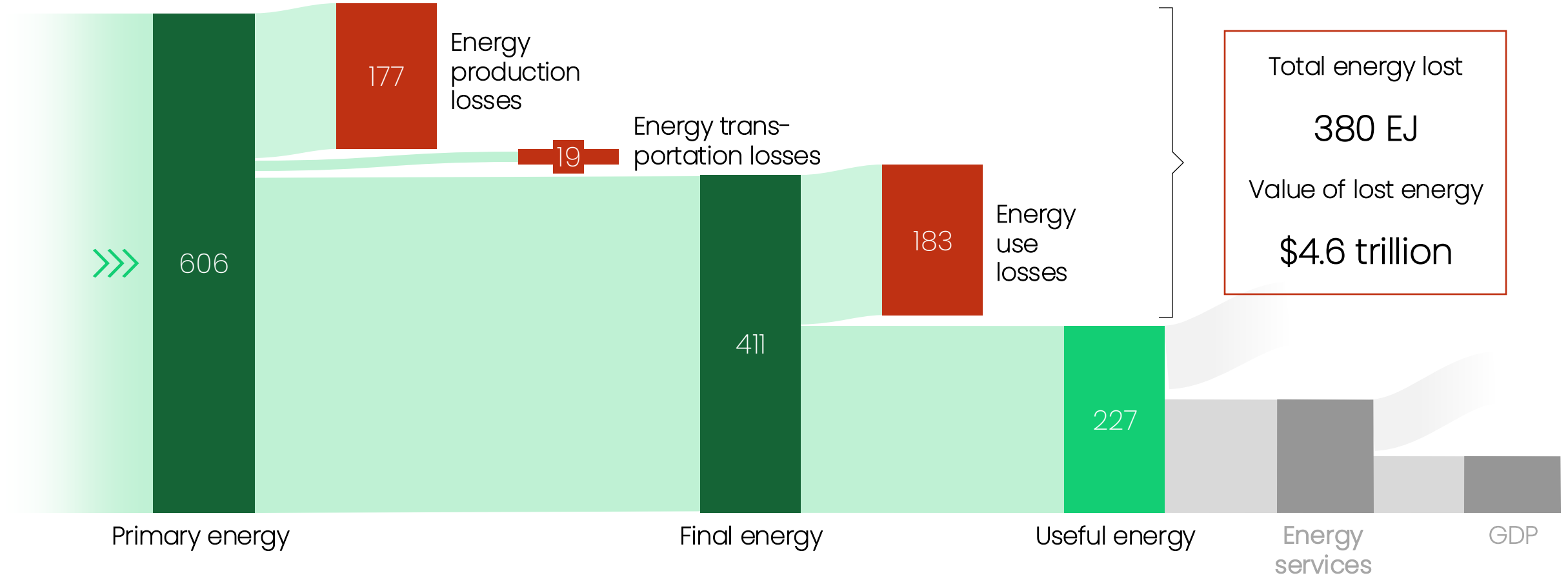
# The current fossil energy system is incredibly inefficient

We lose some two thirds of the energy we put into the system

**Global energy flows and waste, EJ per year, 2019**






Sources: RMI

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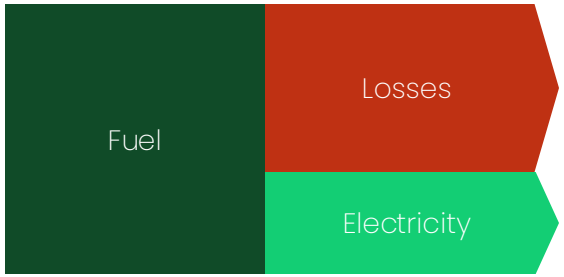
# Electrotech is 3x more efficient

It offers a leap in energy efficiency across the economy

## Supply

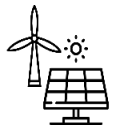
### Electricity generation

Fossil thermal




30-40% efficiency

Wind & solar

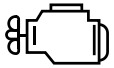


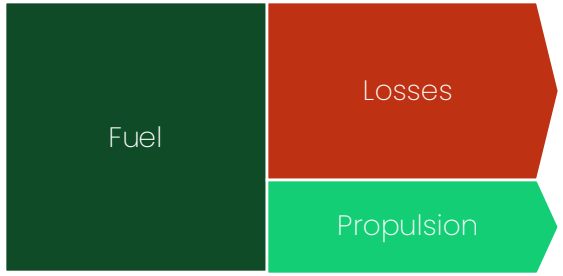

100% efficiency

## Demand

### Transport

Internal combustion engine





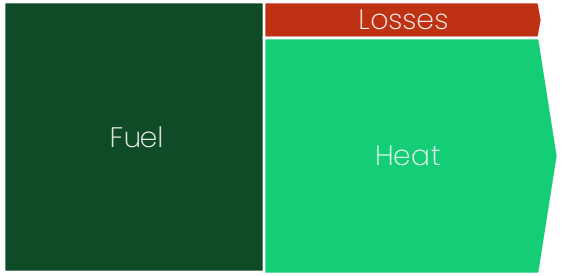

25-40% efficiency

Electric vehicles


80-90% efficiency

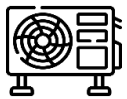
### Heating

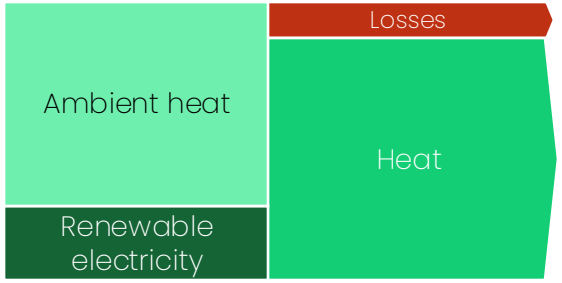
Gas boiler




85% efficiency

Heat pumps






300-400% efficiency

**2-3x**
as efficient

**2-4x**
as efficient

**3-4x**
as efficient



Sources: IEA, IIASA, Visual adapted from Prof. Tomas Kåberger and RMI • Note: heating refers only to low temperature heating

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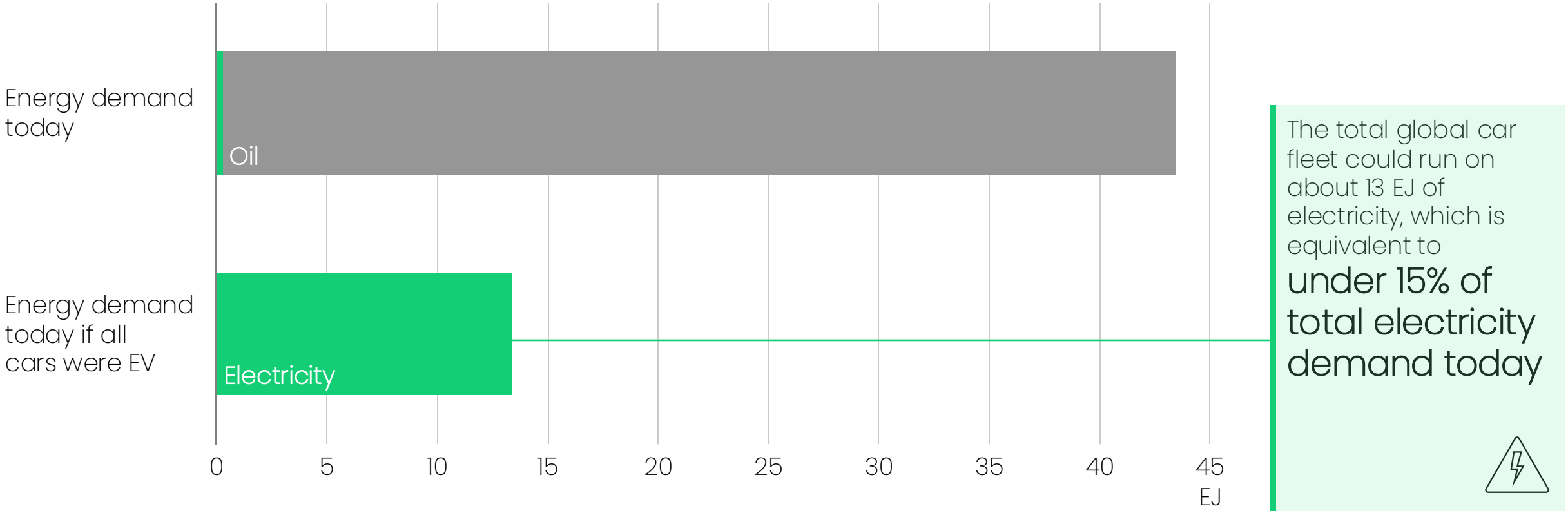
# Electrotech enables us to get much more for much less

Electrotech can provide the same useful services for three times less final energy

## Example: passenger cars

### Final energy demand




The total global car fleet could run on about 13 EJ of electricity, which is equivalent to

**under 15% of total electricity demand today**



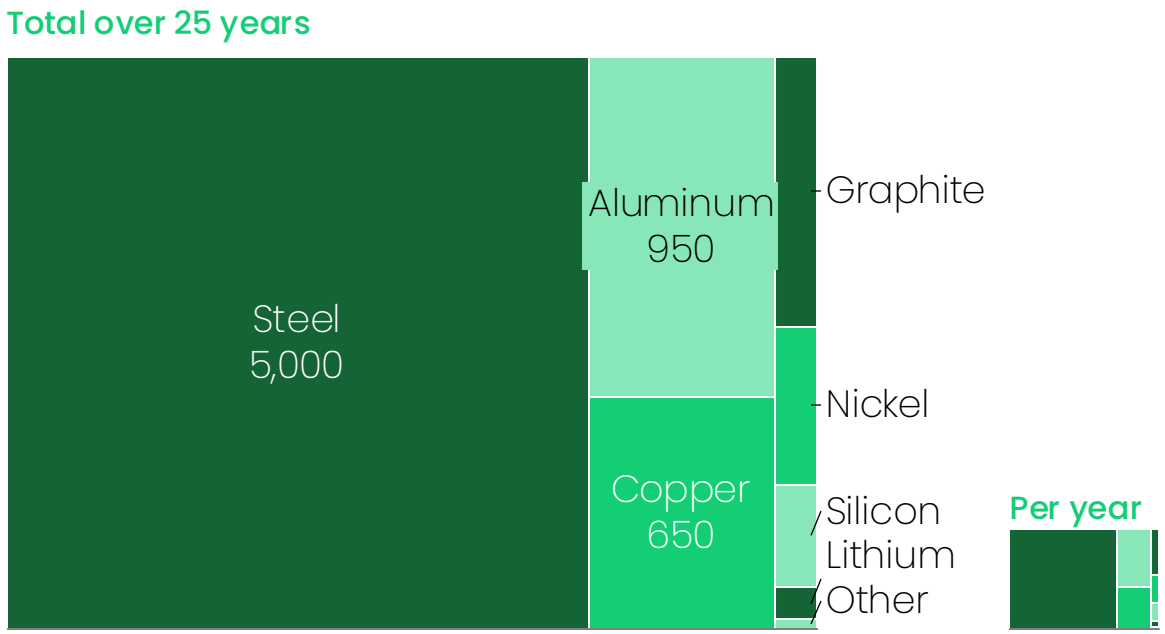
Sources: BNEF; Ember analysis

EMBER

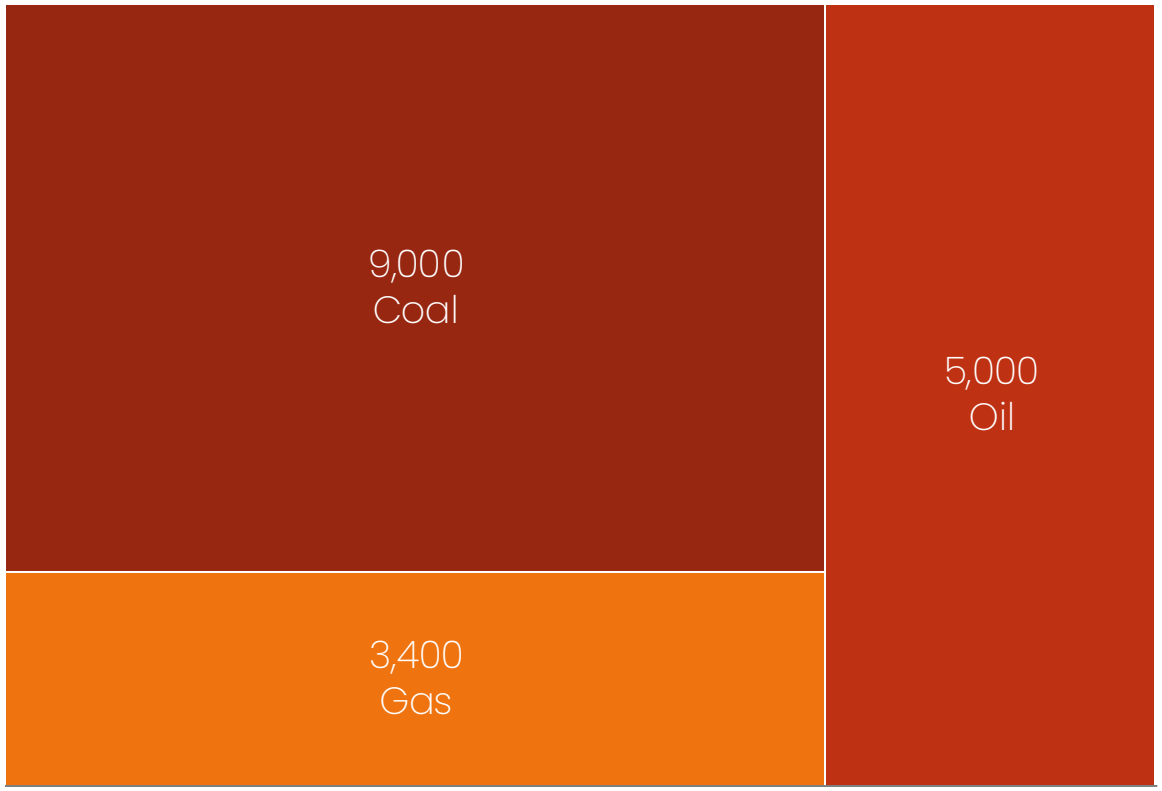
# The unbearable heaviness of the fossil fuel system

The fossil fuel system requires over 50x more materials than electrotech

**Total material demand for the energy transition for 25 years (*2024-2050*),** Million metric tons




**Fossil fuel extraction *per year today*,** Million metric tons






Sources: ETC; EI; Ember analysis

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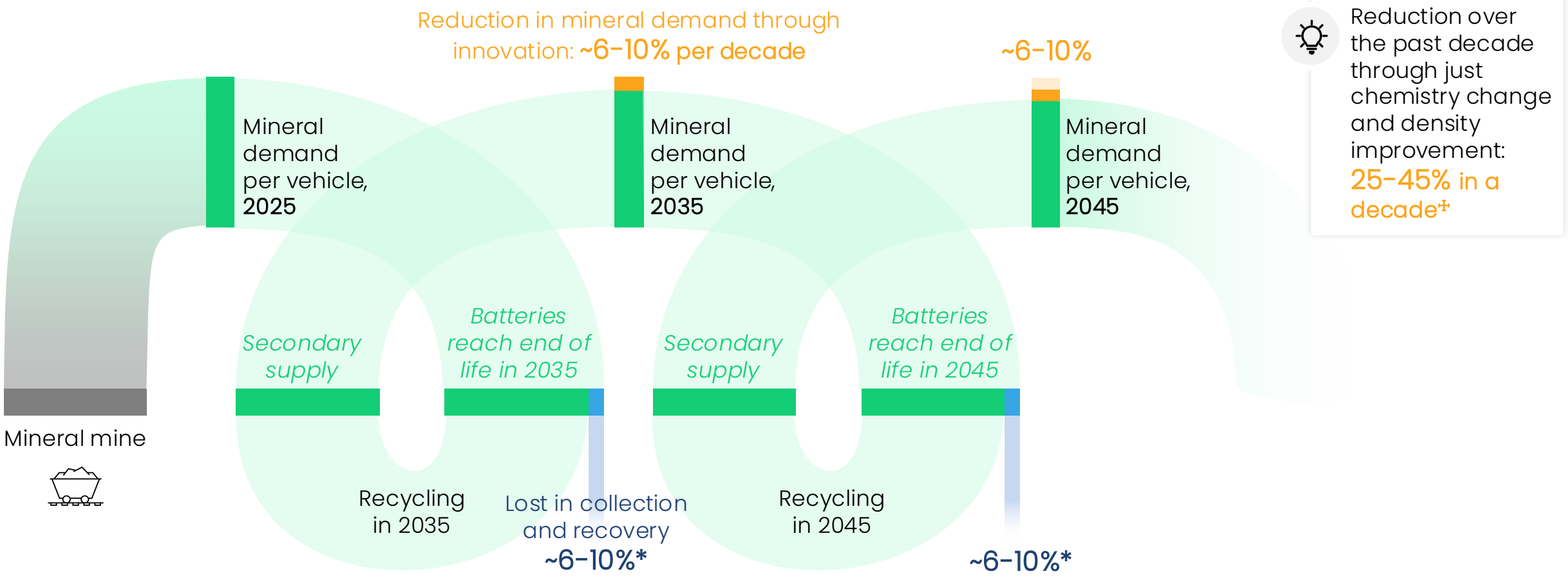
# Borrowing, not burning

If you recycle batteries and improve performance, you don't need to extract new minerals




Reduction over the past decade through just chemistry change and density improvement: 25-45% in a decade‡



Sources: RMI • Notes: Useful battery lifetime of a decade is indicative; lifetimes are likely longer. * Accelerated case ‡ About 25% for lithium, about 50% or more for nickel and cobalt

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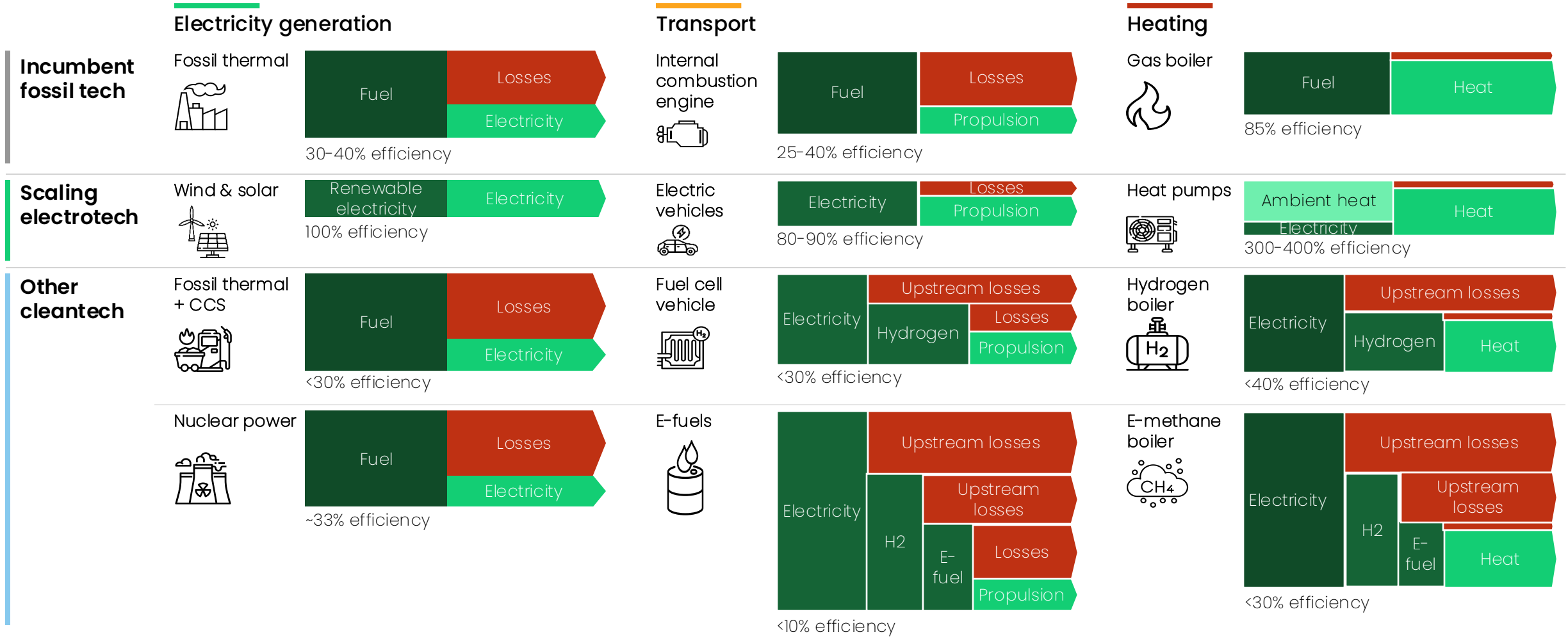
# Efficiency differentiates electrotech from other cleantech

Molecule-based cleantech does not enjoy the tailwinds of being more efficient






Sources: IEA, IIASA, Visual adapted from Prof. Tomas Kåberger and RMI • Note: heating refers to low temperature heating

# Chapter 4.2
# The economics of change

## 01

### Technologies have learning curves

Electrotech is small and modular with lots of opportunity to innovate. The more electrotech you deploy, the cheaper it gets because of learning curves of around 20% for every doubling of deployment. In contrast, fossil fuels need to fight a constant battle against depletion.

## 02

### Technologies grow exponentially

Electrotech grows rapidly on standard S-curves that we have seen in many other technologies over decades. For 30 years, solar capacity has been doubling every three years on average, and since 2020 battery storage has been nearly doubling every year.

## 03

### Electrotech makes you rich

Electrotech drives GDP growth, powers the industries of the future and supplies all the expected growth in energy jobs.

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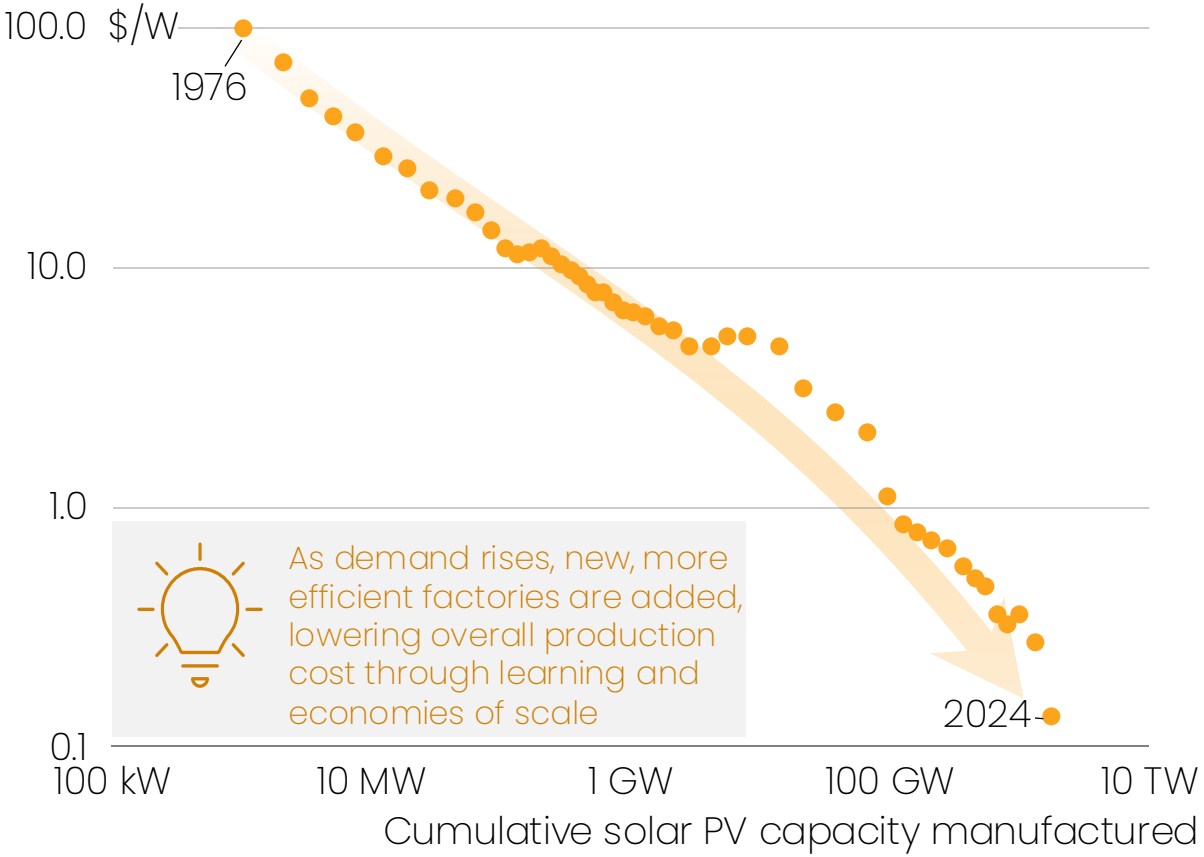
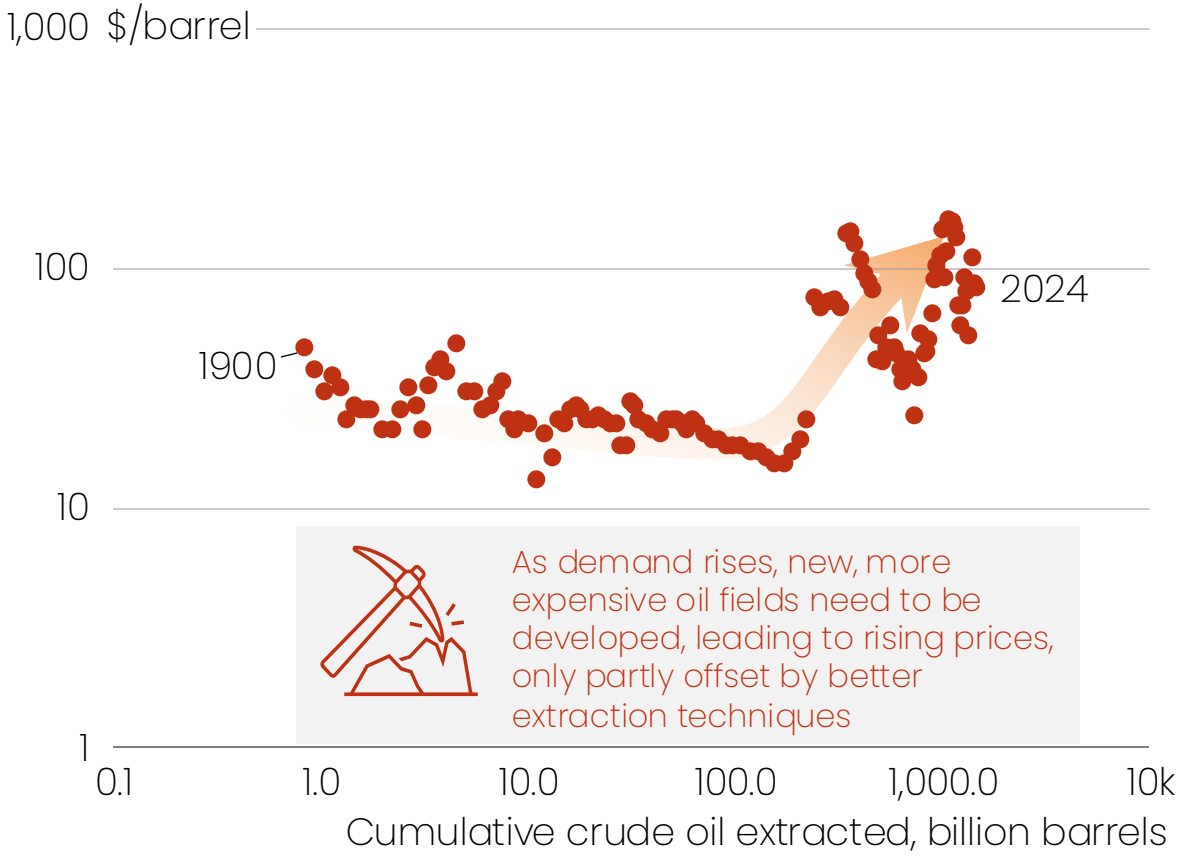
# Learning beats digging

Electrotech gets cheaper with scale, whereas fossil fuels get more expensive

## Solar panel price cost versus amount manufactured




## Oil price versus amount extracted





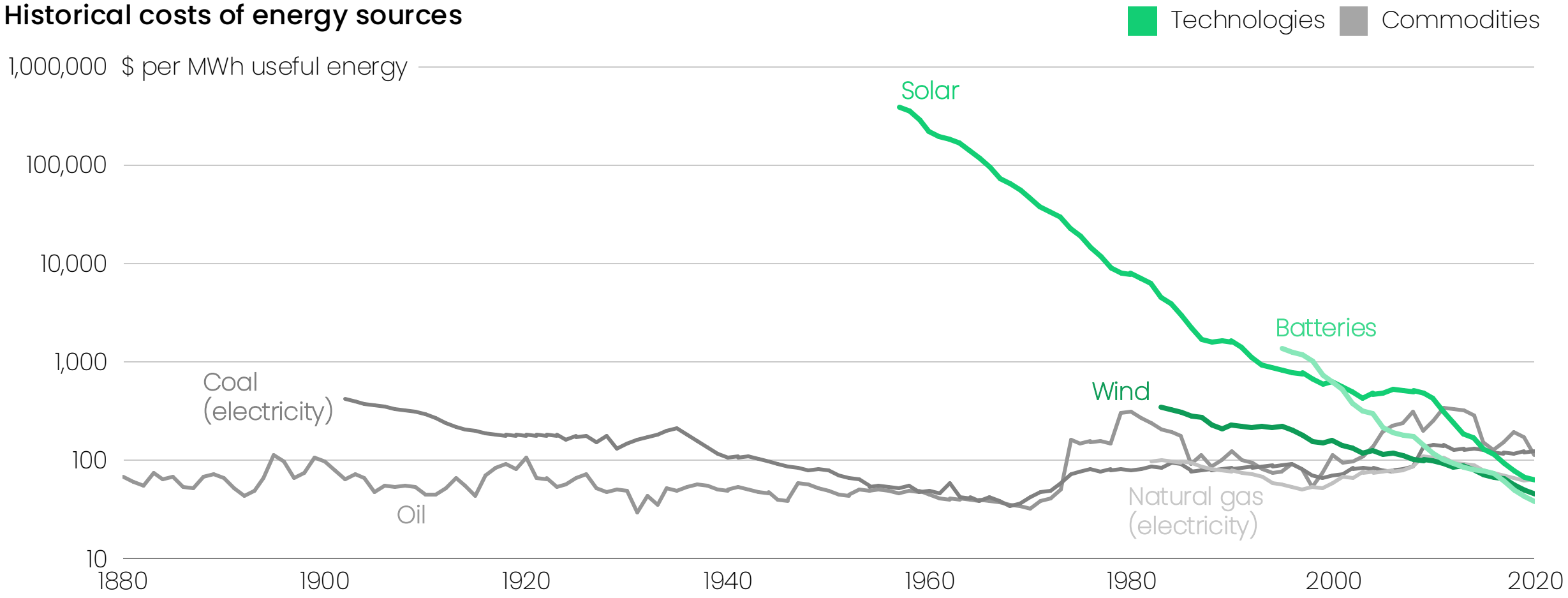

Sources: Rystad; BNEF; Ember analysis

EMBER

# Technologies beat commodities on cost

Electrotech is the triumph of brain over brawn

## Historical costs of energy sources






Sources: Way et al. 2022. Fossil fuel extraction has learning curves but empirically this has been matched by depletion.

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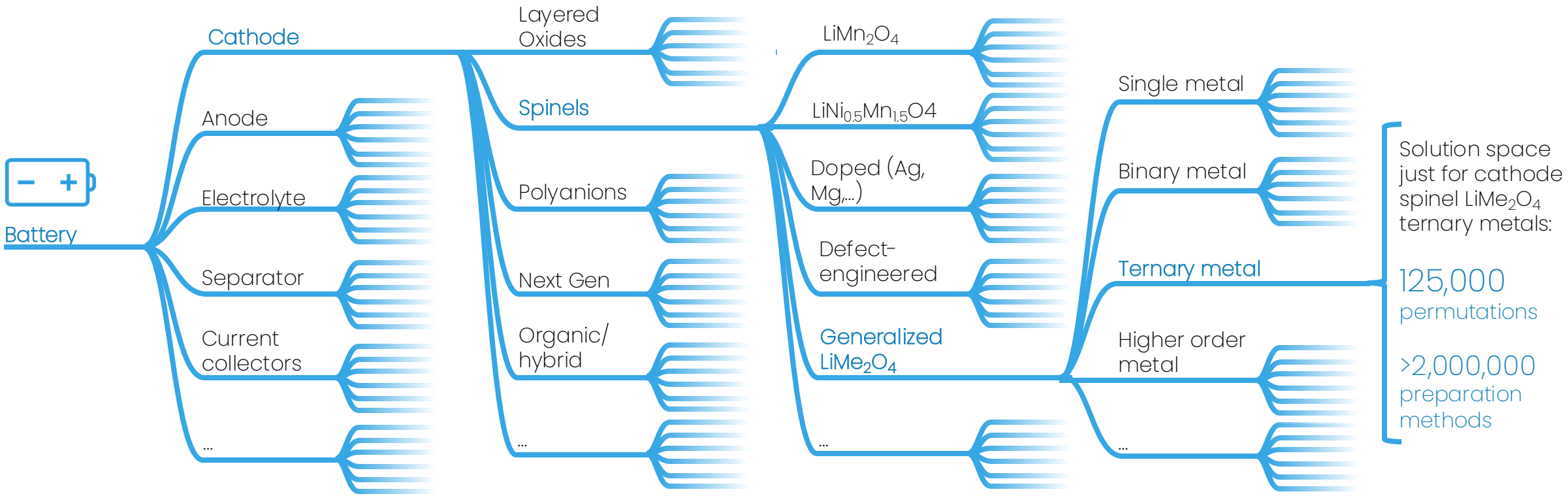
# There is a huge solution space to explore

The electrochemical solution space underlying electrotech is enormous

## Example: battery cell solution space




Sources: Volta Foundation; Yesuraj et al. (2024), Marincas et al. (2020), Liang et al. (2020), Choi et al. (2024), Nisar et al. (2021), Huang et al. (2021) – Note: Me = transition metal



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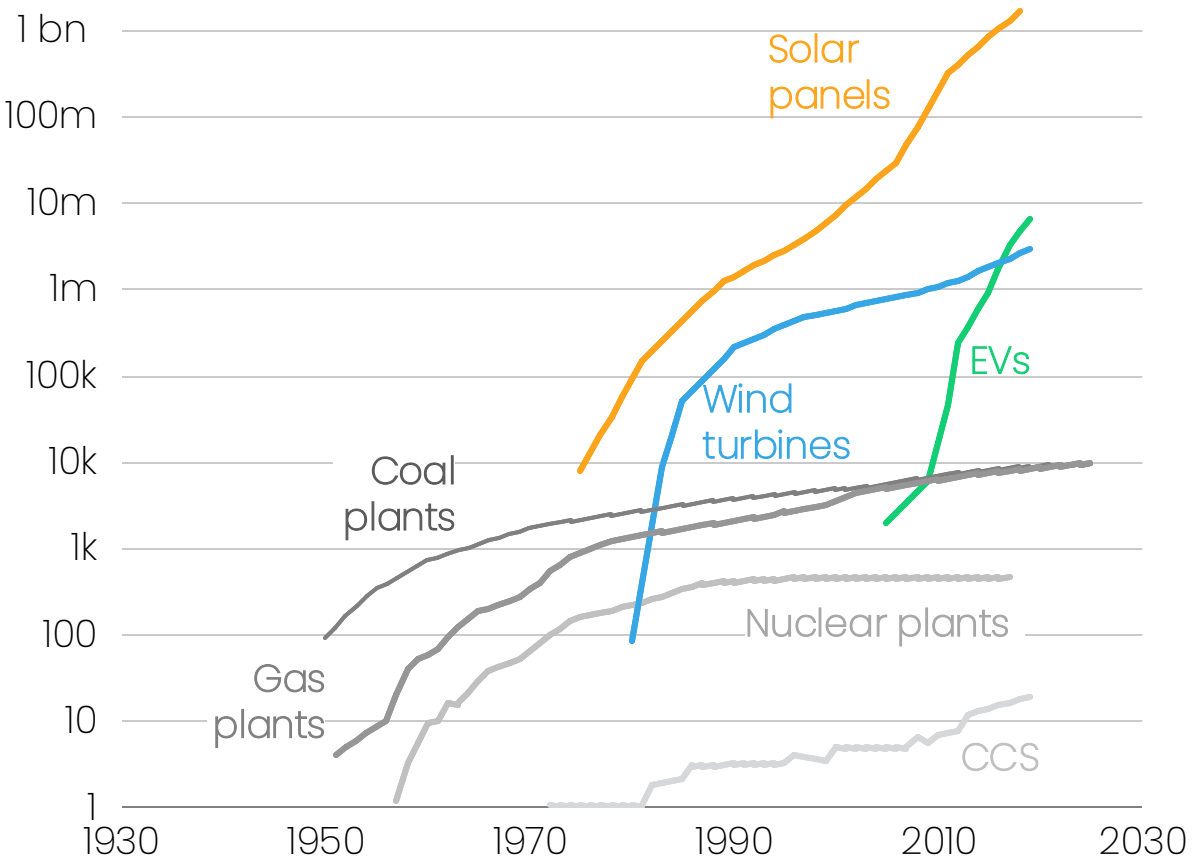
# Learning by doing

Electrotech is small, modular and cheap, allowing for a lot of experimentation and learning

## Cumulative units produced




## Typical deployment effort

**Solar panels**
1-6 months
$ 100/unit

**EVs**
1-6 months
$ 30,000/unit

**Wind turbines**
6-24 months
$ 3,000,000/unit

**Gas plants**
3-4 years
$ 800,000,000/unit

**Coal plants**
4-6 years
$ 3,000,000,000/unit

**Nuclear plants**
6-10 years
$ 7,000,000,000/unit

**CCS projects**
5-10 years
$ 1,000,000,000/unit



Sources: Global Energy Monitor, Greg Nemet, Ember

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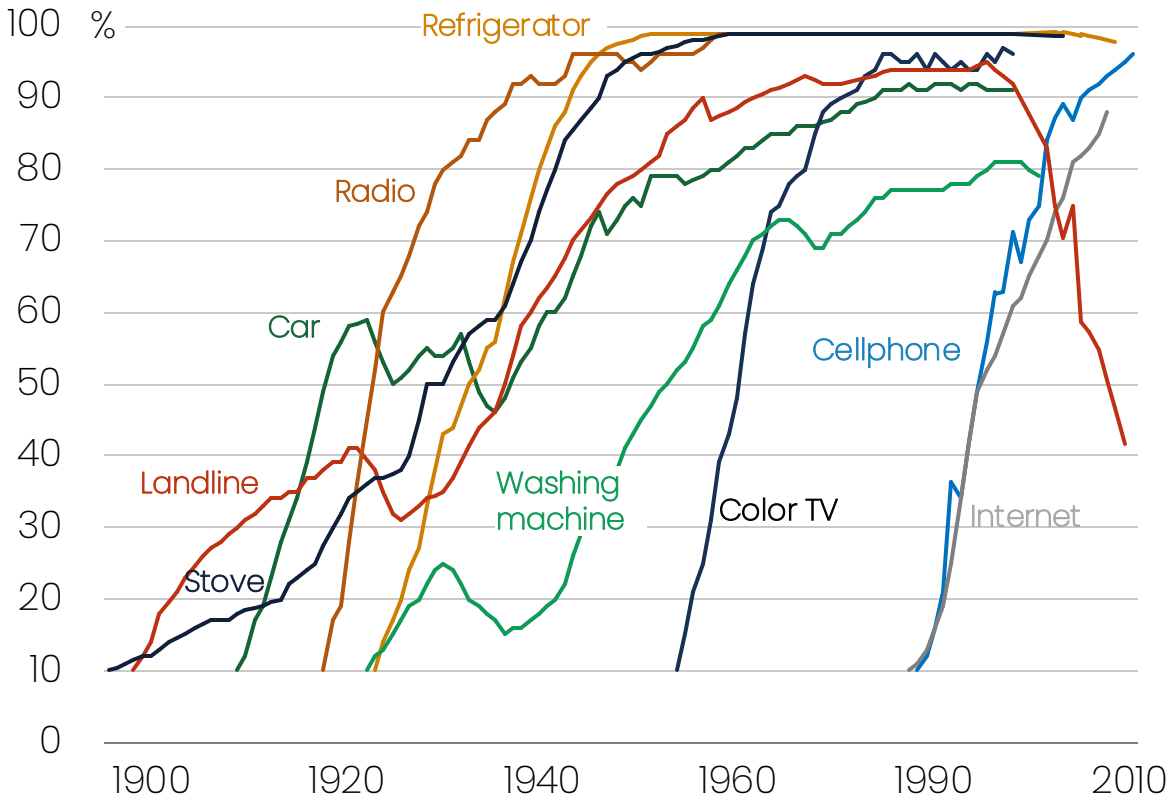
# S-curve as usual, not business as usual

Successful technologies grow along S-curves

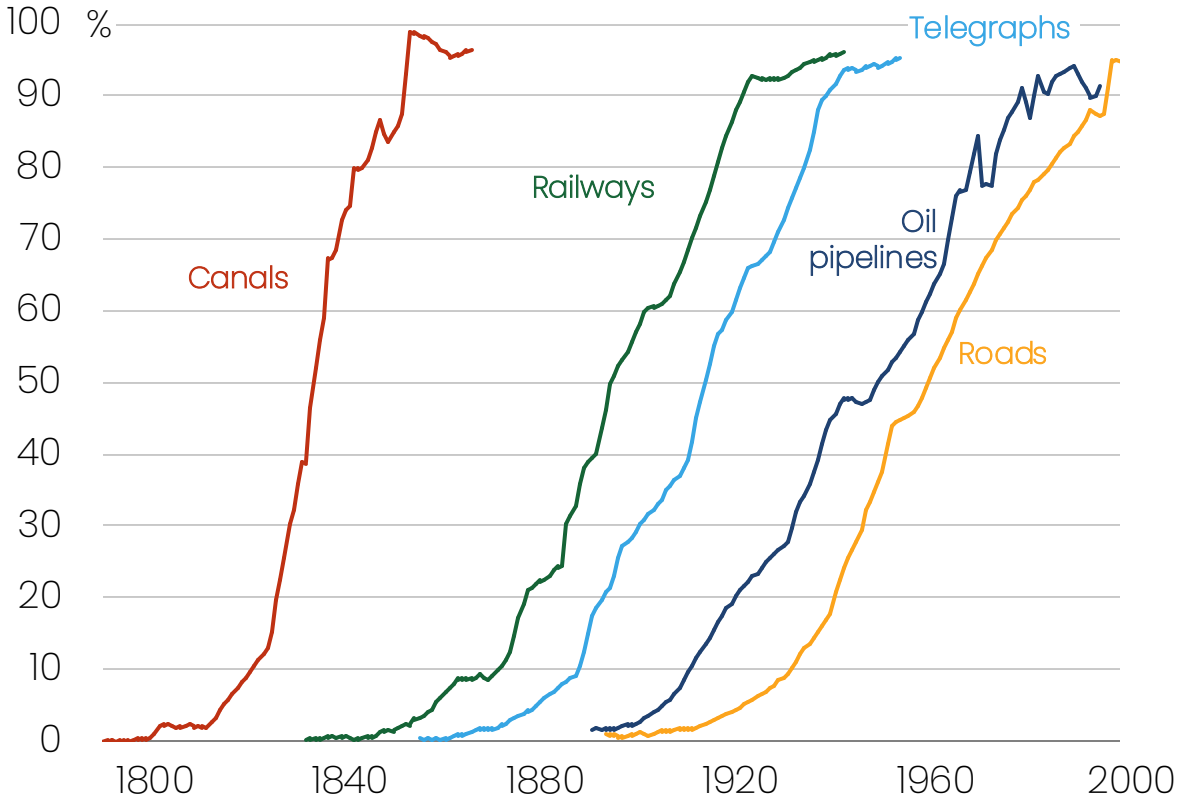
## Individual products

Technological adoption by household in the United States




## Infrastructure systems

Share of maximum size in the United States






Sources: Comin & Hobijn via OWID, Grubler, RMI.

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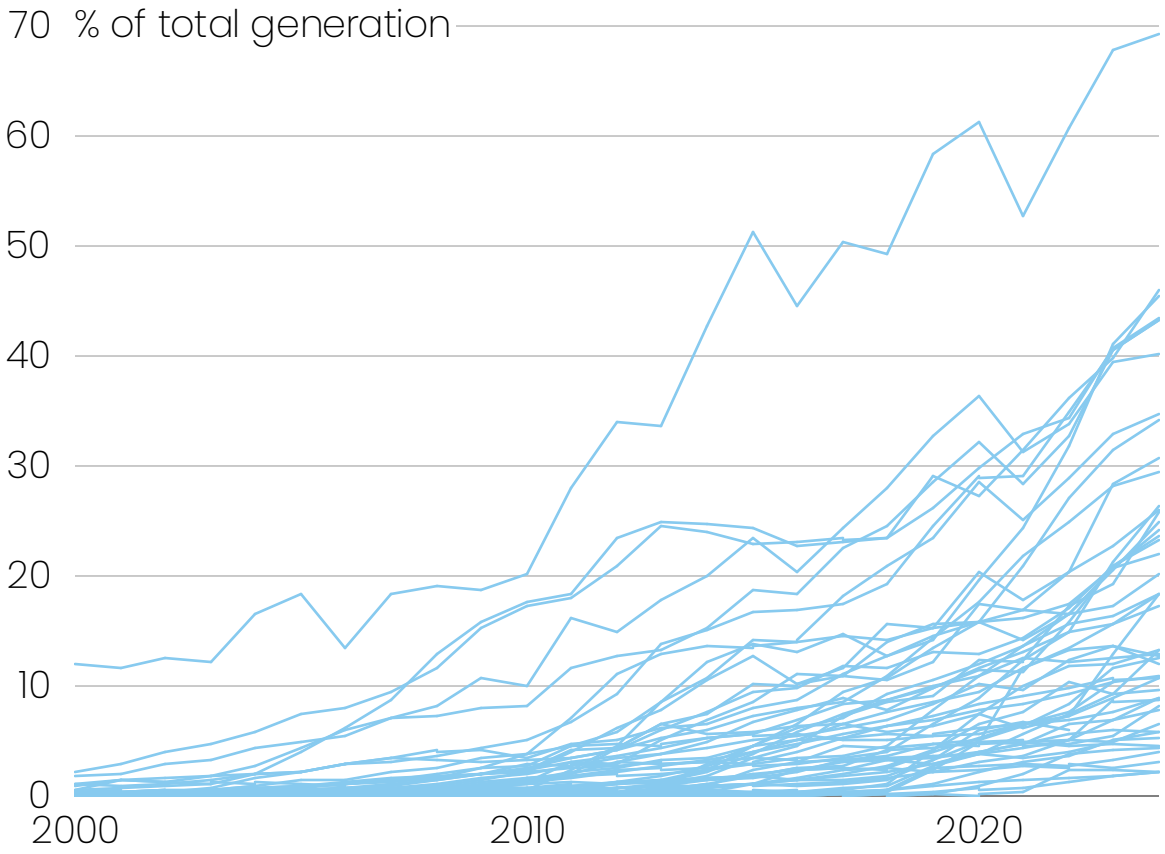
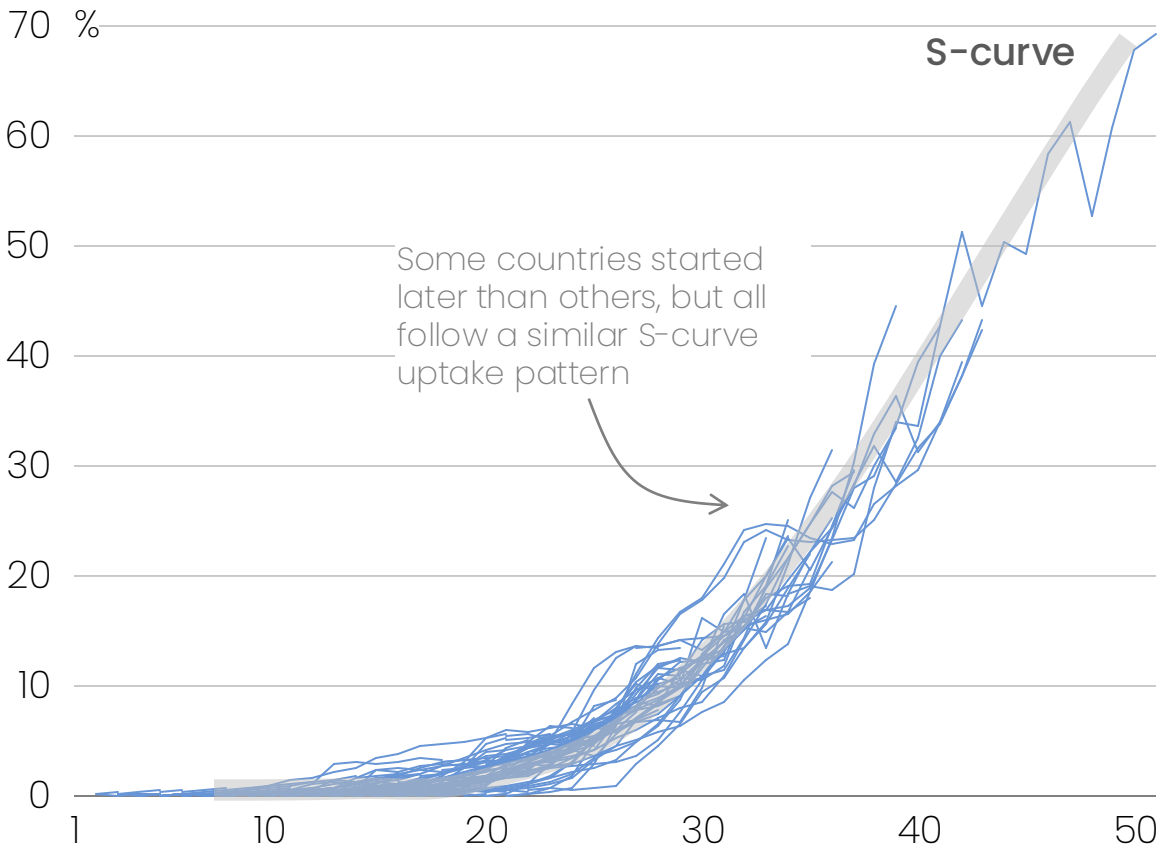
# S-curves are the signal in the noise

Electrotech is growing on S-curves; timing varies but the shape is surprisingly uniform

**Solar and wind uptake by country – actual**




**Solar and wind uptake by country – time-shifted**






Sources: Ember data & analysis. Note: Based on the 75 largest economies by electricity demand, filtered by countries with >2% of generation from solar and wind (N=52). Country solar & wind shares were time-shifted to a global logistic S-curve.

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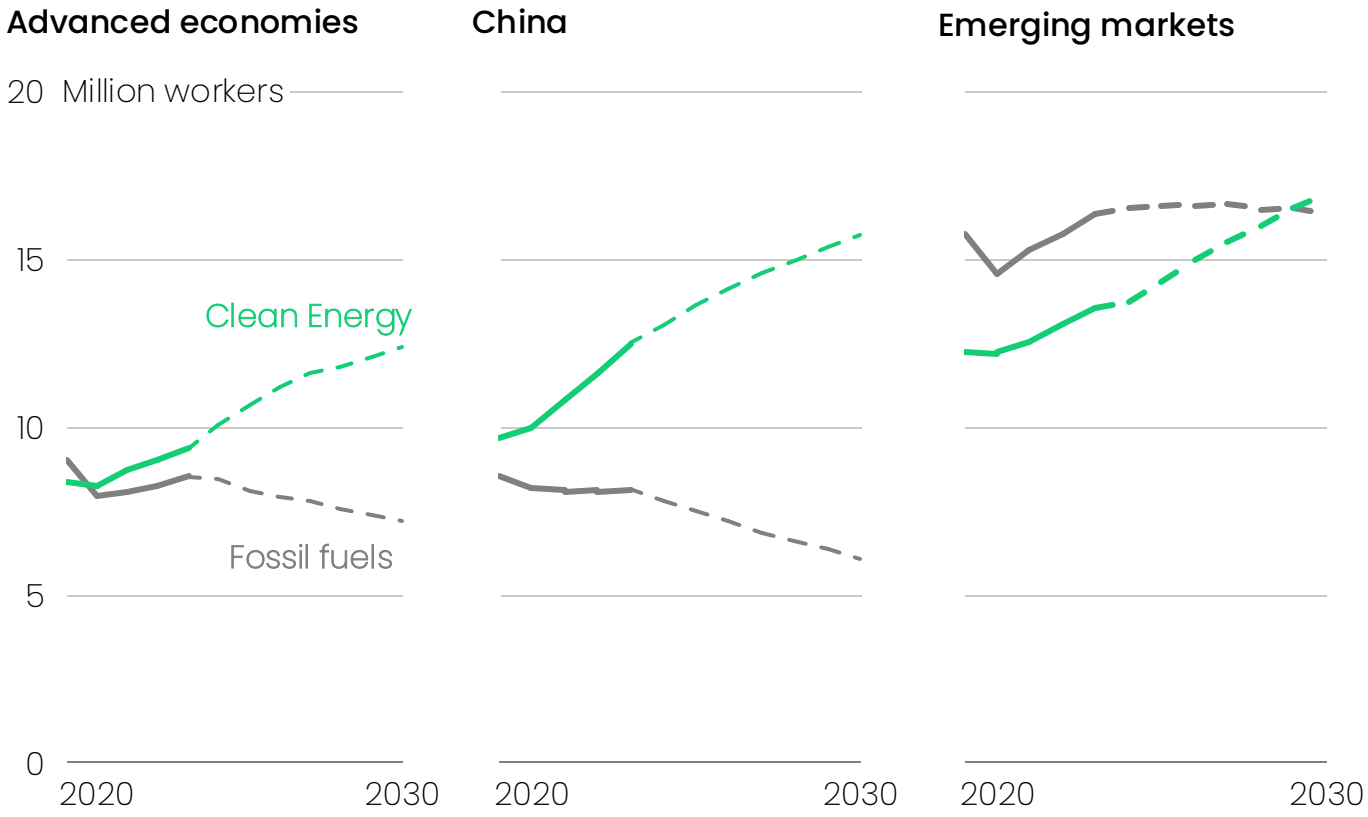
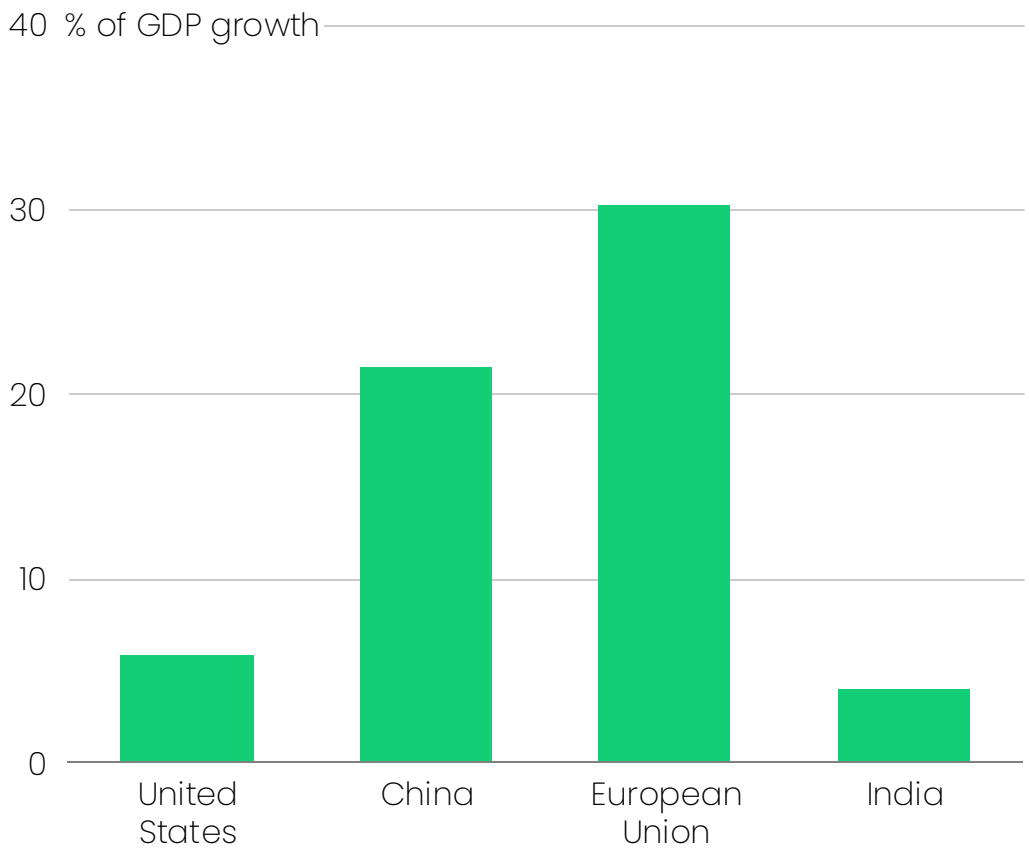
# To the victor go the spoils

Winning at electrotech means gaining cheap energy, jobs, growth, and future industries

## Change in energy employment, 2019-2030




## Contribution of cleantech to GDP growth, 2023






Sources: IEA World Energy Employment 2024 for STEPS scenario (I), IEA ETP

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## Chapter 4.3
# The geopolitics of change

01

### Fossil fuels create dependency and risk

Fossil fuels are burnt every day and have to be bought again the next day, creating system risks for the buyers. Three quarters of the world live in fossil fuel importers, and regions like Europe are dependent on imported fossils for two thirds of their energy supply. In a world or rising tension, that is far too much risk to bear.

02

### Electrotech enables energy security

Electrotech is the foundation of energy security because every country has access to the sun and wind, and can electrify end demand. Renewables added to the electrification of transport and low temperature heat can reduce fossil imports by 70%. Once electrotech is bought, it lasts for decades, providing insulation from the vagaries of global pricing.

03

### China is leading the race to the top

China is leading the electrotech revolution and deploying its technology at scale and speed into the emerging markets. Other countries seeking independence and influence will need to compete in this race to the top for the superior technologies of the future.

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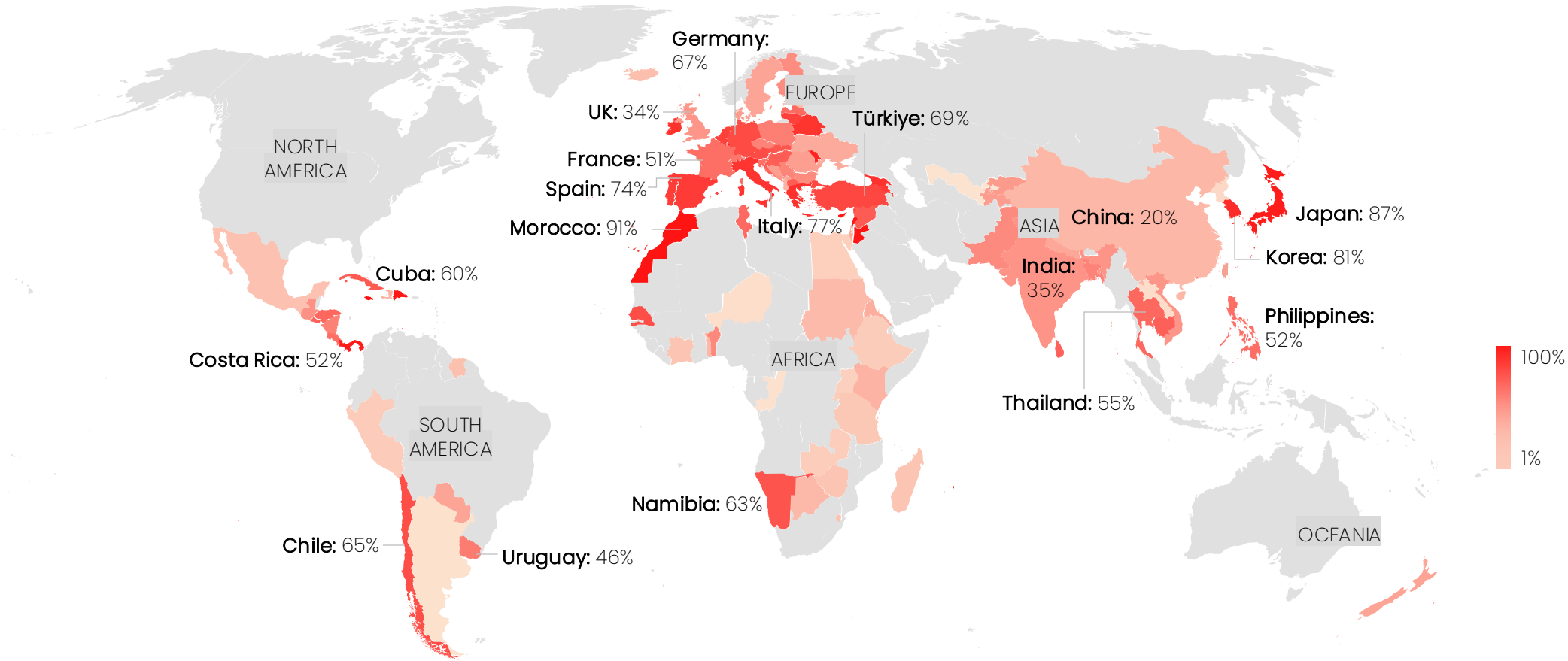
# Fossil import dependency is widespread

Over 50 countries import more than half their primary energy as fossil fuels

## Fossil net imports as a share of primary energy demand 2022, %






Sources: IEA WEB, Ember analysis. Map boundaries are from Microsoft Bing and do not imply any judgment on legal status or sovereignty.

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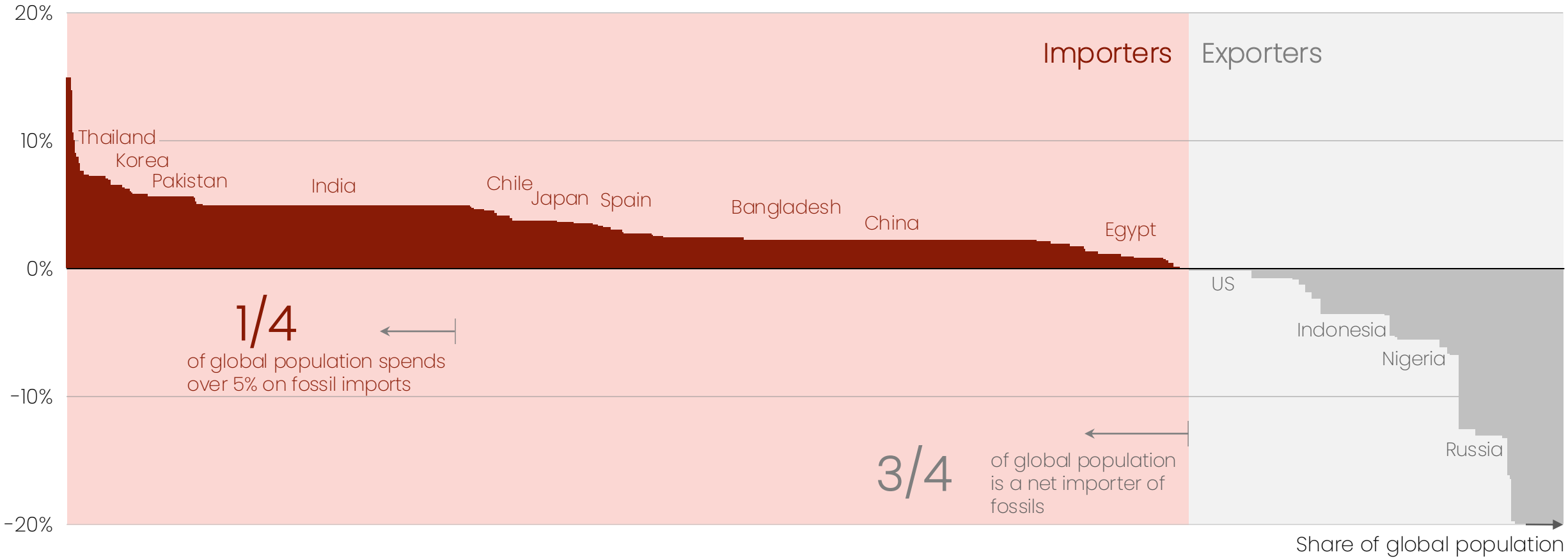
# Fossil fuel imports are very expensive

A quarter of the world spends over 5% of GDP on annual fossil fuel imports

## Fossil fuel net imports (-) and exports (+) value as share of GDP, 2022




Note: GDP balance based on energy trade balances in EJ from 2022, multiplied by typical commodity prices from IEA.
Sources: IEA WEB, Ember analysis. • Note 1: the y-axis is capped at -20% for readability.



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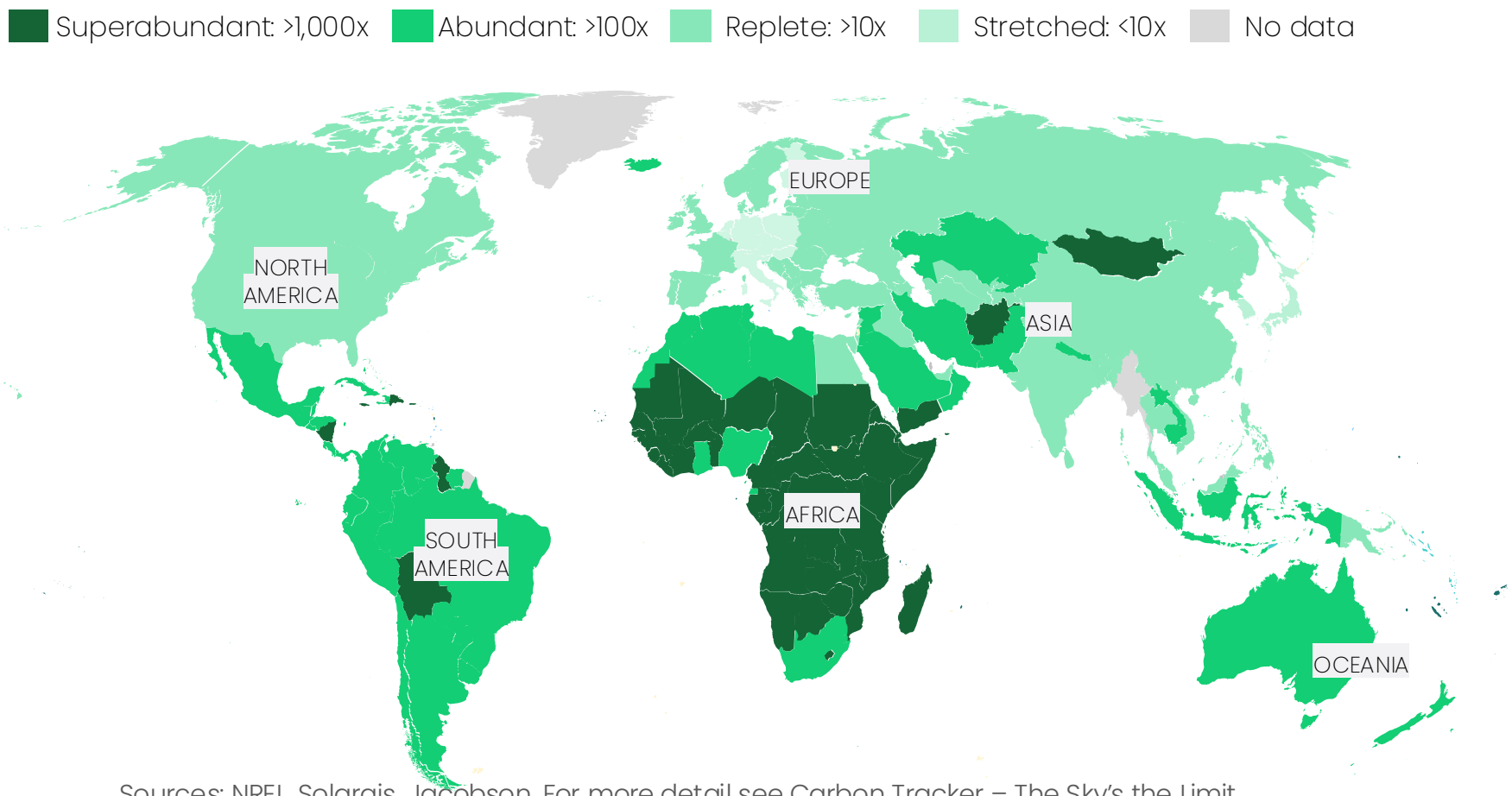
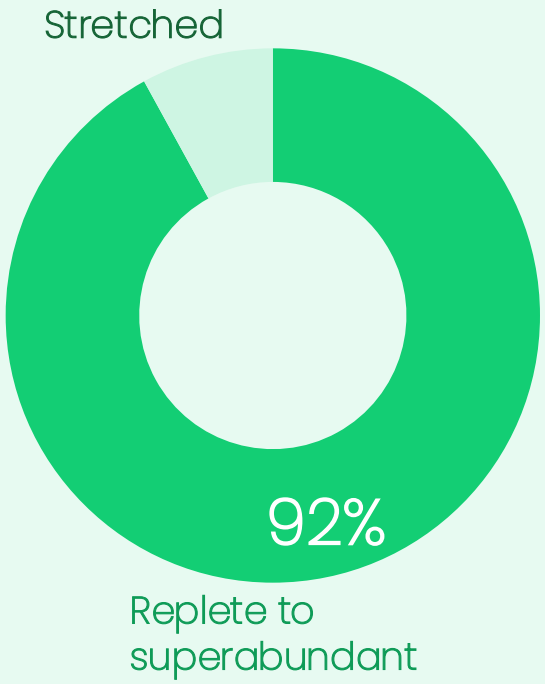
# Renewables are available to all

They are 100x bigger than fossil fuels and every country has enough to be self-sufficient

## Renewable potential as a multiple of energy demand in 2022




## Share of population endowed with replete or better renewable resource




Sources: NREL, Solargis, Jacobson. For more detail see Carbon Tracker – The Sky's the Limit
Map boundaries are from Microsoft Bing and do not imply any judgment on legal status or sovereignty.



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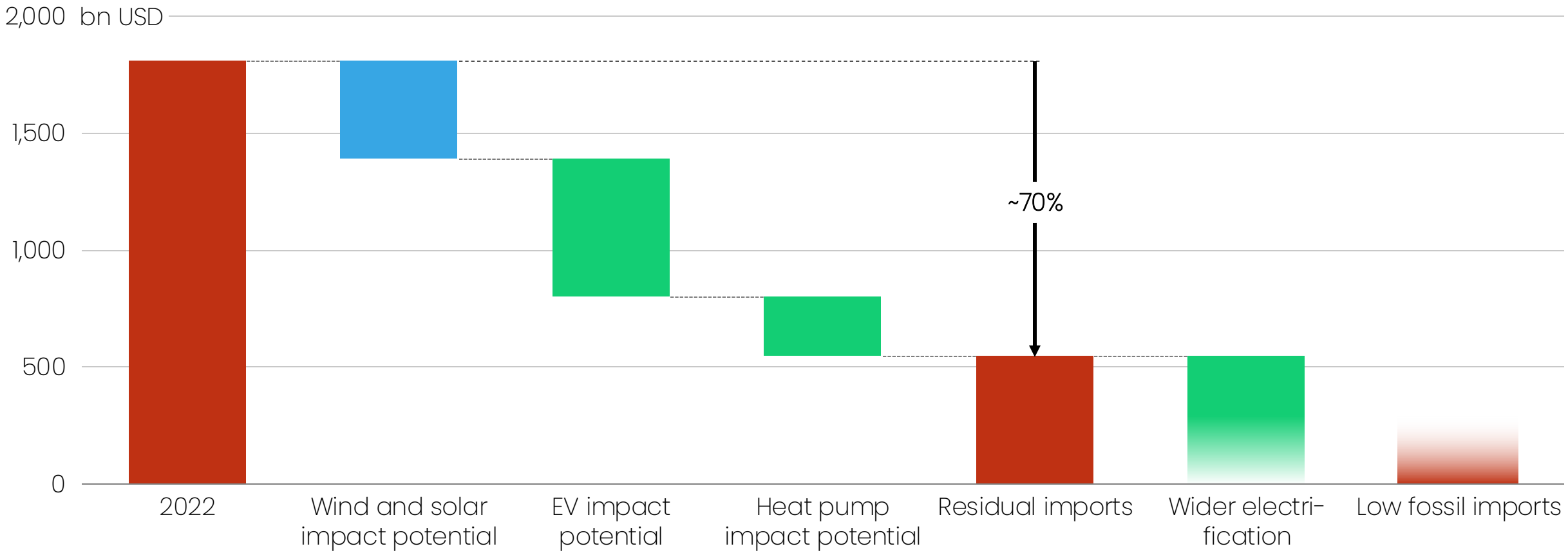
# Renewables, EVs and heat pumps set you free

Just a few technologies can reduce global energy imports by 70%

## Global net spending on fossil fuels by importers




Sources: IEA WEB, World Bank, Ember - Energy Security in an insecure world. The chart illustrates the reduction in fossil fuel imports possible by deploying solar, wind, electric vehicles and heat pumps



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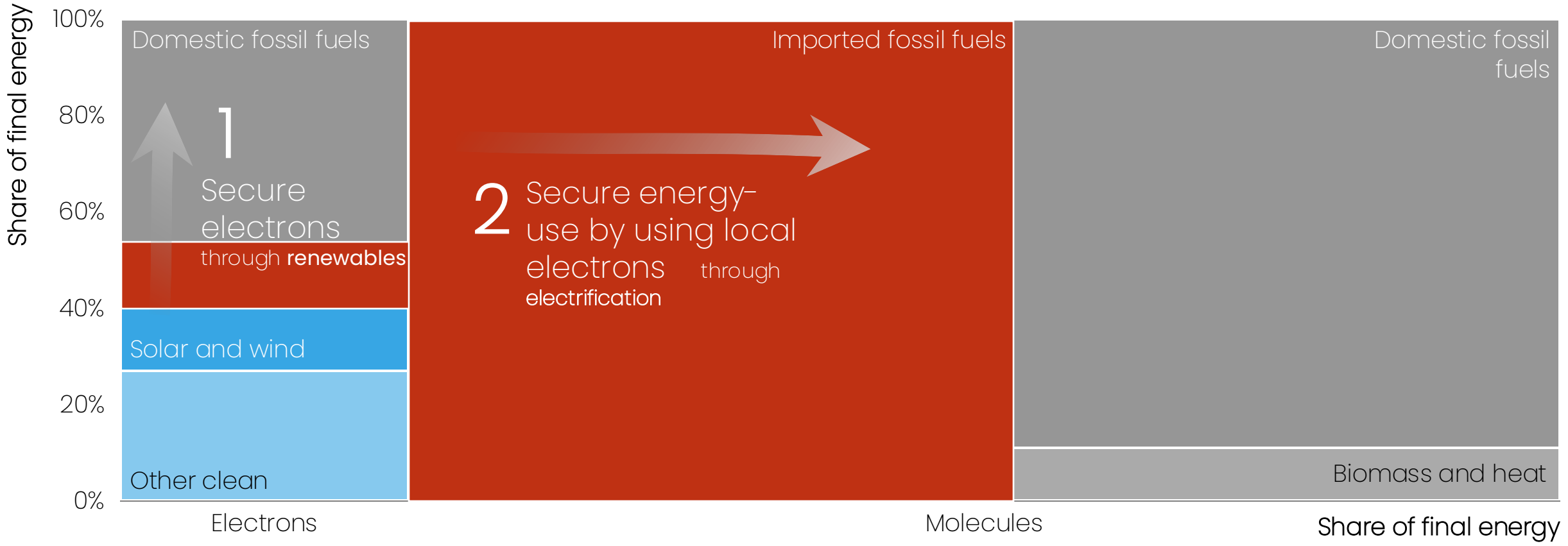
# Electrotech brings energy security

More domestic renewables and electrification can drastically curb energy dependence

## Global energy demand in 2023






Sources: IEA WEO 2024, IEA WEB, Ember • Notes: In gross terms and in final EJ. Other clean electrons are mainly hydro and nuclear.

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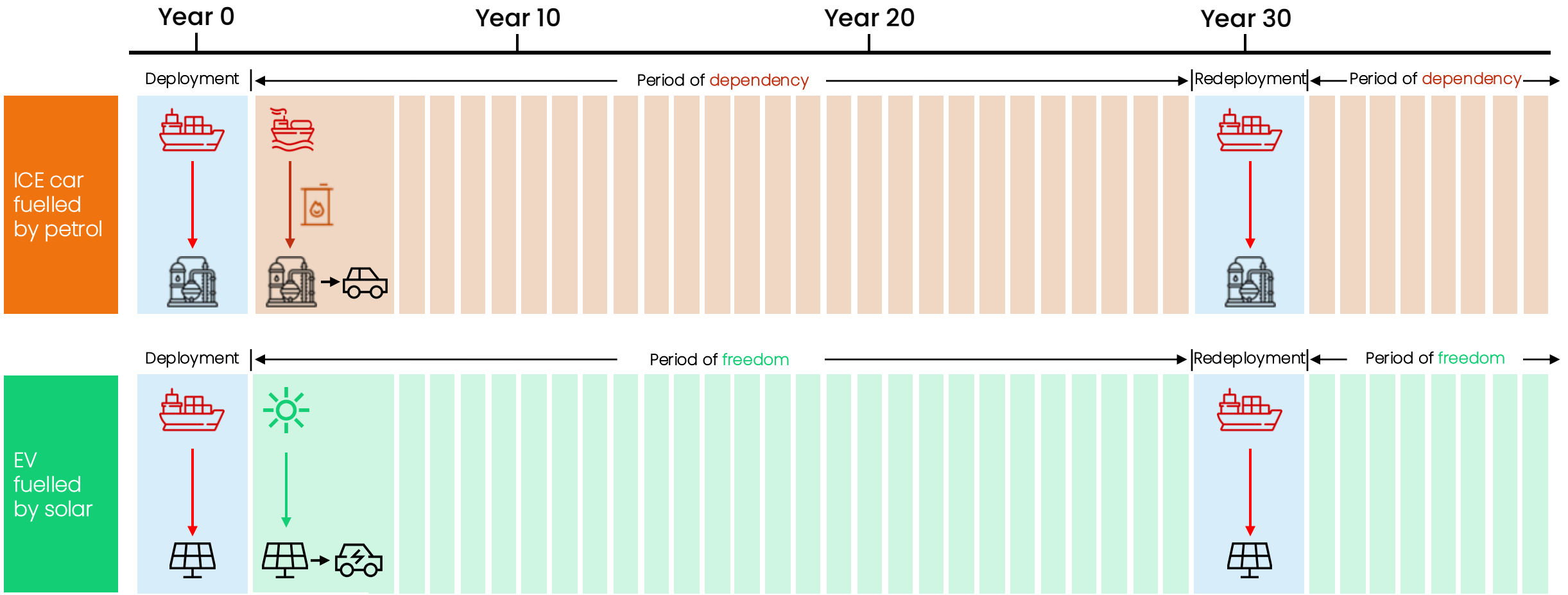
# You can’t turn off the sun

A solar panel provides 30 years of energy freedom






Sources: Ember

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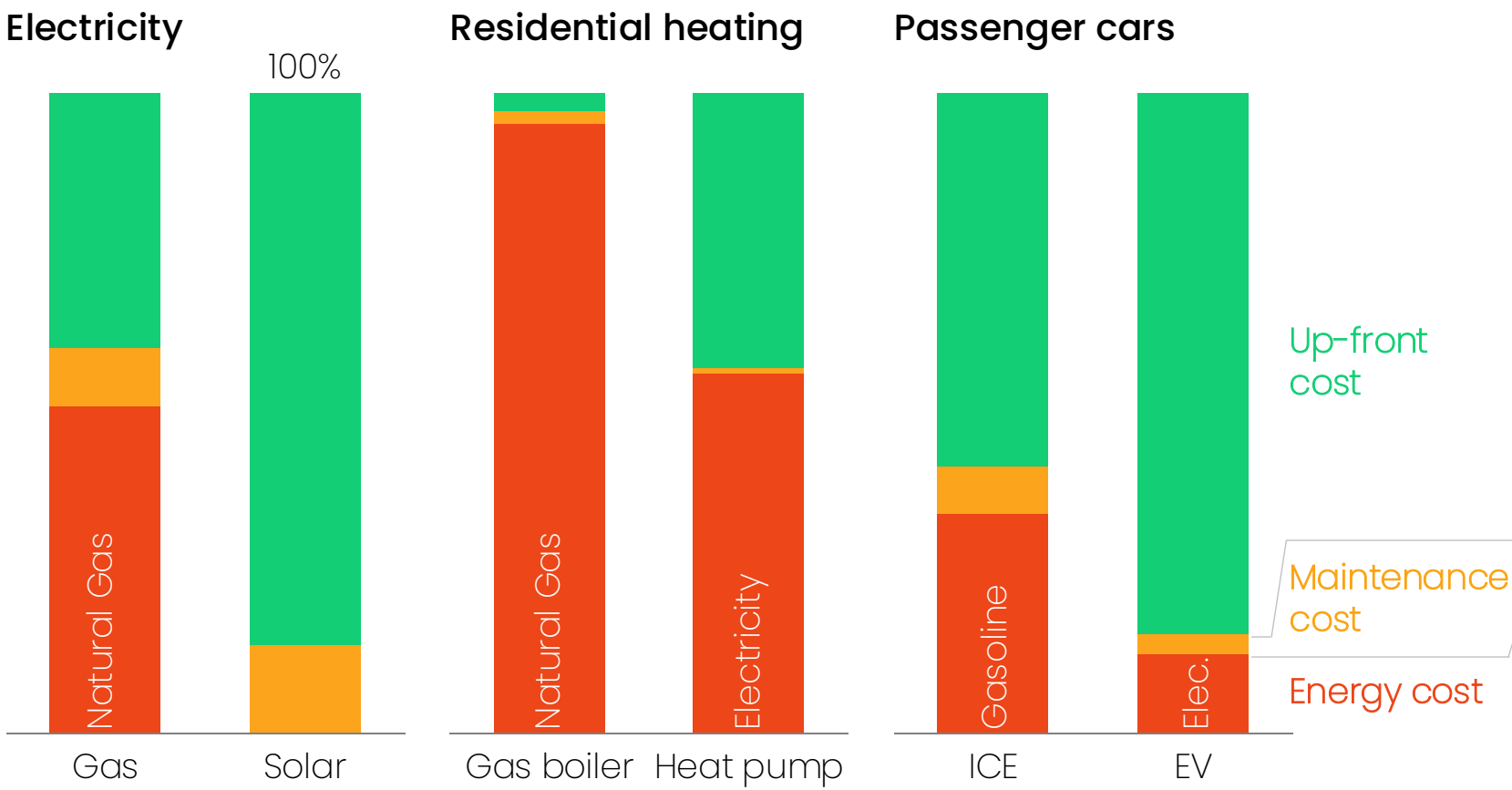
# Electrotech saves you from fossil volatility

Once installed, electrotech costs remain stable — even if global supply chains falter or fuel costs rise

## Total cost of ownership breakdown, %, US examples




## Inflation risk after deployment

**Low/ None** — Cost already sunk
Cost don't change with inflation as technology is already deployed.

**Mid** — Labor & manufacturing inflation
Inflation in labor and replacement parts can raise maintenance cost.

**High** — Energy inflation
Note: This applies less to electricity, as purchased electricity can originate from renewables like solar power, which primarily involve fixed costs and therefore carry minimal inflation risk.



Sources: Lazard 2024; NREL; IEA EV TCO tool; RMI analysis

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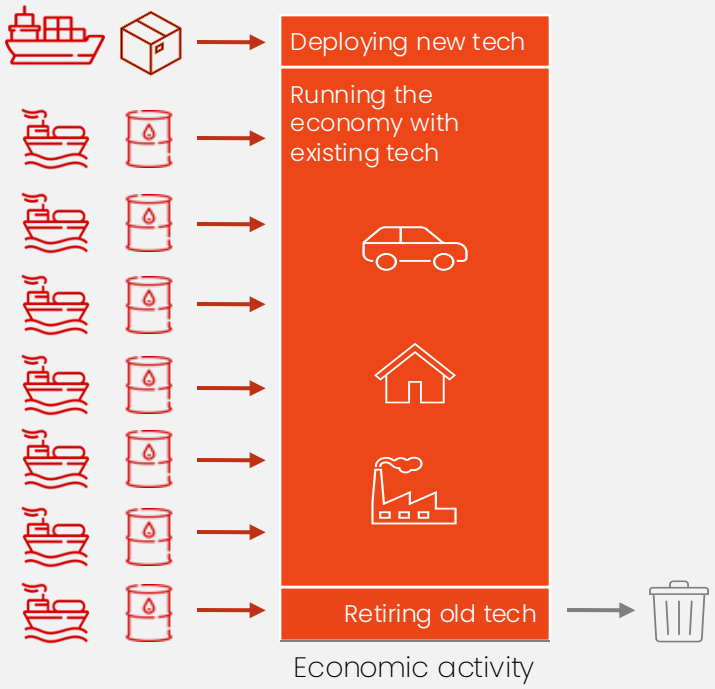
# Electrotech offers a path to permanent energy security

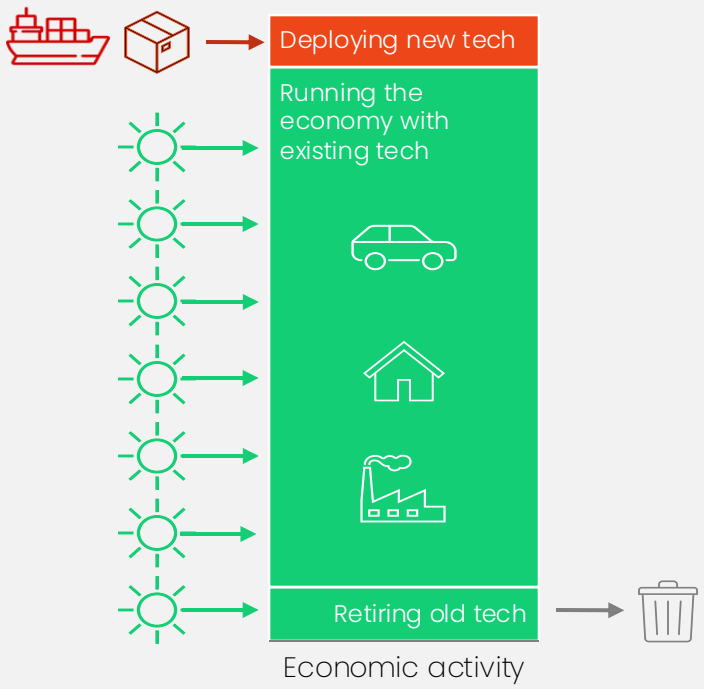
When fossil flows stop, the economy stops. When electrotech flows stop, only growth is at risk

## From fossil import dependency... → ...to electrotech import dependency... → ...to full circular energy independence.

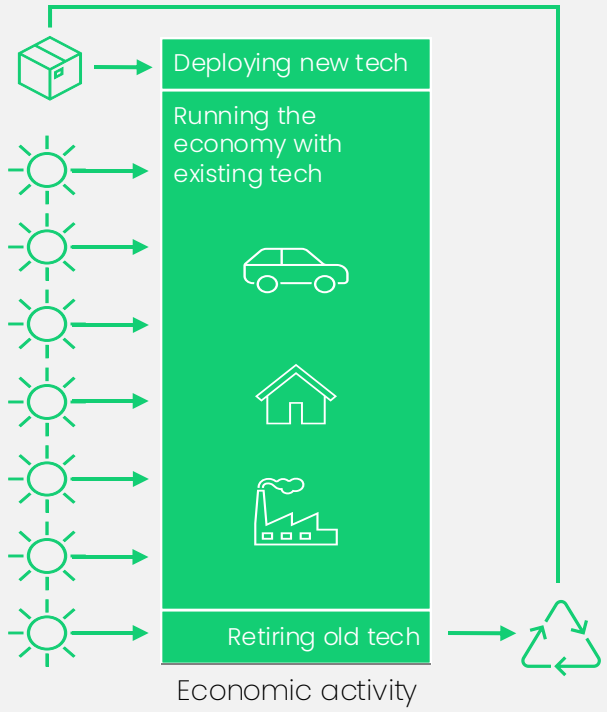
In an economy running on fossil imports, **when imports stop, all activity stops**




In an economy running on imported electrotech, **when imports stop, only growth is inhibited.**




In an economy running on local circular electrotech, **trade shocks have little impact**




At immediate risks without imports  Not at immediate risk



Sources: Ember• Note: bar sizes are illustrative

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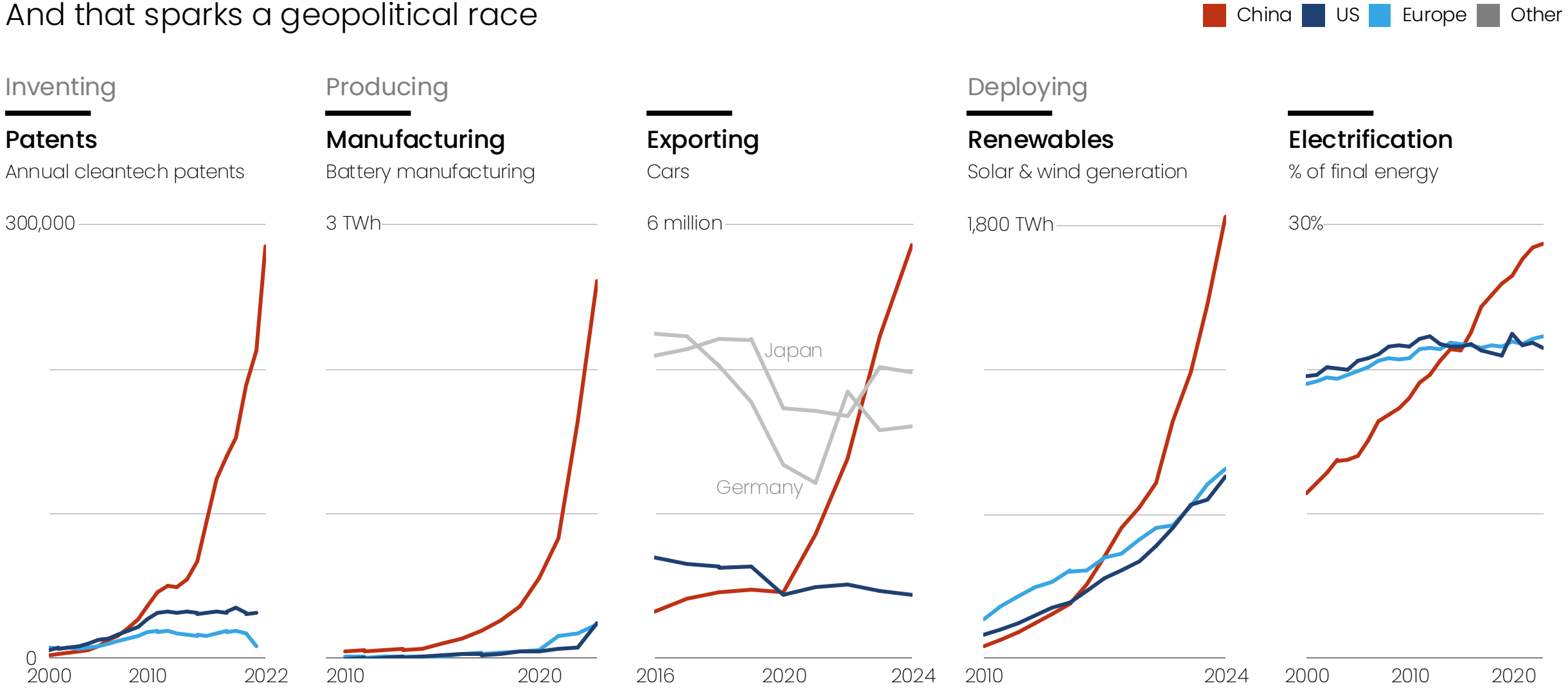
# China is the first major electrostate

## And that sparks a geopolitical race






Sources: Ember, IEA WEB, IRENA, BNEF, NYT.

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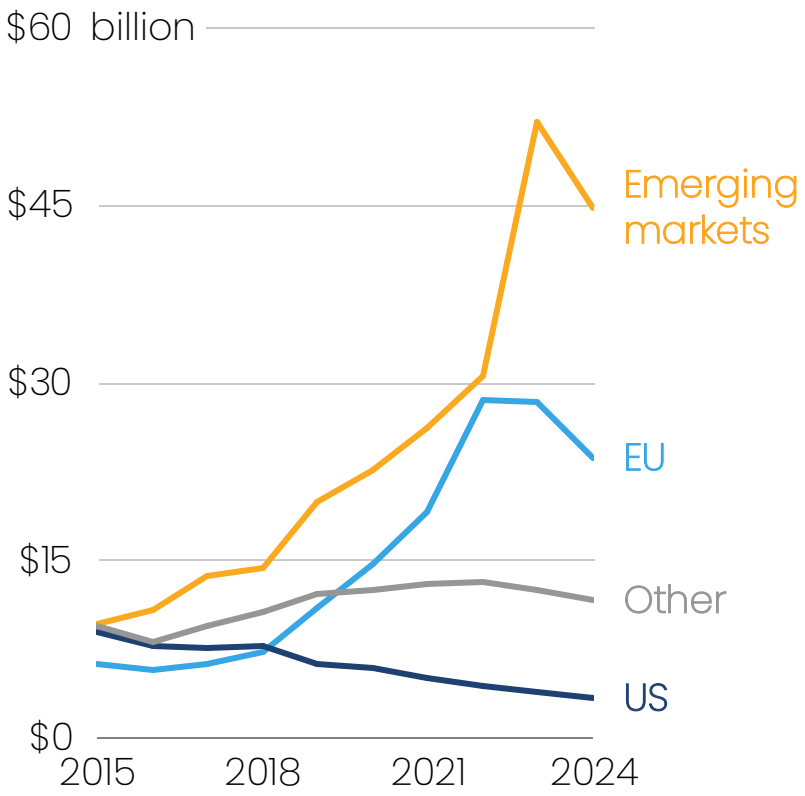
# China is exporting the electrotech revolution to the world

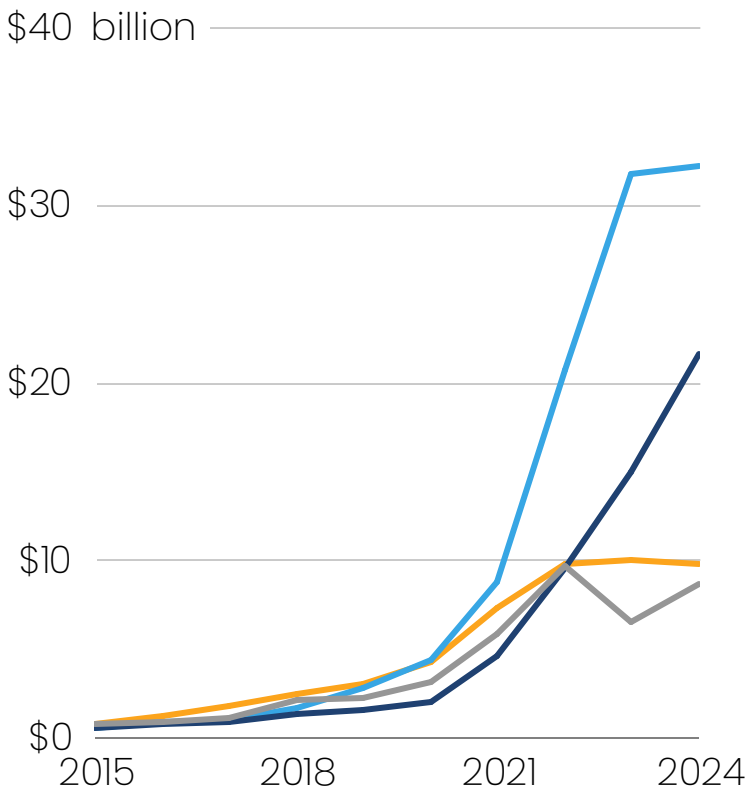
Gaining allies along the way — especially in the emerging markets

## Chinese exports

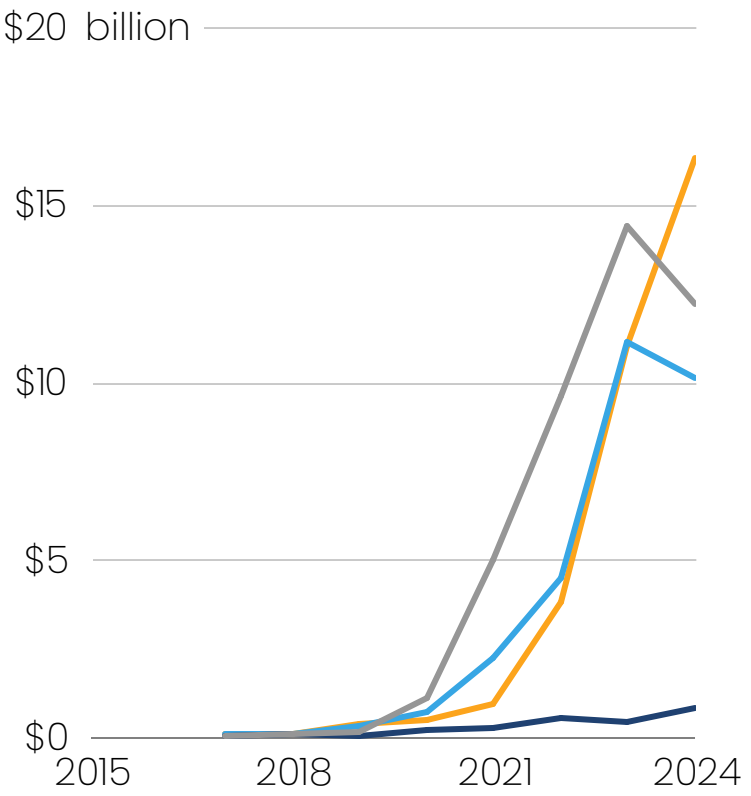
### Solar PV




### Batteries




### Electric vehicles






Sources: Comtrade; Dialogue Earth; Nat Bullard

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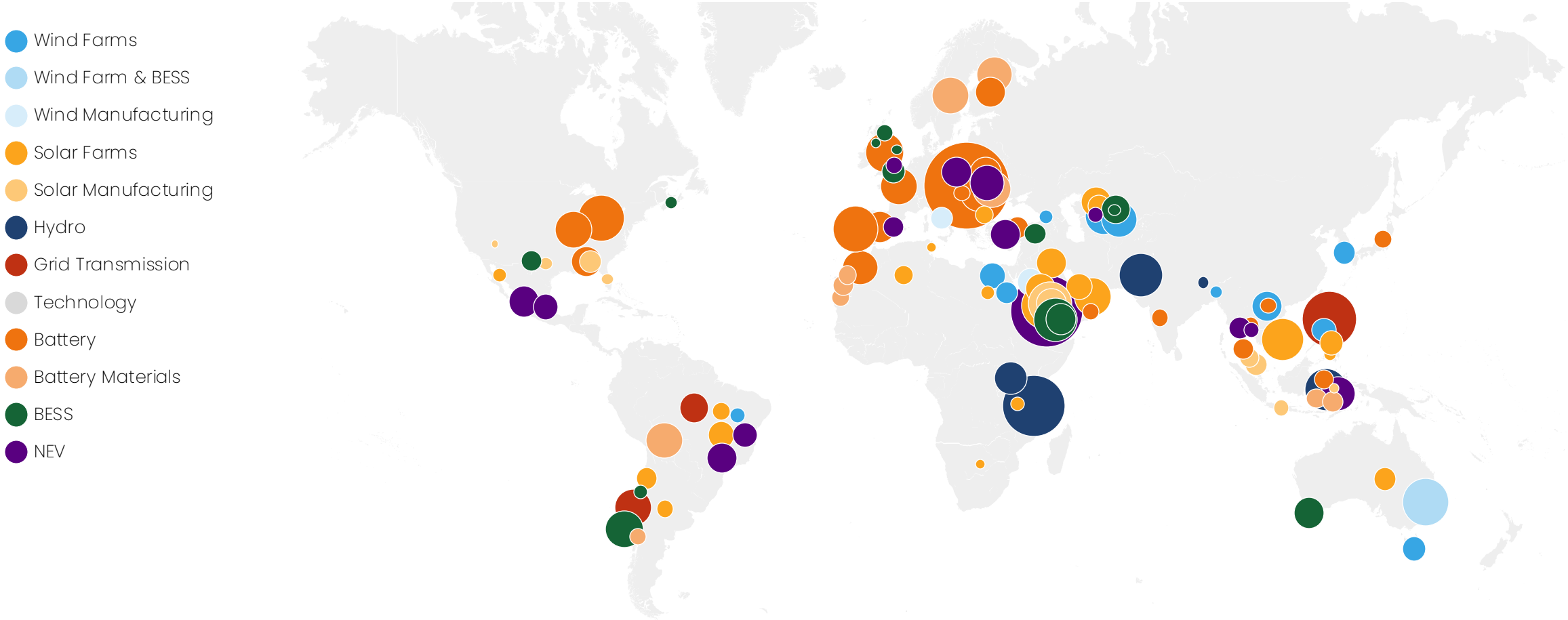
# China is exporting the capacity to build electrotech

Over $100bn of outbound FDI on electrotech since 2023

## Chinese electrotech investment since 2023






Sources: Climate Energy Finance: Power Shift, Ember annotation

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## Chapter 5.1

# Profound impact on the energy system

01

### Electricity 2.0 speeds up change

Electrotech solutions are converging into a river of change which will drive more rapid electrification and a continuation of the growth of renewables up S curves.

02

### The emerging market leapfrog continues

The emerging markets will continue their energy leapfrog, led by the growth nations of Asia. Many emerging markets are deploying renewables more rapidly than developed markets did before them and are electrifying end demand more quickly.

03

### Fossil fuel demand will be in decline by 2030

Fossil fuel demand is on a bumpy plateau at present, but the continued rapid growth of electrotech will increasingly push fossil fuels into decline by the end of the decade. This is substitution not addition. And that creates vulnerability for areas such as refining or LNG.

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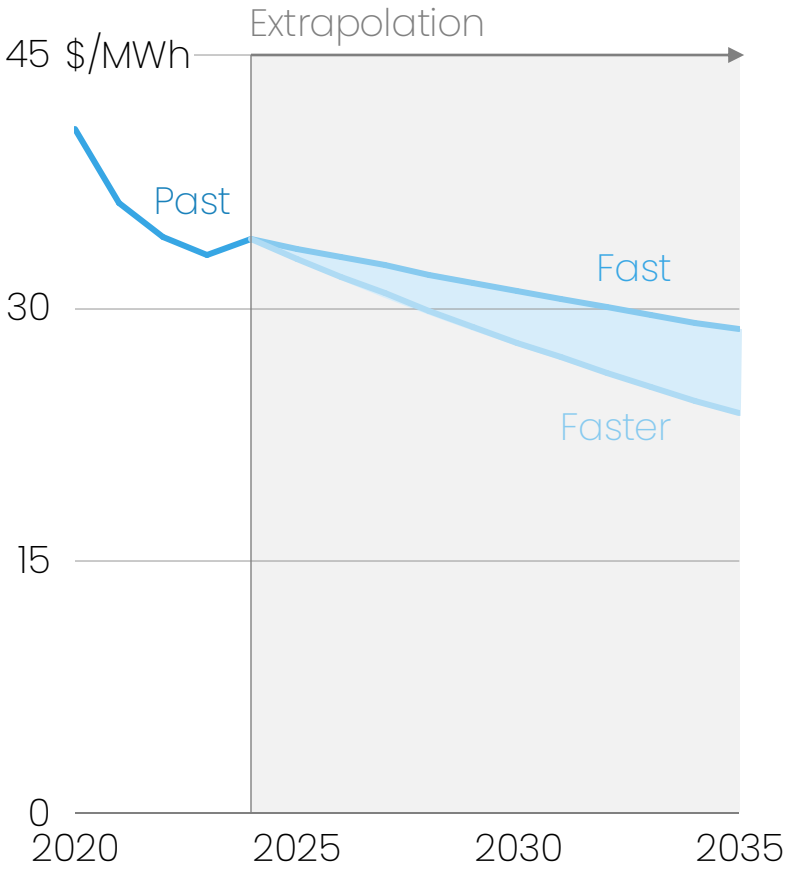
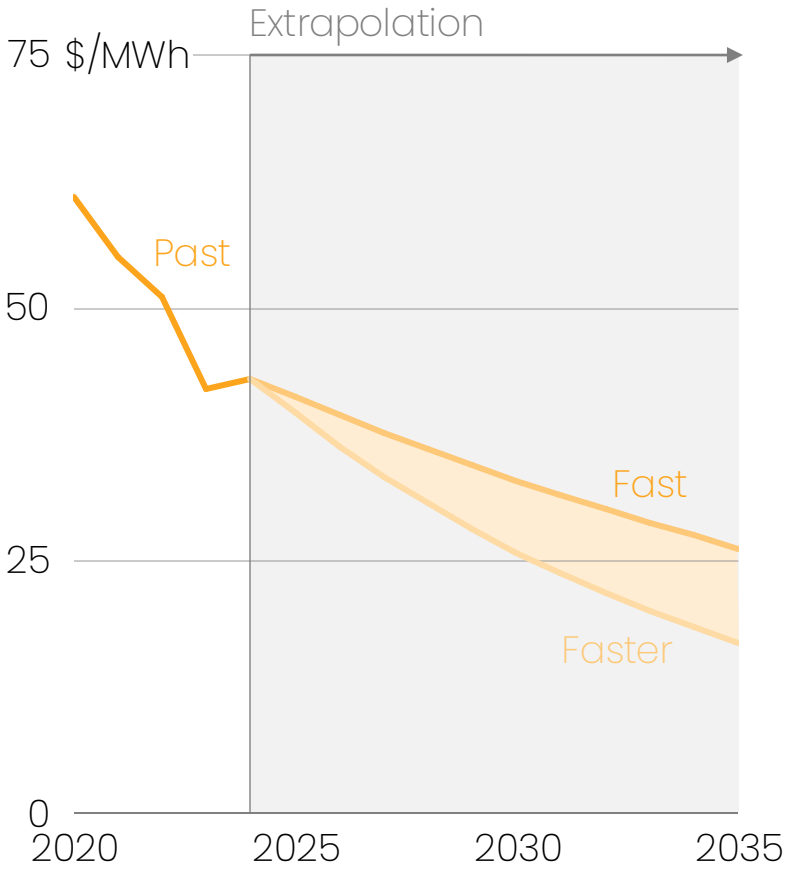
# Electrotech will get cheaper driven by learning curves

From competitive to irresistible

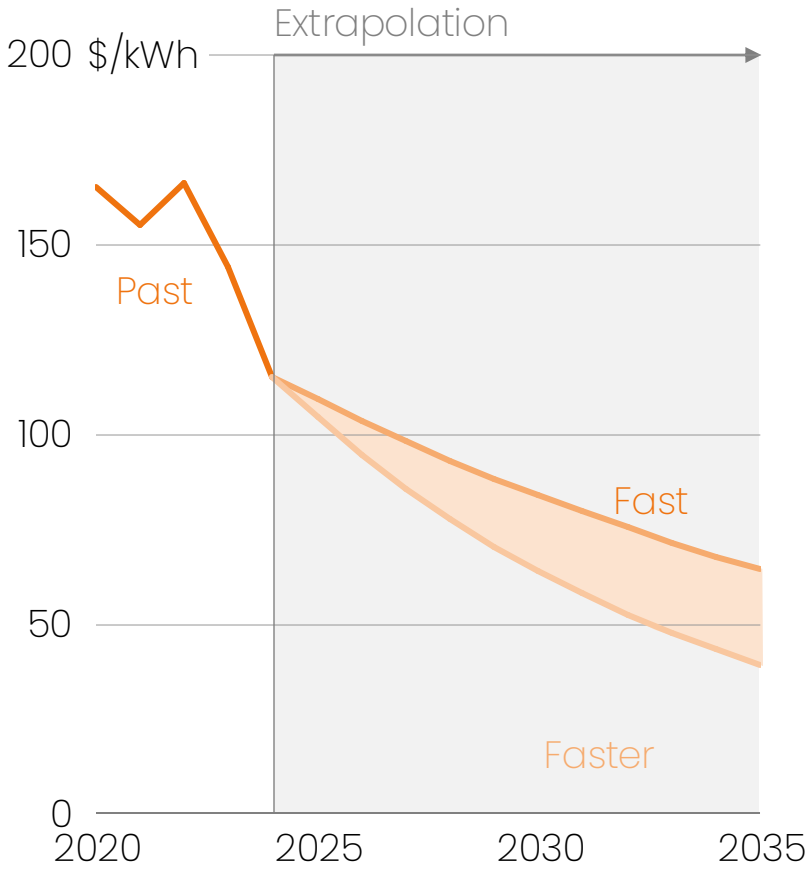
## Wind costs




## Solar costs




## Battery costs




Sources: IRENA, BNEF, Ember Futures extrapolation based on learning rates; a method set out in detail by Oxford INET among others. Costs are derived by extrapolating historic growth rates and learning rates for each of the key technologies for the next decade. Solar assumes growth (g) of 15%-18% and learning rates (LR) of 20-30%. Wind 8-13%(g) growth 12-17% (LR). Batteries 19-22% g & 19-29% LR.



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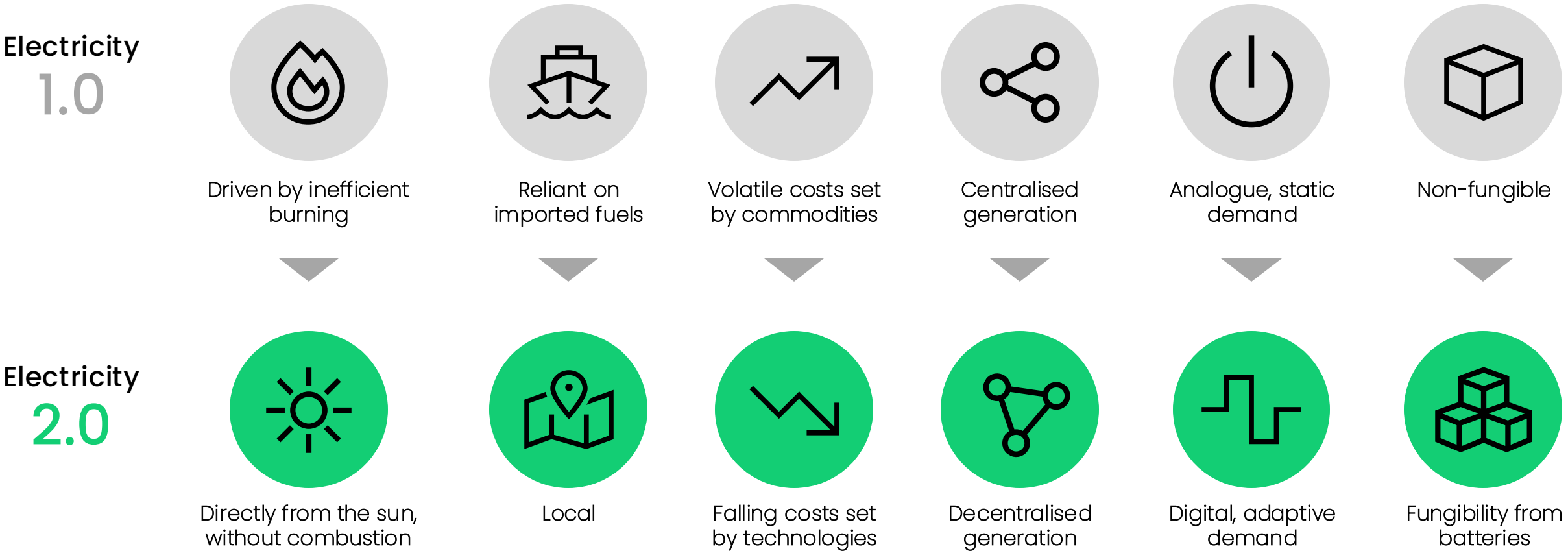
# Electricity 2.0 is here

Electrification will speed up driven by cheaper, more efficient, local and digital electricity

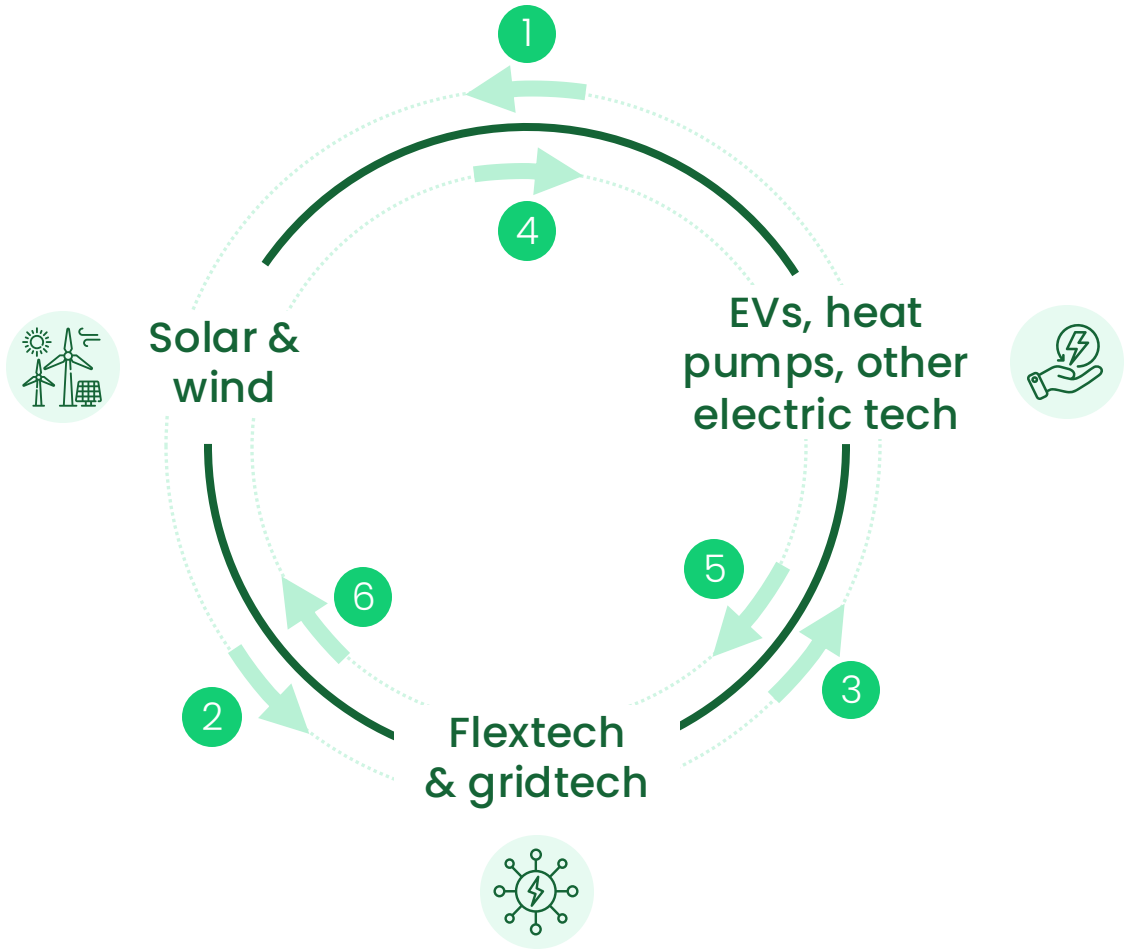





Sources: Ember

# Electrotech unleashes a virtuous spiral

Advances in one area make the other areas more attractive




1. Electrified demand scales renewables, driving costs lower
2. Variable renewables need smoothing and create arbitrage opportunities for flextech
3. Using electricity when it's cheapest incentives demand
4. Cheaper, local renewables make electrifying more attractive
5. More demand to pool & optimise
6. Flex & gridtech enable higher penetration

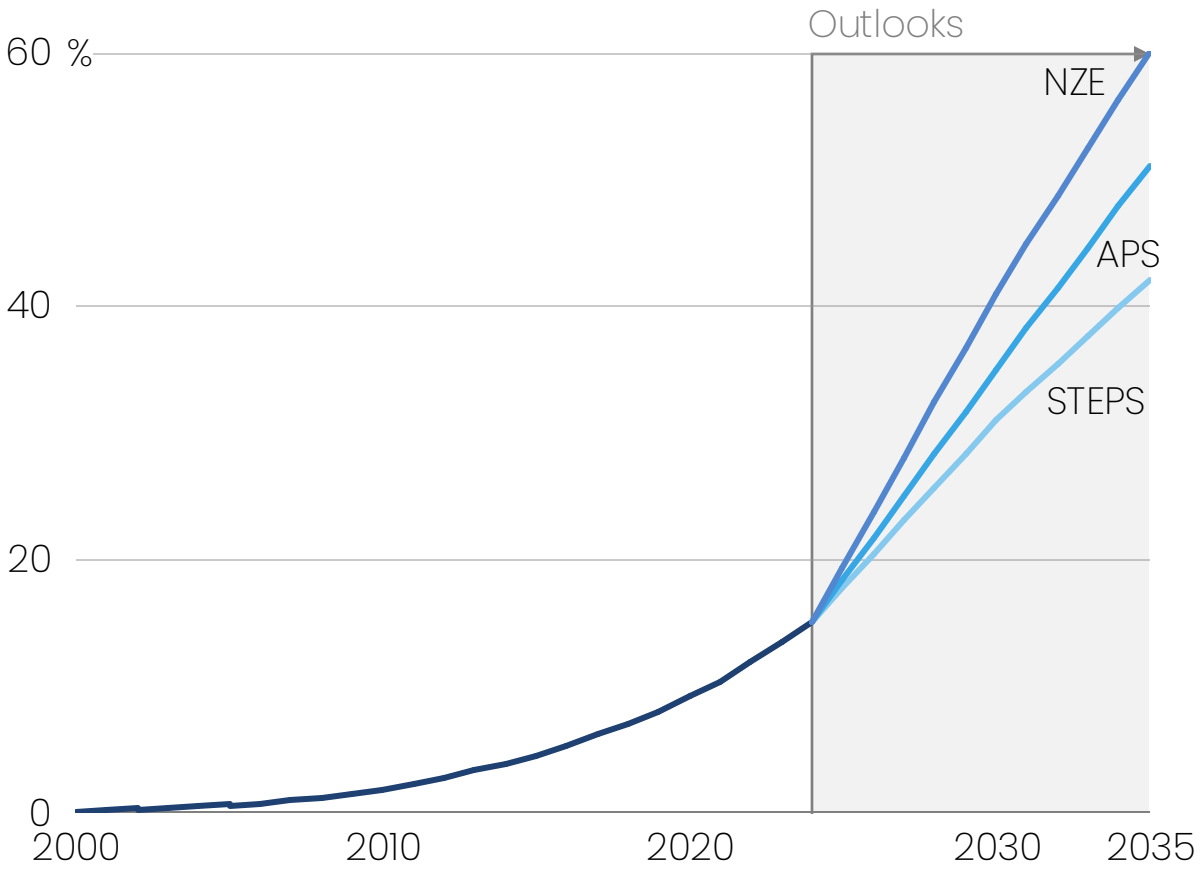


Sources: Ember

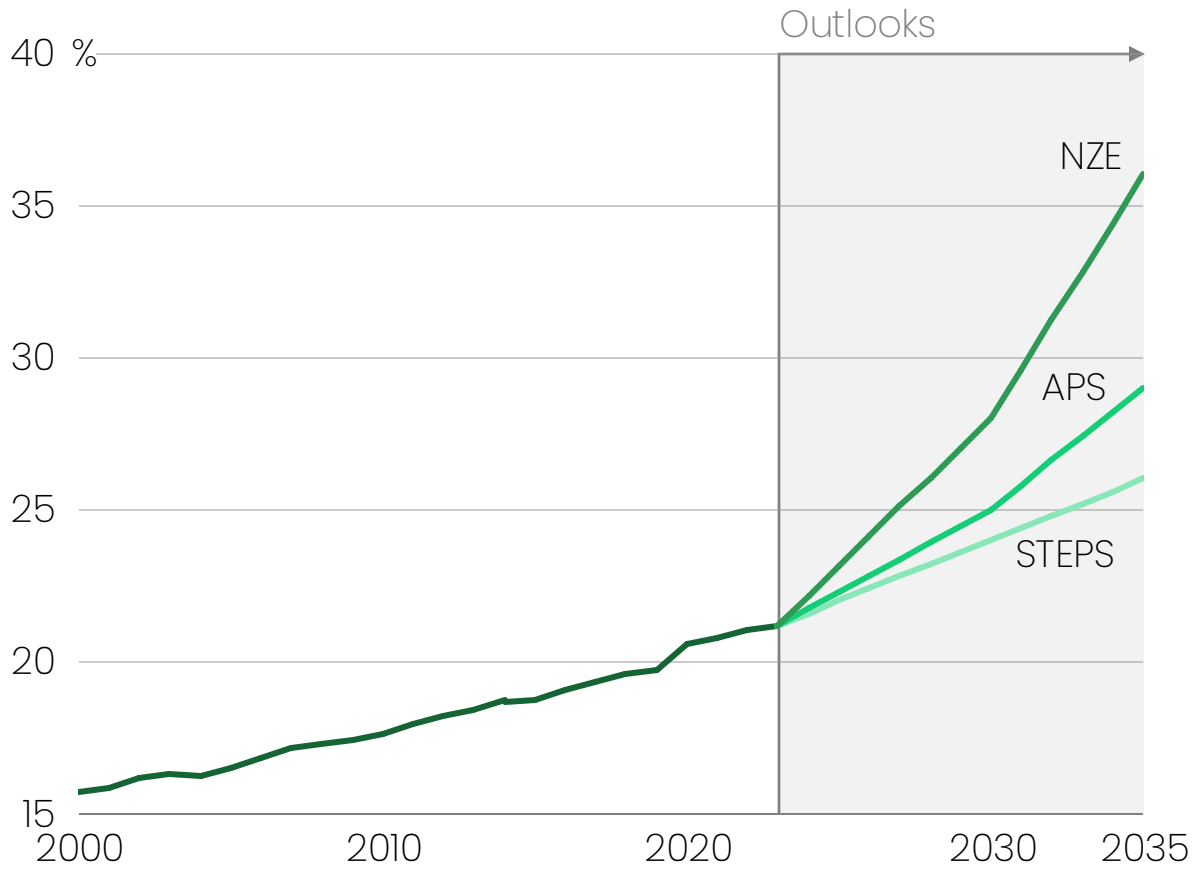
# Renewables and electrification will keep growing

The momentum will continue

## Solar & wind share of global generation




## Electricity share of final energy






Sources: Ember, IEA WEO scenarios. Note NZE stands for (Net Zero), Announced Policies (APS), Stated Policies (STEPS)

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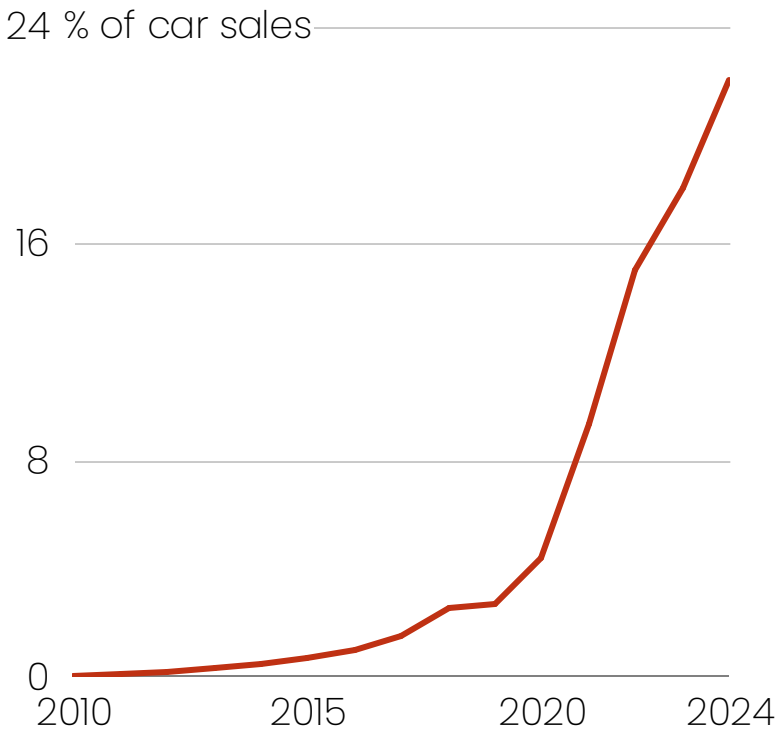
# Don’t expect the road to be smooth

Global curves are smooth; but locally it is a bumpy ride of lagging and leading

## Smooth global curve

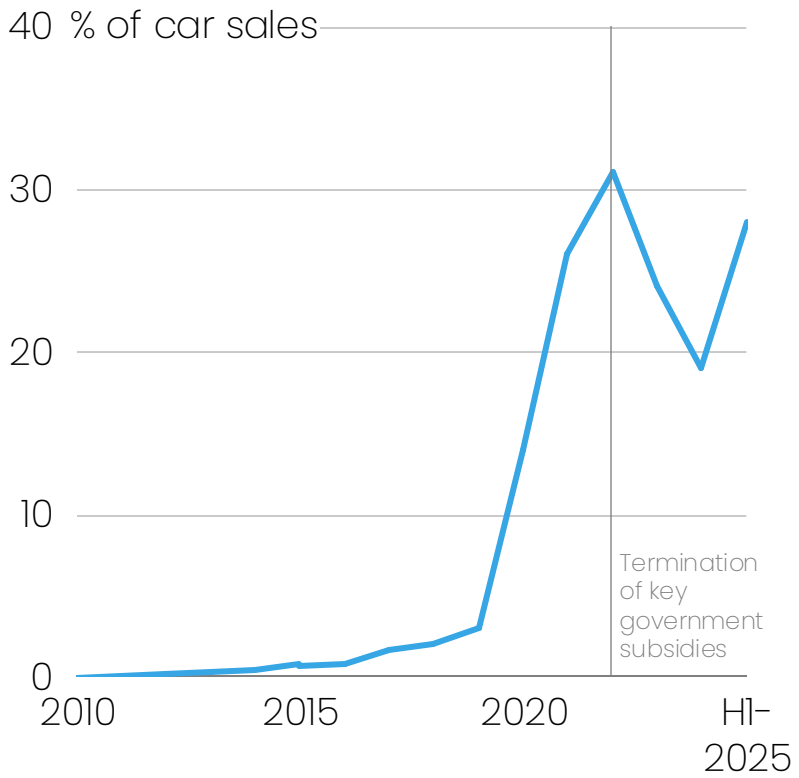
### Global EV car sales




## Bumpy local curves

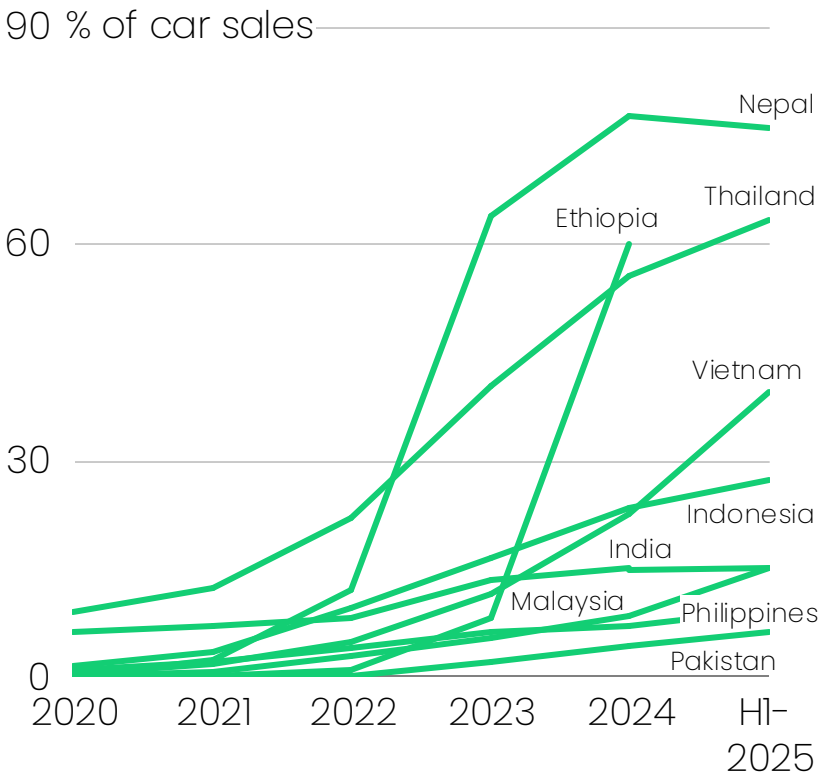
### Larger-than-expected slowdown

Germany EV sales




### Faster-than-expected acceleration

Emerging market EV sales






Sources: IEA; Segment Y via New York Times; Ember analysis

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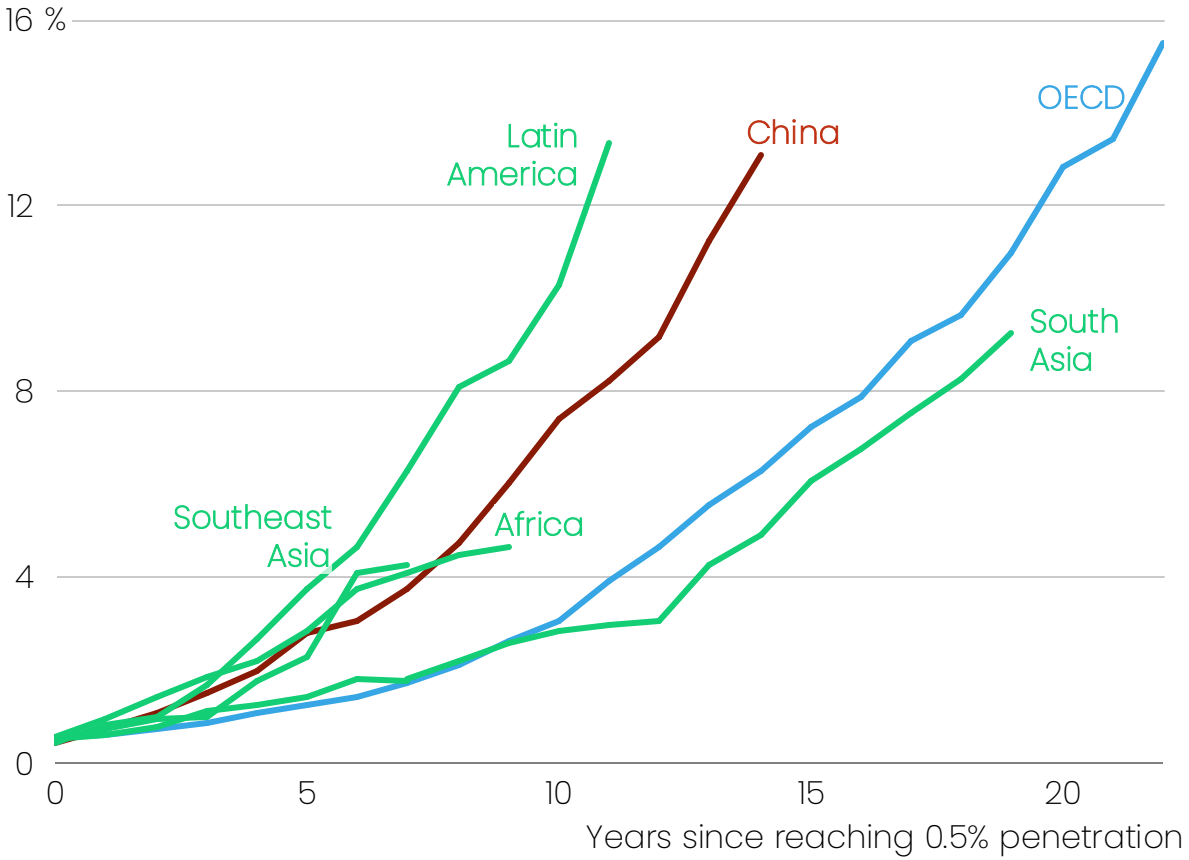
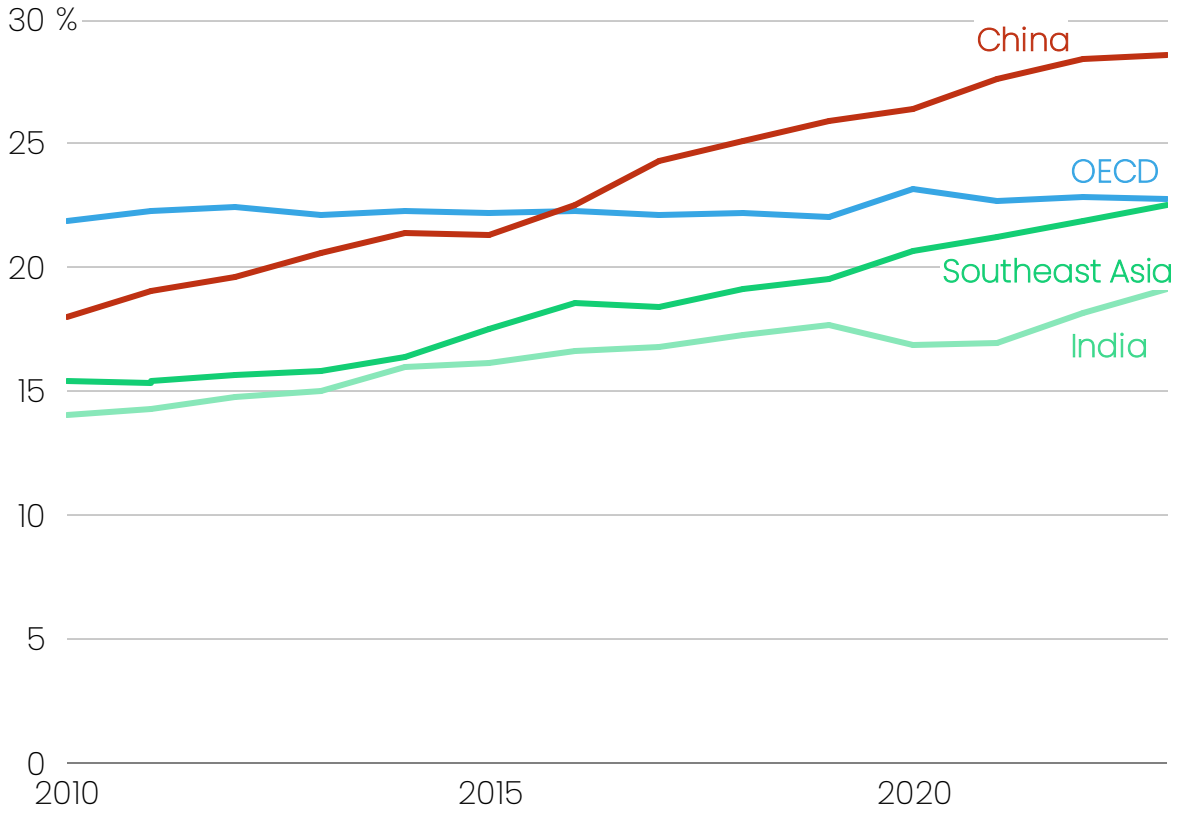
# The emerging market leapfrog has strong momentum

Change is happening faster than in the West

## Solar & wind share of electricity generation, time-shifted




## China and Asia are leapfrogging the OECD in electrification






Sources: IEA, RMI, Ember

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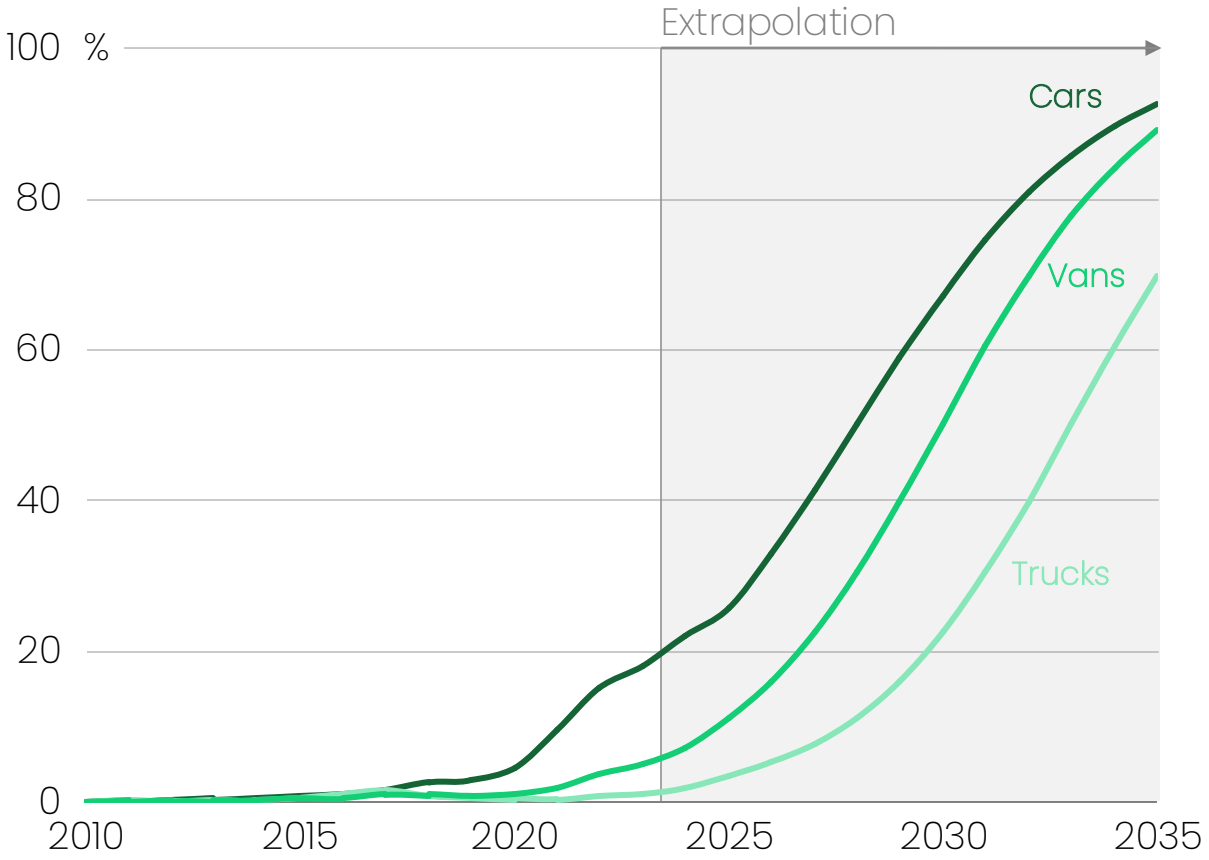
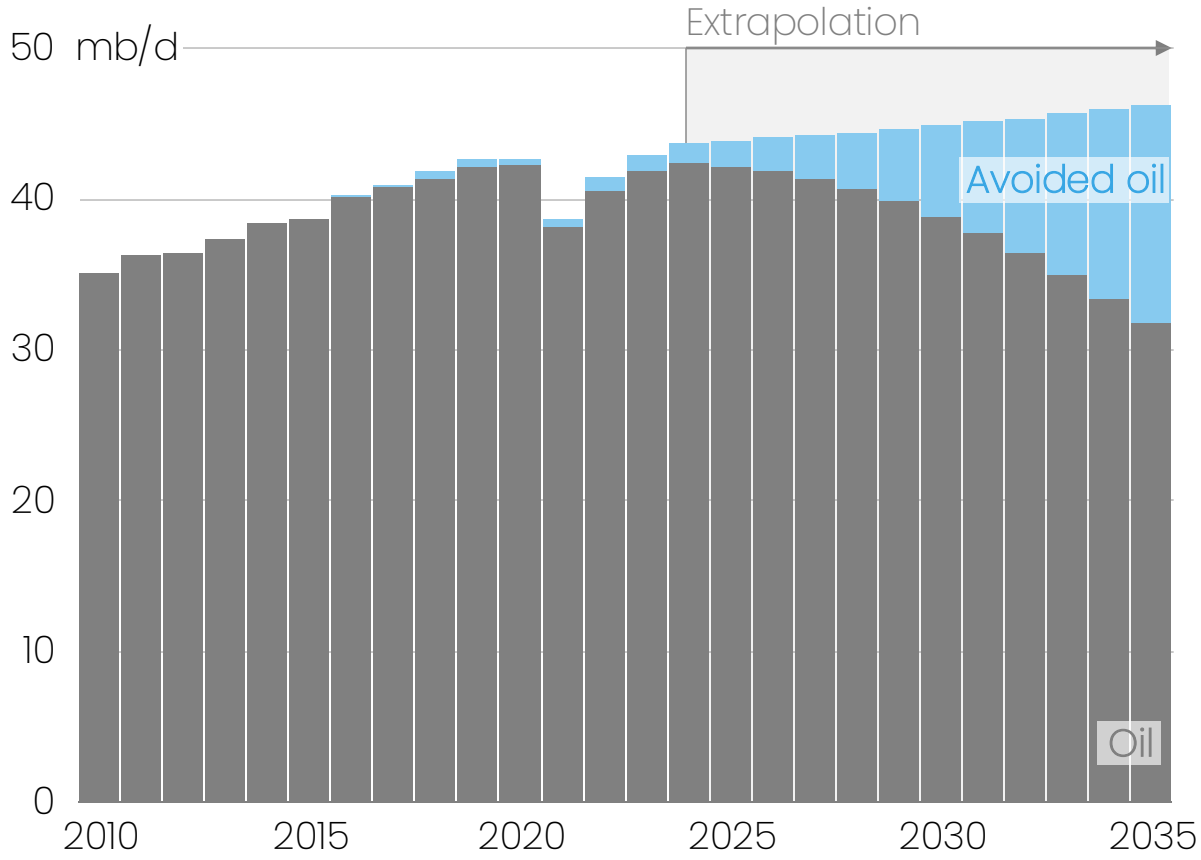
# Road transport is the soft underbelly of the oil system

Sales translate into stocks within 15 years or less

## Electric vehicle sales




## Oil demand for road transport




Sources: IEA (past), Ember Futures extrapolation. EV sales are modelled on logistic S-curves and converted to stocks using a standard scrappage formula.



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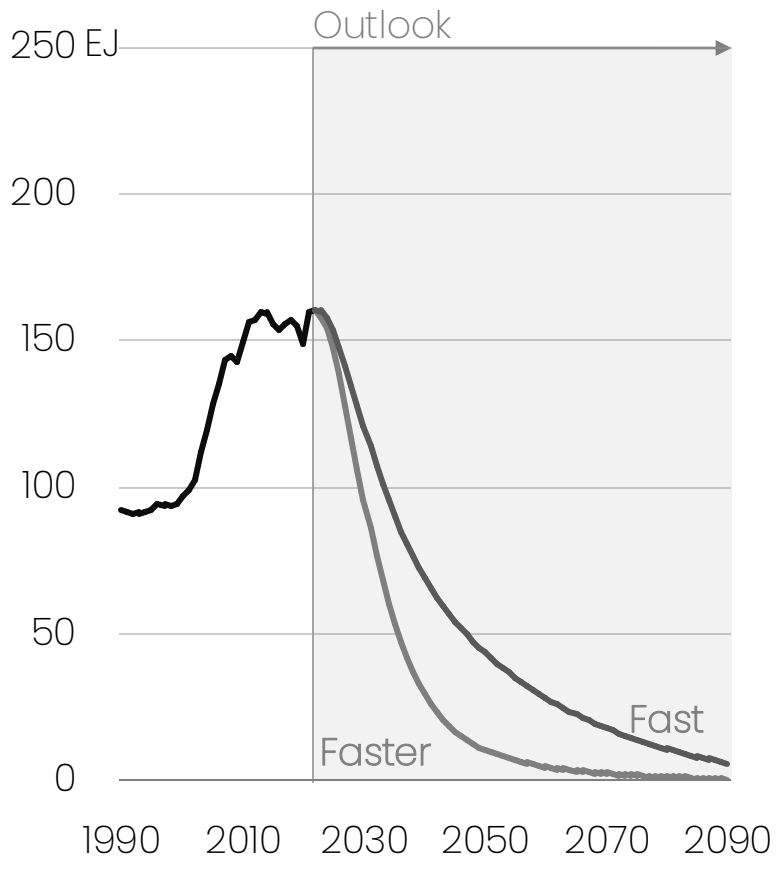
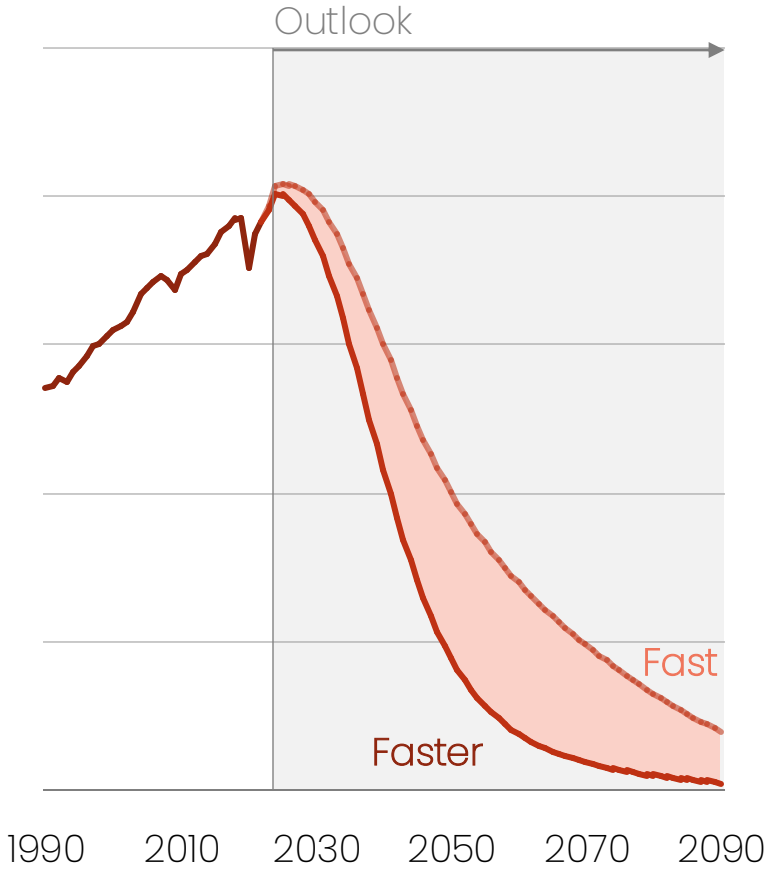
# The growth of electrotech means the decline of fossil fuels

After taking all the growth by the end of this decade, electrotech will start to push fossils out

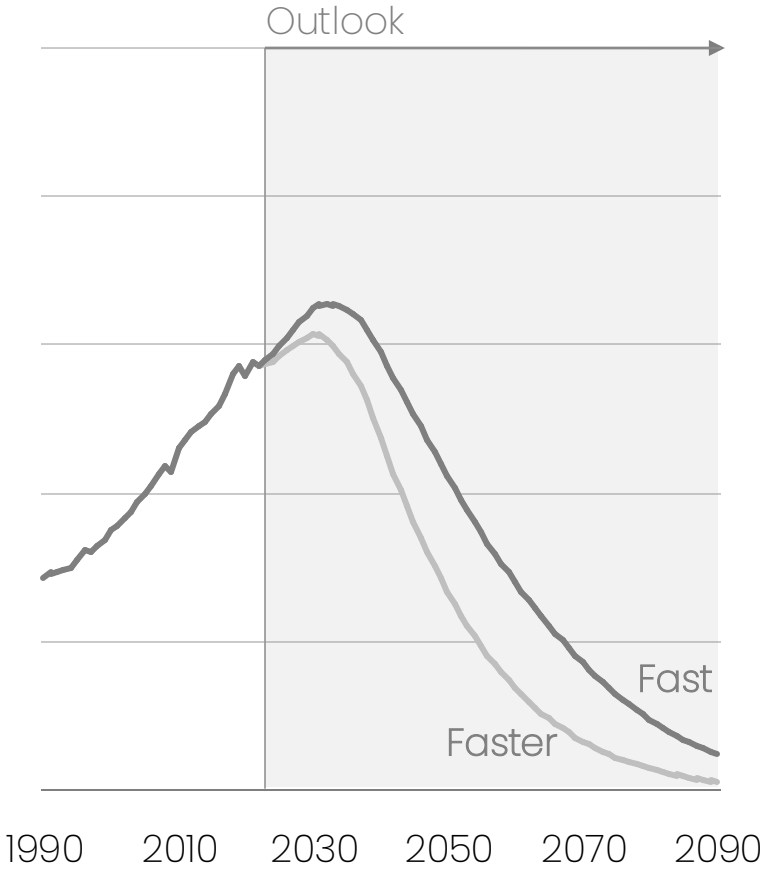
## Global coal demand




## Global oil demand




## Global gas demand






Source: Rystad Energy (Fast 1.8°C, Faster 1.6 °C ), RMI

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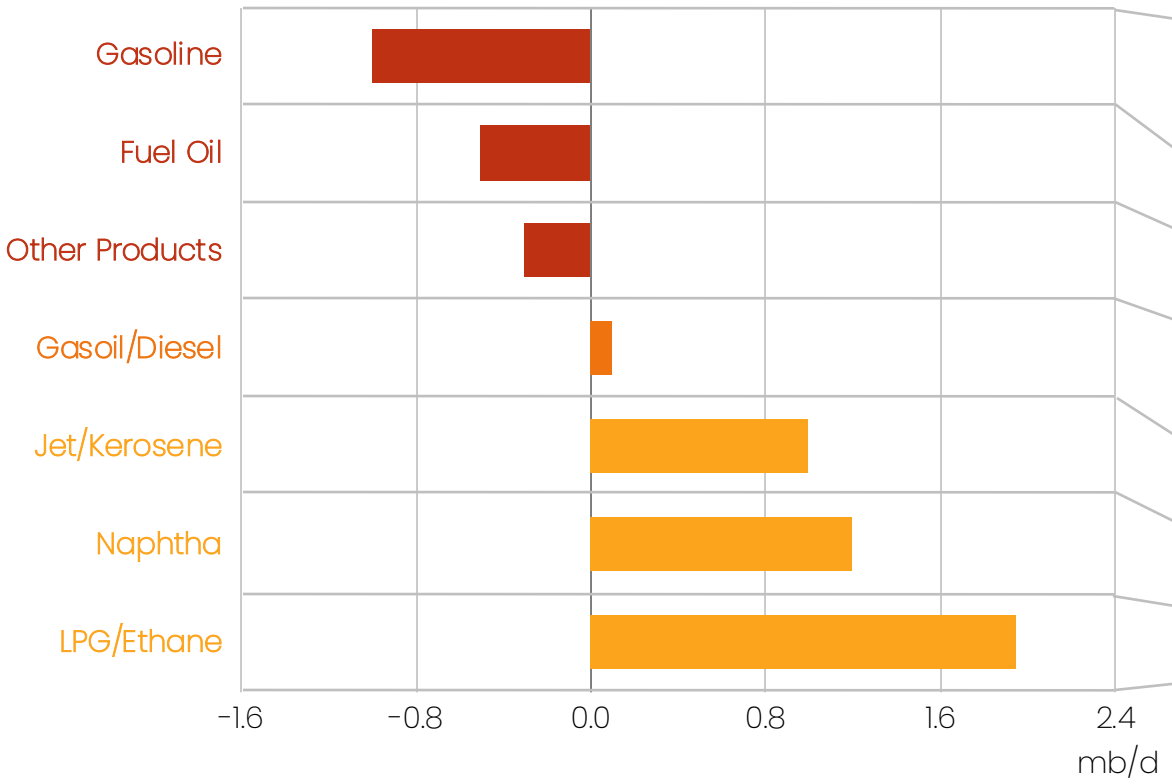
# Skewed oil demand will disrupt refining

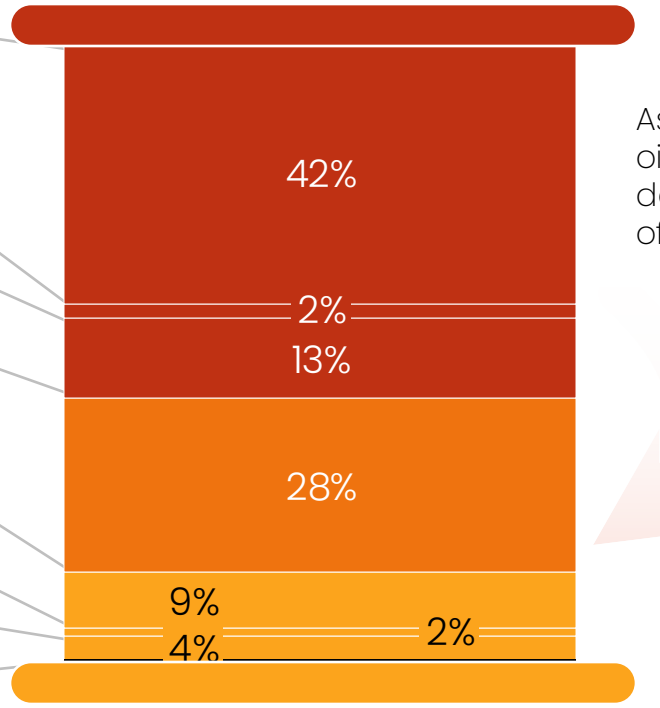
For the first time in history, the demand for a certain part of the barrel will start to structurally decline…

…which will put many refineries which are dependent on gasoline and other product revenues under pressure

## Growth in world oil demand by product, 2024-2030




## Typical yield of one barrel of oil in a refinery




As demand for gasoline, fuel oil and other products falls, it depresses prices for over half of typical refinery output

Only more complex refineries can shift (some) of the barrel to kerosene or other chemical products — many refineries cannot and will struggle



Sources: IEA; EIA; Ember analysis

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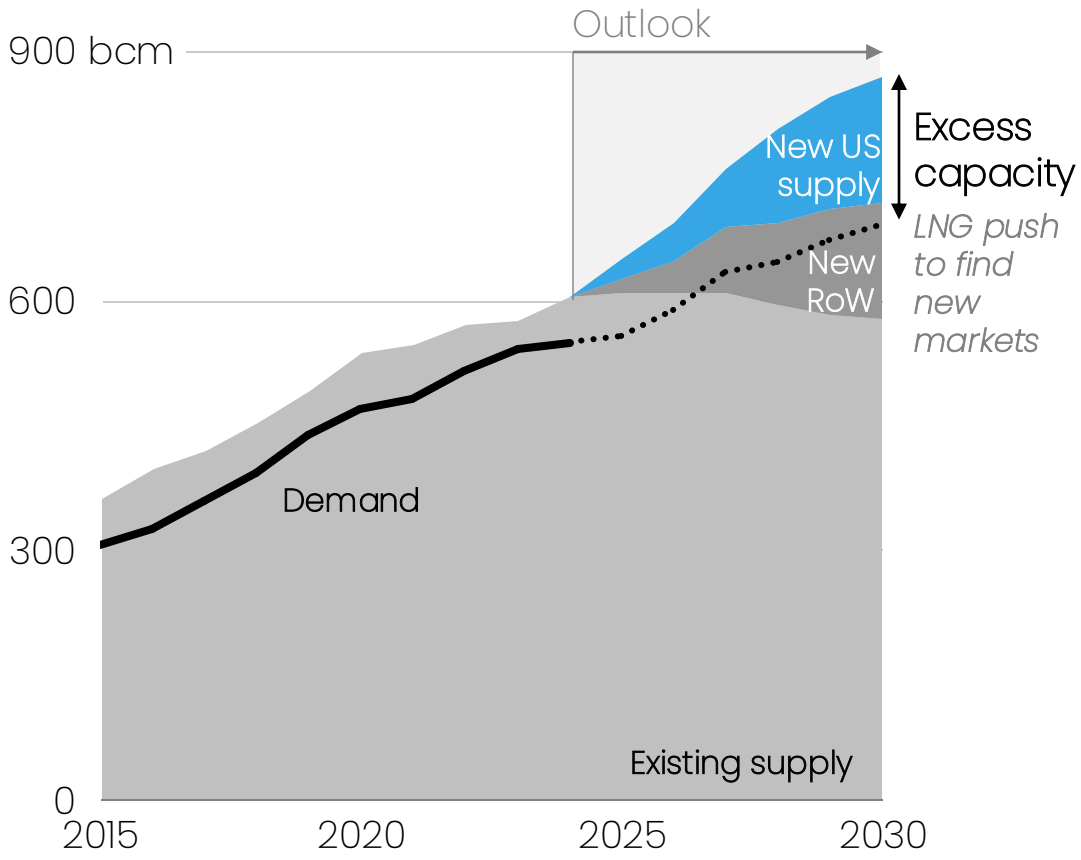
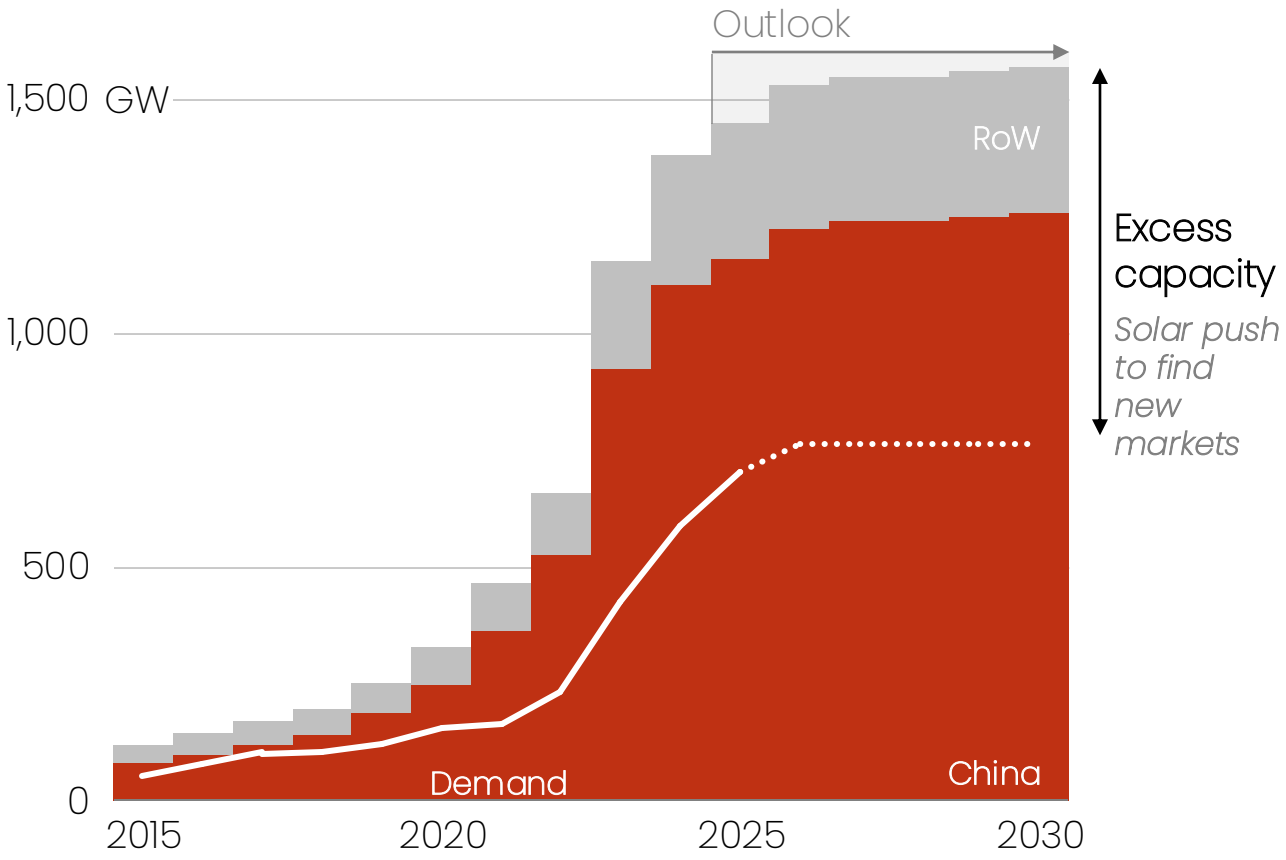
# A battle between overcapacities

LNG versus solar is the great battle for the future of energy

## LNG overcapacity – supply and demand




## Solar PV module overcapacity — supply and demand






Sources: IEA; Ember analysis

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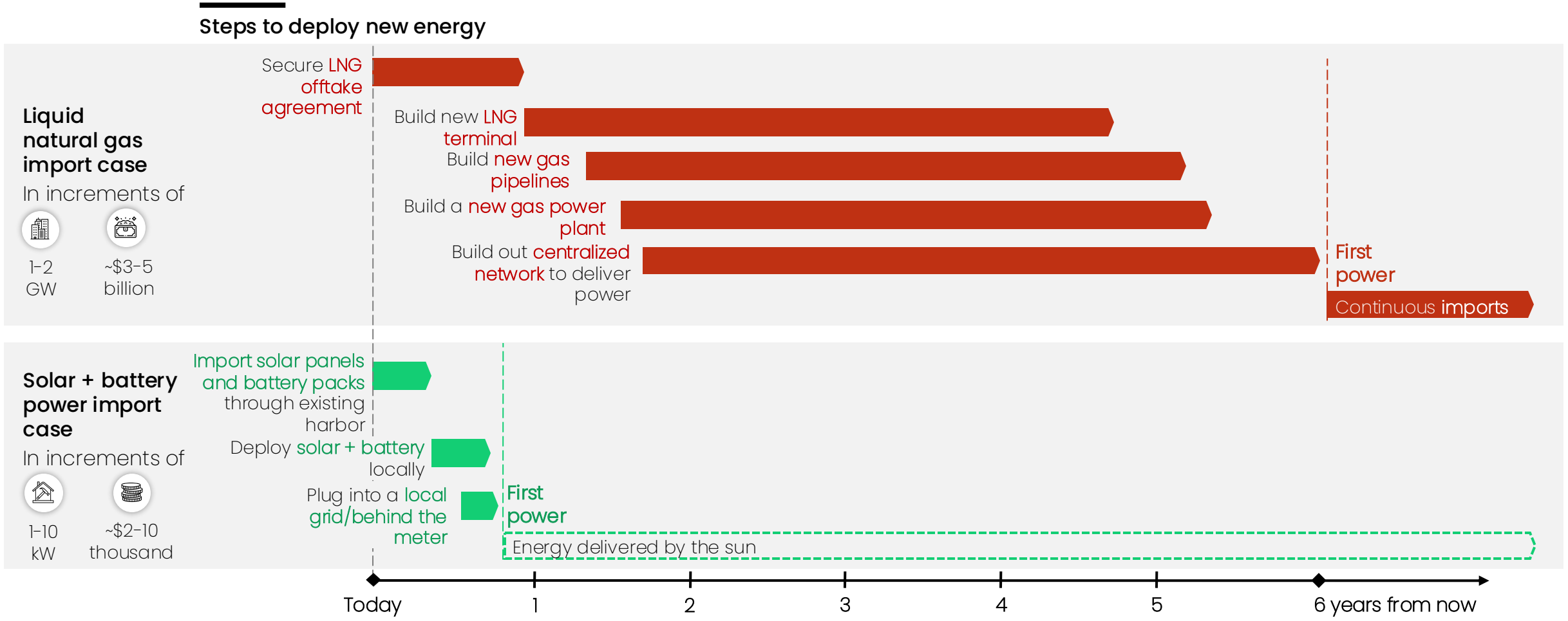
# Solar will win the battle for the energy future

Because solar offers a better deal: more efficient, faster, cheaper, and local






Sources: Rystad, Ember analysis • Note: timelines are averages and indicative

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## Chapter 5.2
# Wider implications of changes in energy

01

### Energy change means system change

IT and AI have brought the marginal cost of information down to the marginal cost of electricity. Electrotech is now doing the same for energy itself, pushing its marginal cost toward zero. Together, this unlocks a world of abundant energy and information. That means the end of oil intensive development.

02

### Winners will be digital and solar-powered

A new class of industrial nations will rise—those with both abundant sunlight and the AI to harness it. The opportunity is greatest in the global sunbelt.

03

### Losers will be those who cling to the old

As fossil demand slips off the plateau, price swings will intensify—triggering crises for countries and companies that remain dependent on fossil revenues for too long. Fossil assets at the top of the cost curve will be stranded, and returns to new fossil projects will disappoint.

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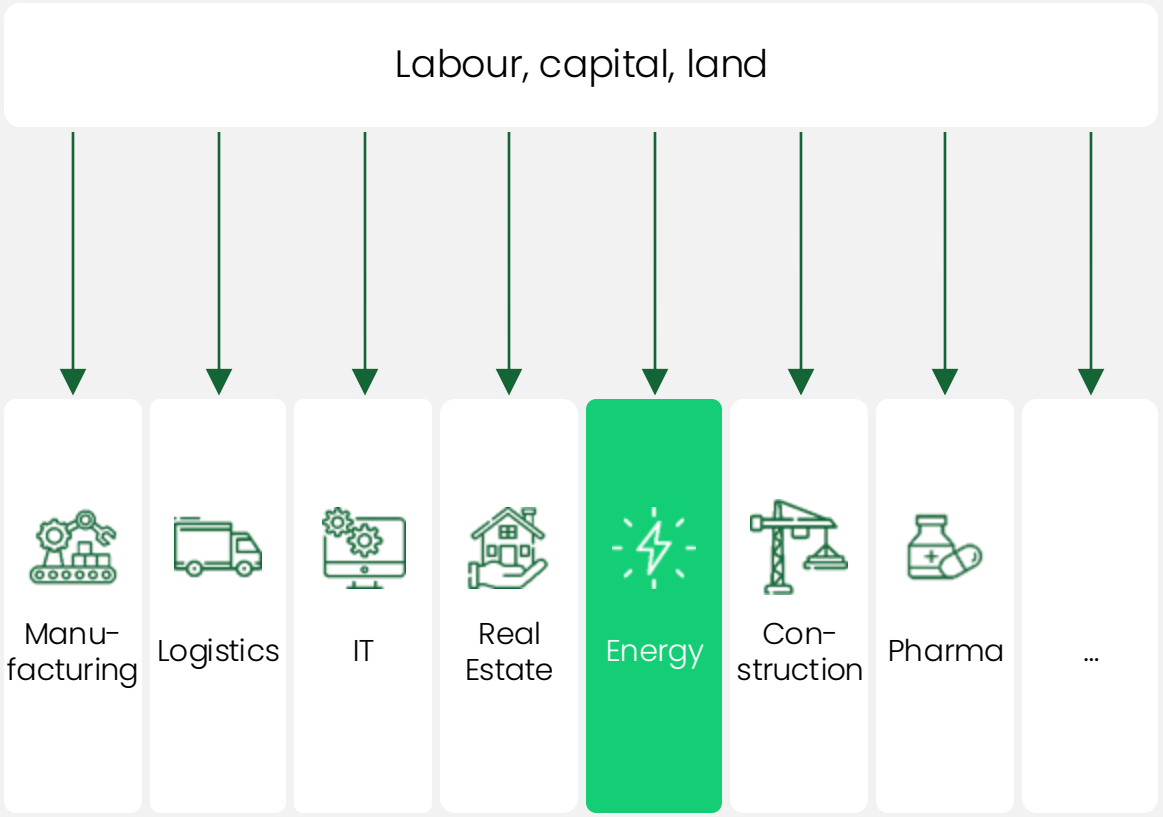
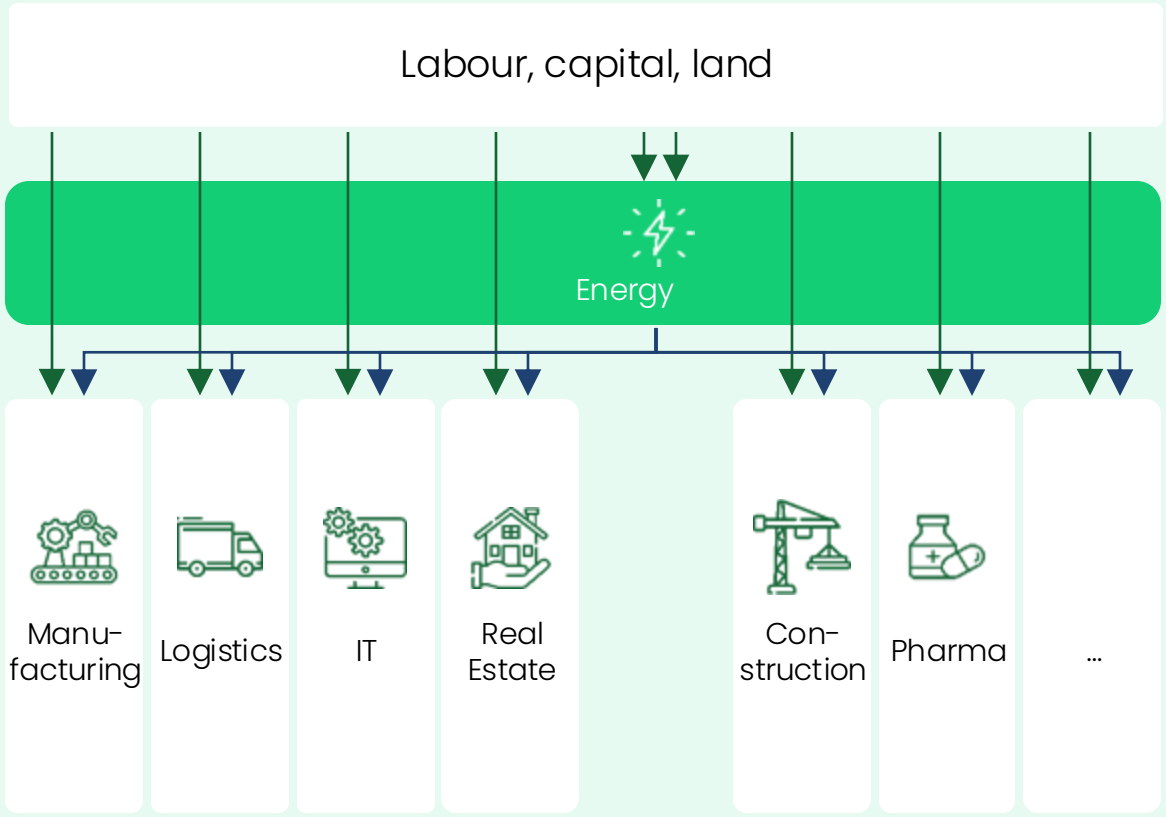
# Everything is driven by energy

So energy transition means economic transition

## The conventional, wrong view of the energy sector




## The more accurate, systemic view of the energy sector






Sources: Ember

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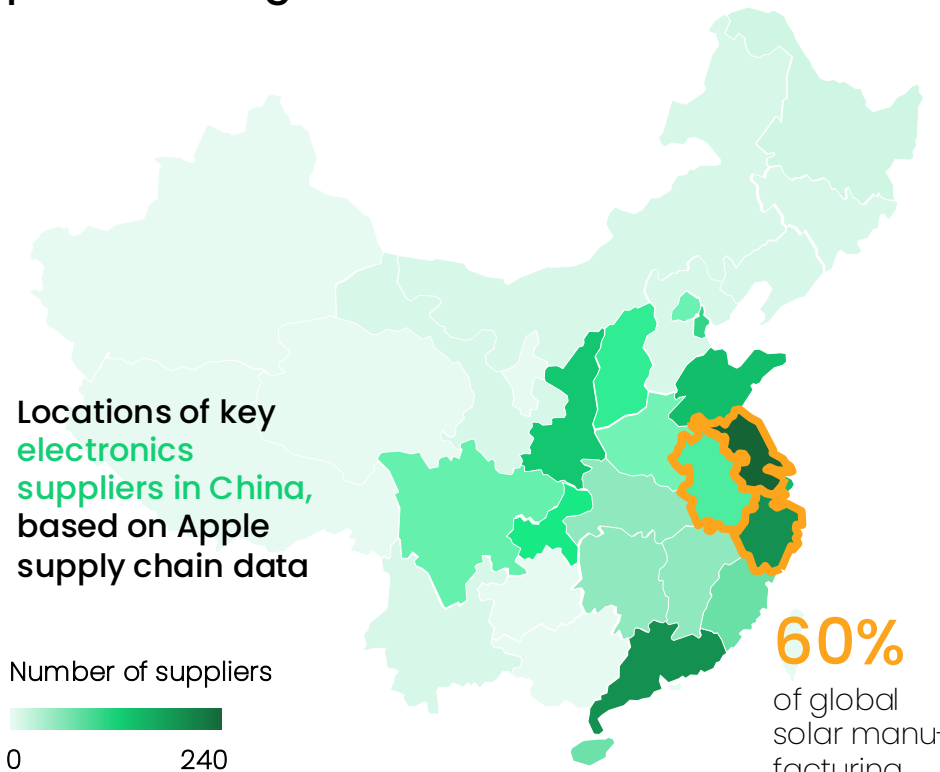
# Tech is coming for the energy sector

The same people and places that made digital tech, mainly in China, are now making electrotech

ILLUSTRATIVE AND NON-EXHAUSTIVE

## Electrotech is manufactured in the same places as digital tech




**60%** of global solar manu-facturing capacity

## Many electrotech leaders started in digital tech

CATL

**Robin Zeng Yuqun**

*Founder & Chairman*

Spent a decade at ATL developing Li-polymer batteries for iPhones and other smartphones

BYD

**Wang Chuanfu**

*Founder, Chairman & CEO*

As GM at BAK Battery Co., scaled Li-ion cells for Nokia & Motorola phones

SUNTECH

**Shi Zhengrong**

*Founder & Chairman (until 2013)*

Led thin-film PV R&D at UNSW, pioneering semiconductor-style solar cell fabrication before commercial scale-up.

NIO

**William Li (Li Bin)**

*Co-founder & CEO*

Built Bitauto app as an online auto-services platform, before starting Nio

LONGi

**Li Zhenguo**

*Founder & President*

Early role at Huashan Semiconductor Materials, processing wafers for PC & mobile chips, building semiconductor expertise.

XPENG

**He Xiaopeng**

*Co-founder & Chairman*

Co-founded UCWeb, developing China's leading mobile-browser, then applied that mobile-tech know-how to EVs.

NEBULA

**Huang Shilin**

*Former Vice Chairman & Deputy GM, CATL*

Spun off ATL's CE-battery arm into EV focus, leveraging his battery-tech background in consumer electronics.

Li Auto

**Li Xiang**

*Founder, Chairman & CEO*

Created Autohome as a data-driven car-sales & AI platform, blending digital-marketing and automotive retail.

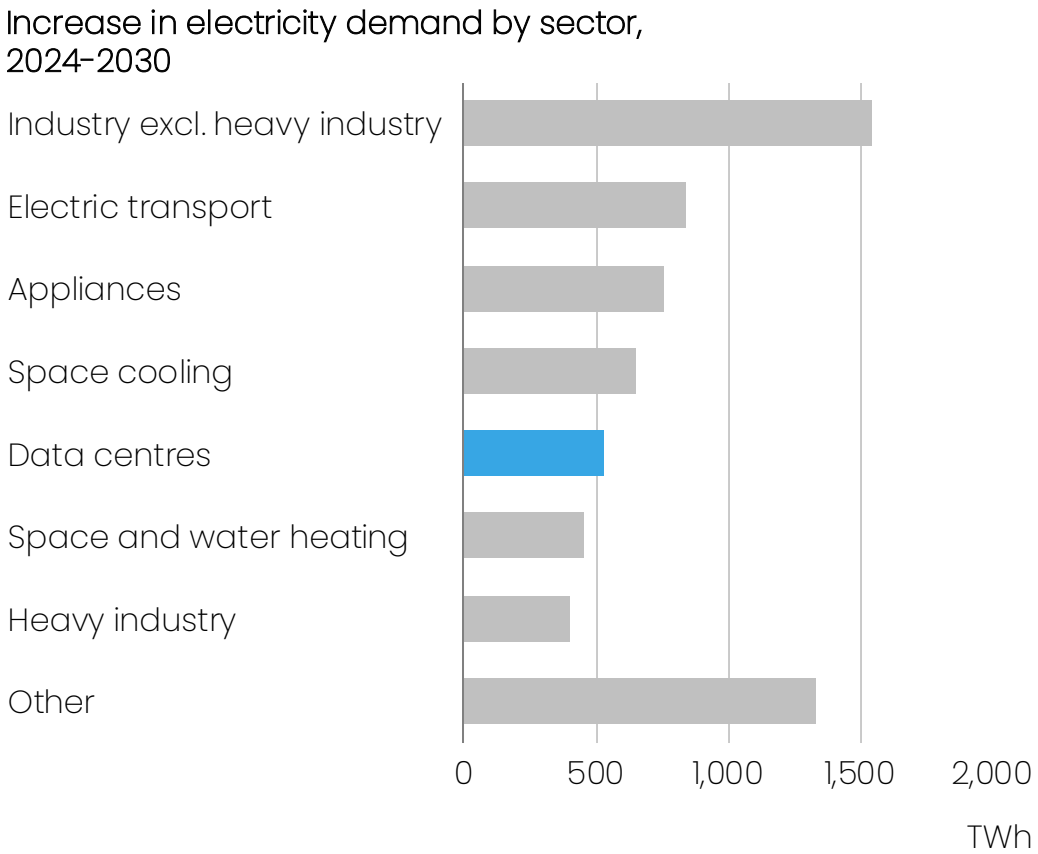


Sources: RMI; Bloomberg; FT; Apple; Ember analysis; Company websites; Press search

# AI accelerates change

AI may raise electricity demand, but it is of tremendous benefit to scaling electrotech

## AI energy demand growth in context




## Impact of scaling AI on electrotech, examples

- Predictive maintenance
- Autonomous operations
- Smart charging
- Adaptive heating
- Grid optimisation
- Battery longevity
- Materials discovery
- Power-electronics tuning
- Automated permitting



Sources: IEA Energy and AI; Ember analysis

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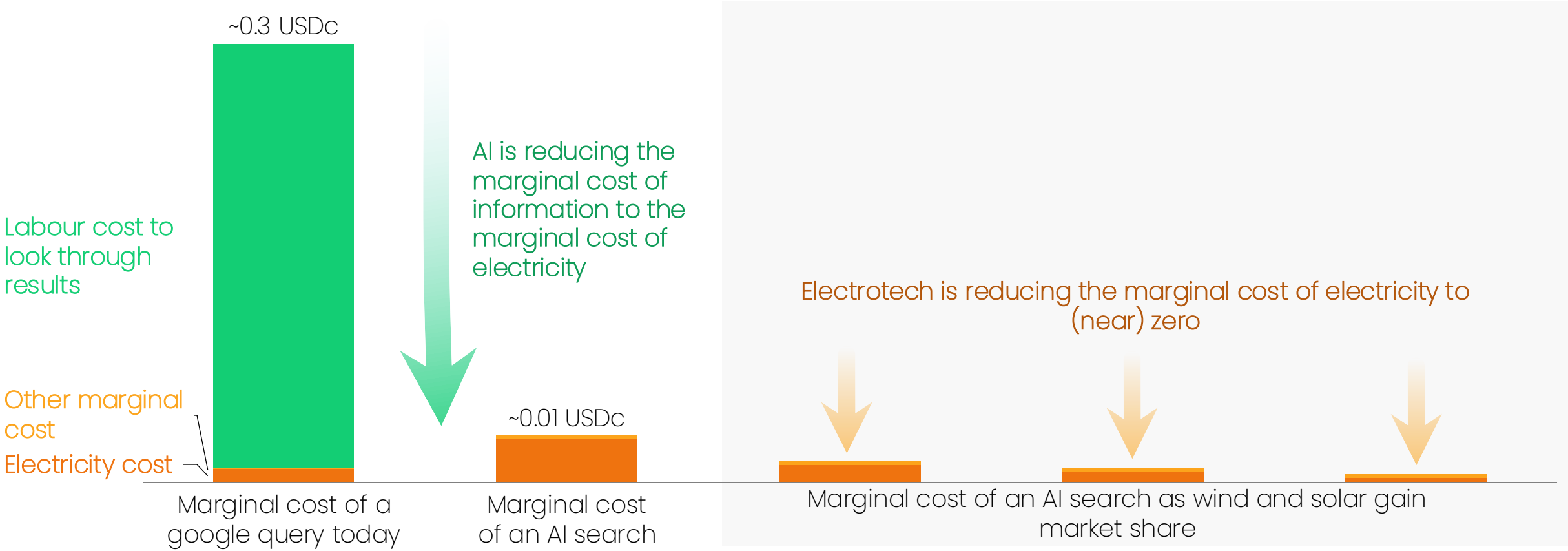
# The zero marginal cost economy is coming

Between AI and electrotech, the marginal cost of energy and information will fall dramatically

ILLUSTRATIVE

## Cost of information






Sources: Google; Ember analysis • Note: this page focuses on marginal cost, not levelized cost; i.e., without capex write-offs

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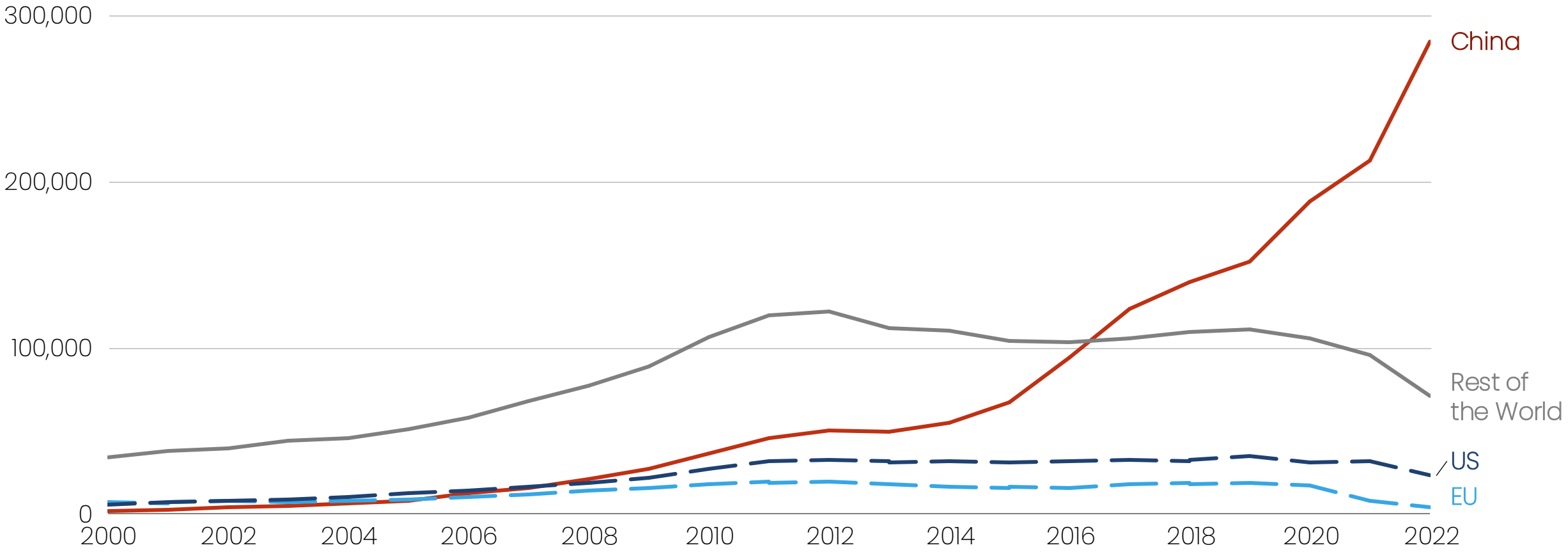
# The energy technology frontier has moved East

Patents are a leading indicator of where the leading companies of the future will be

## Annual applications for patents in clean energy technologies





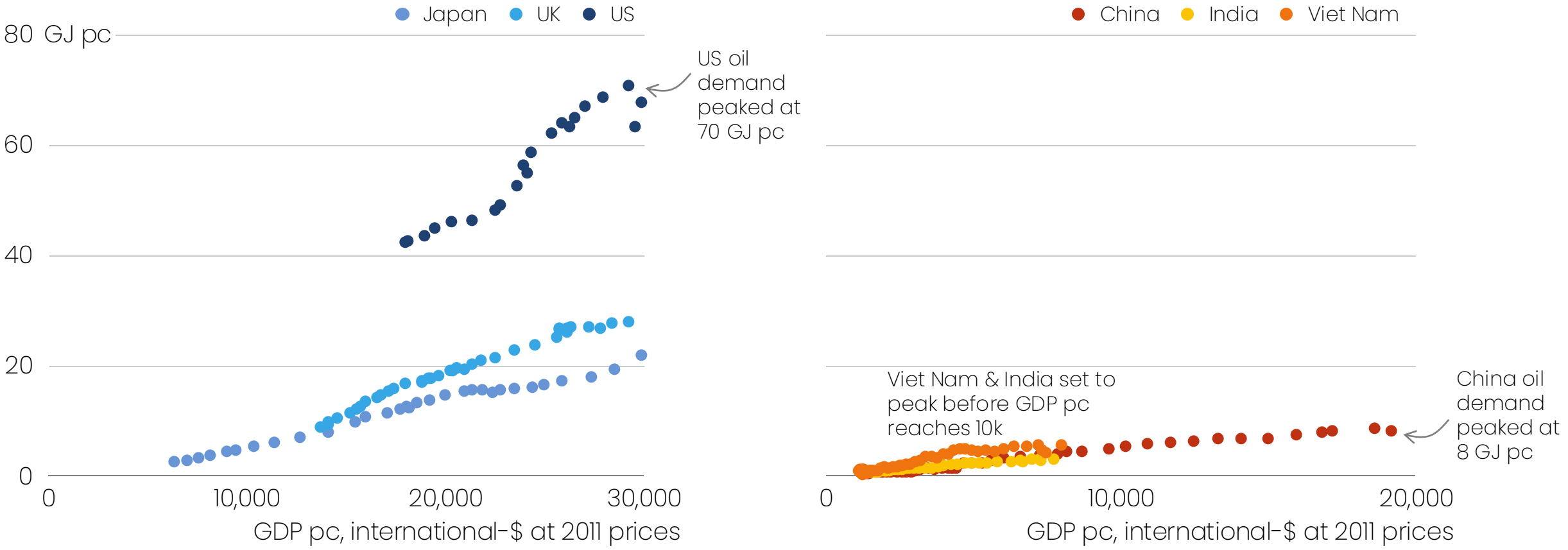

Sources: IRENA, Ember analysis

EMBER

# The end of oil-intensive development

China's per capita road oil demand peaked at a tenth of US levels – other emerging markets are set to follow

**Per capita road oil demand and GDP**






Sources: Maddison (via OWID), IEA WEB; Ember analysis. Note: LHS x-axis ends at 30k pc.

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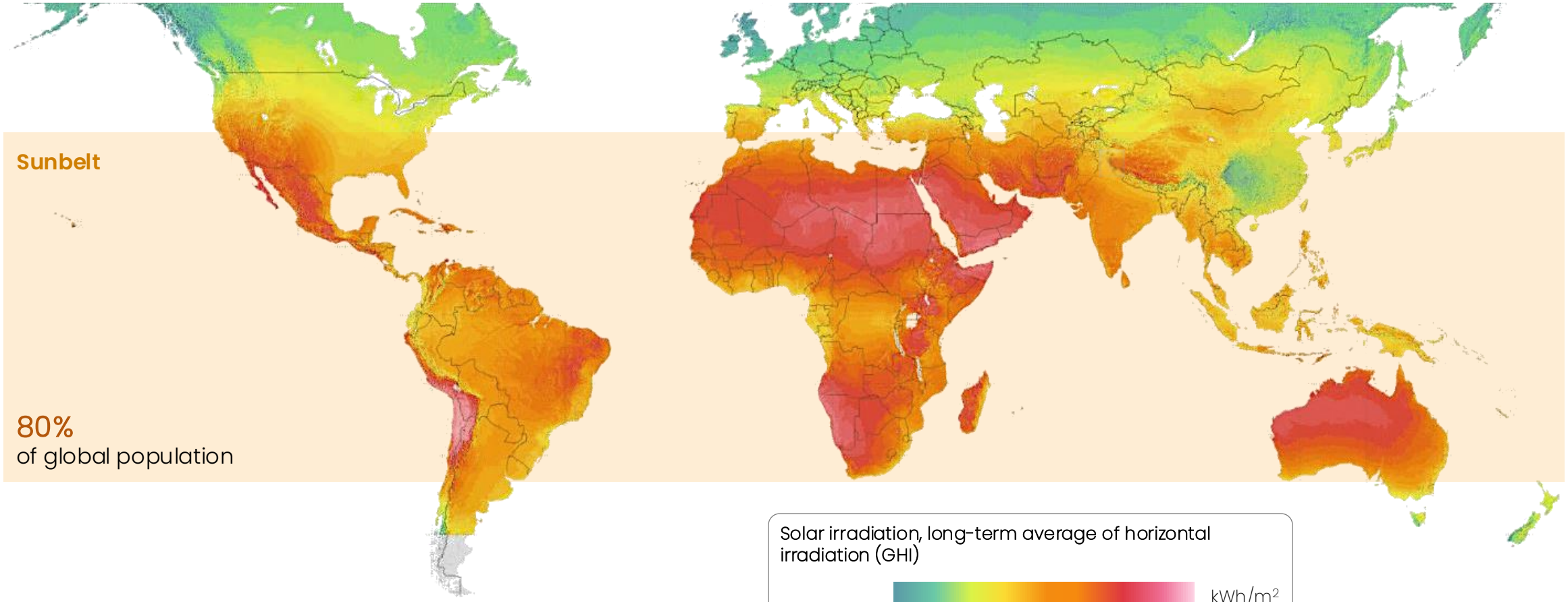
# Electrotech liberates the power of the Sunbelt

The emerging markets will have the lowest electricity cost






Sources: Global Solar Atlas, Ember. Map boundaries do not imply any judgment on legal status or sovereignty.
ETC for long-term forecasts of electricity costs by region

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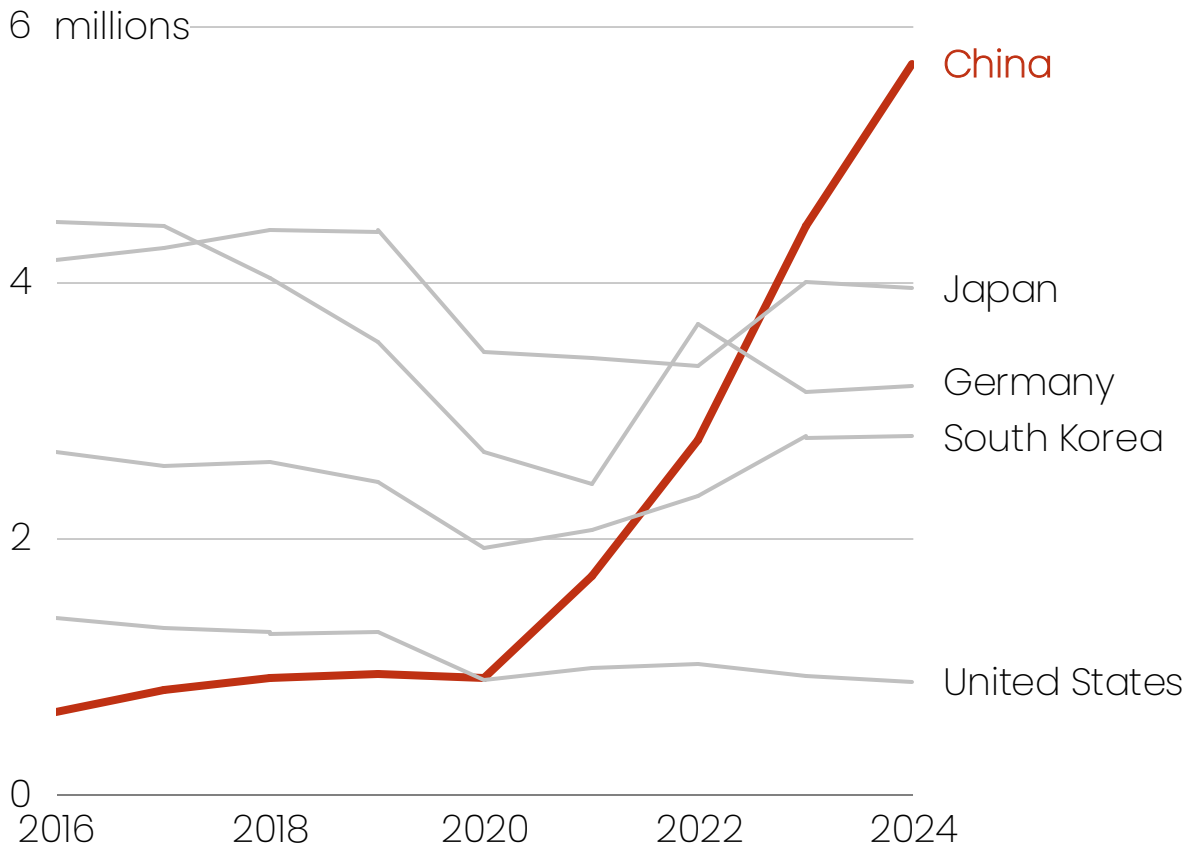
# The automotive sector is a warning sign for other industries

In four years, China went from small to dominant

## Car exports: China is taking over, enabled by EVs




## Role of automotive in selected economies




Sources: Alix Partners, NYT, OICA, Wikipedia • Note: 2024 values are estimated.

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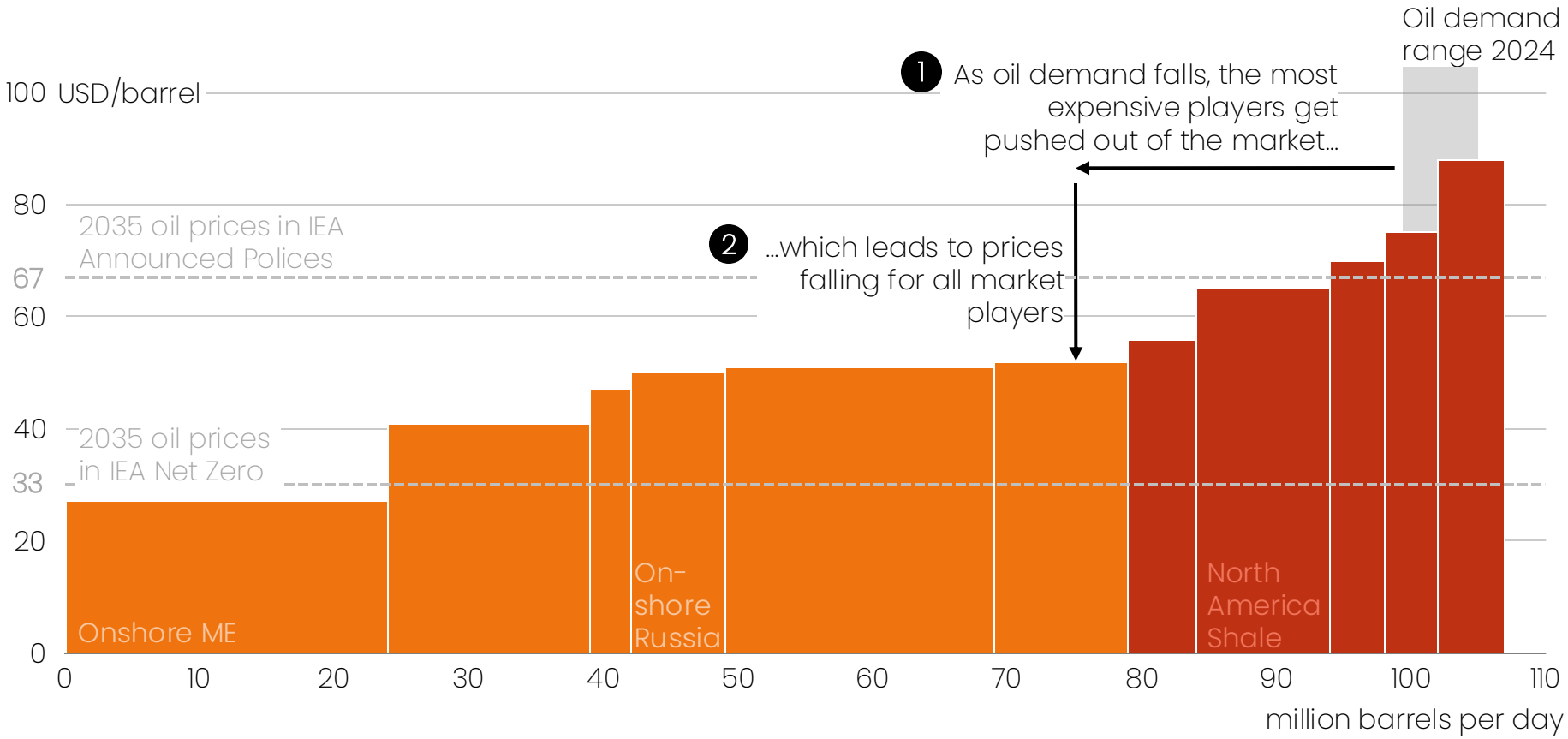
# The first few million barrels decline will hurt

Companies and countries dependent on the price of oil will face hardship as prices fall

## Global oil supply cost curve




## Notes

1. Top quartile is dominated by independents and majors, and fewer national oil companies. Even a few percent decline in oil demand can evaporate most of the production of some players.

2. Many petrostates need oil prices well over $50/bbl to have government finances break even:

Fiscal breakeven oil price

- Saudi Arabia: $98/barrel
- Iraq: $84/barrel
- Kuwait: $88/barrel
- UAE: $51/barrel



Sources: Rystad; IEA; Ember Analysis

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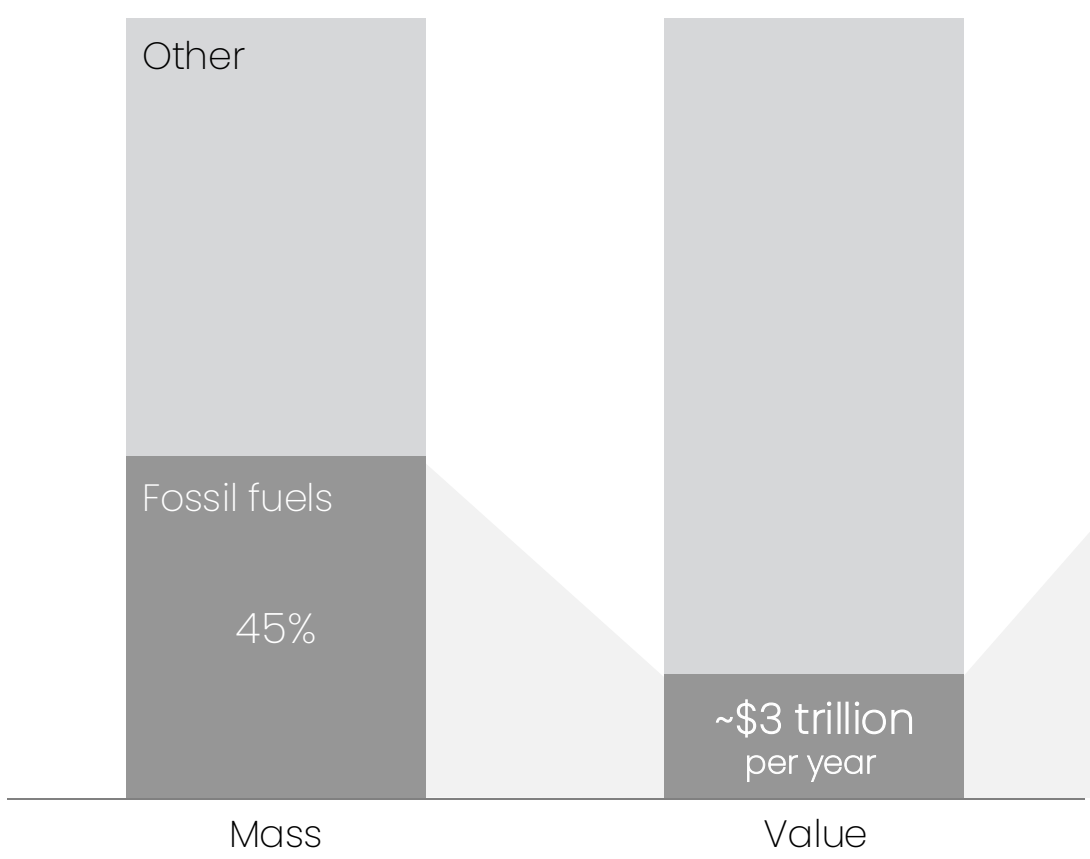
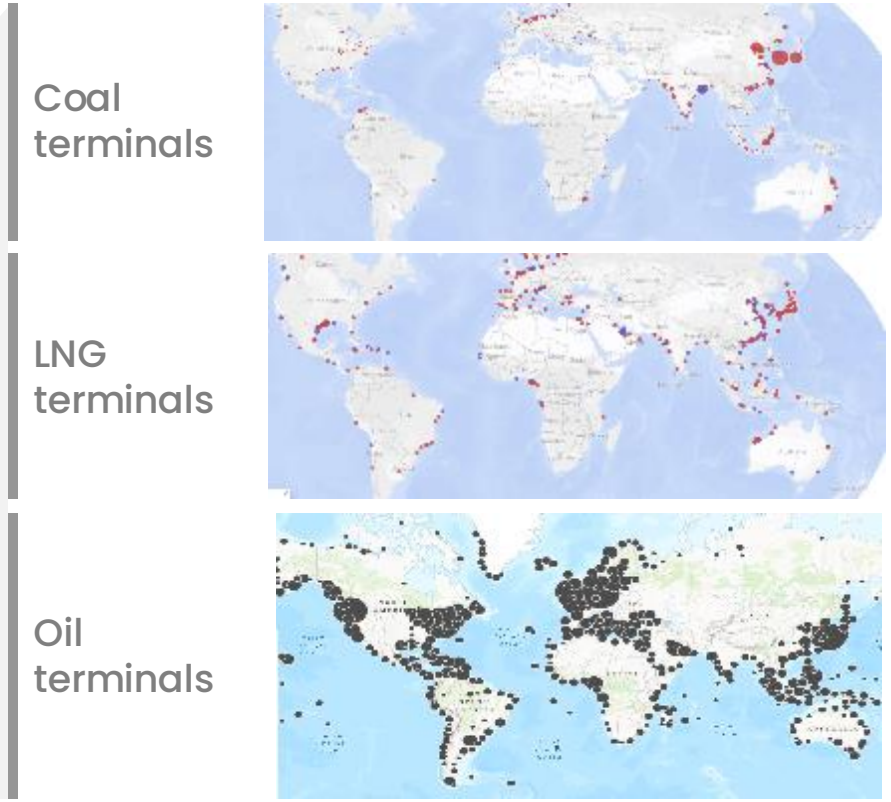
# Fossil demand decline will have much wider implications

For example, ports all over the world are set to lose major customers

## Share of global shipping from fossil fuels




## Fossil ports around the world






Sources: Global Energy Monitor; IEA; Ember analysis

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# Chapter 6
# Seize the opportunity

## 01

### The time is now

This is the decade that everything changes. Leaders will build the capacity, electrotech prices will become irresistible, electrotech will continue to grow up S-curves, and fossil demand will start to decline. It is time to rethink standard energy models because by 2030 the new reality will be priced into markets.

## 02

### Change is hard

Inertia and the lobbying power of incumbents combine to make change difficult. It is hard to deploy new technologies and identify future leaders. Even policymakers who want to drive change can pick the wrong solutions.

## 03

### Intelligent policy action is vital

Policymakers who wish for their countries to reap the benefits of the electrotech era need to rethink their strategy. That means getting the price of electricity down and electrifying end demand. It also means experimenting with policy, and moving on from failed solutions.

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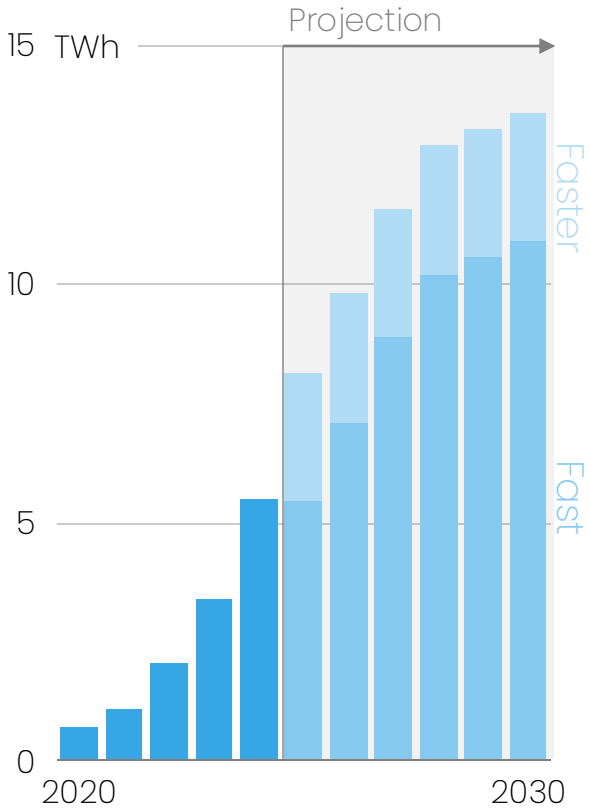
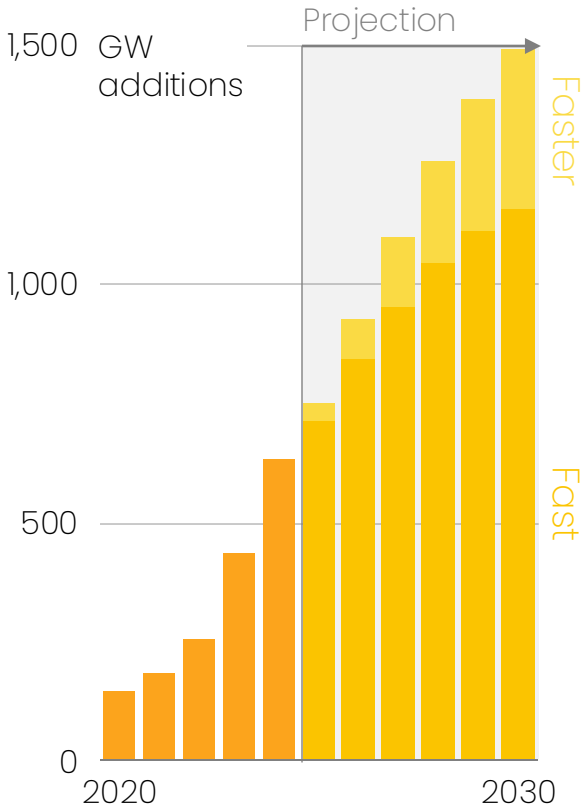
# This is the decisive decade

A century in the making, electrotech will define this decade

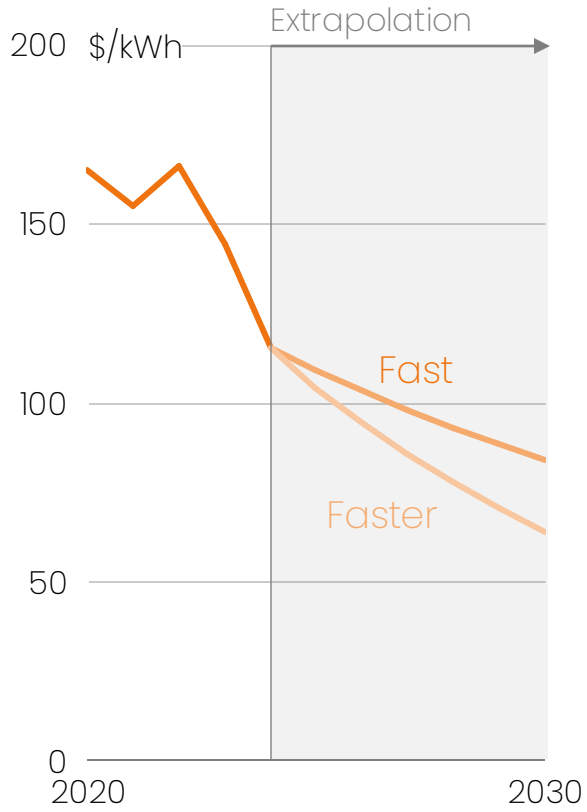
## Manufacturing capacity is built: Batteries



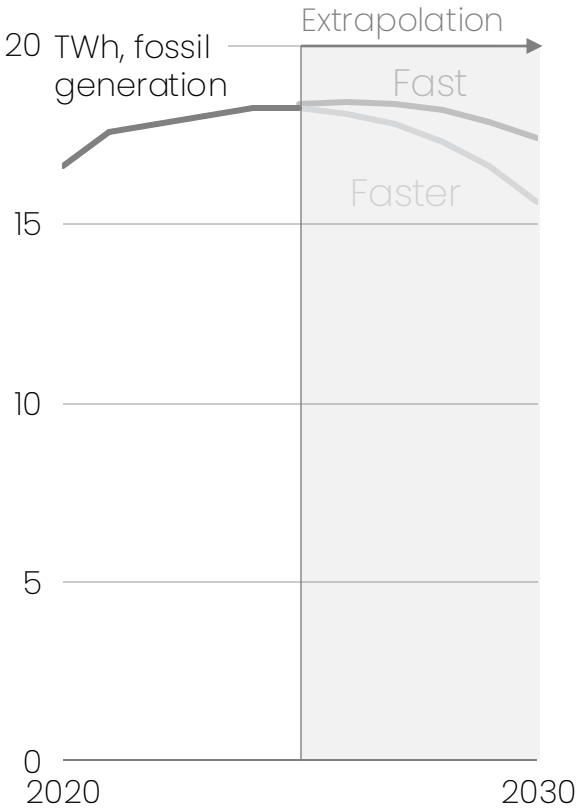

## S-curves hit their steepest parts: Solar




## Electrotech get too cheap to resist: Batteries




## Fossil fuel demand enters terminal decline






Sources: BNEF, RMI, Ember Futures extrapolation for fossil fuel demand, assuming 3% growth in electricity demand and 15-20% growth in solar and wind supply

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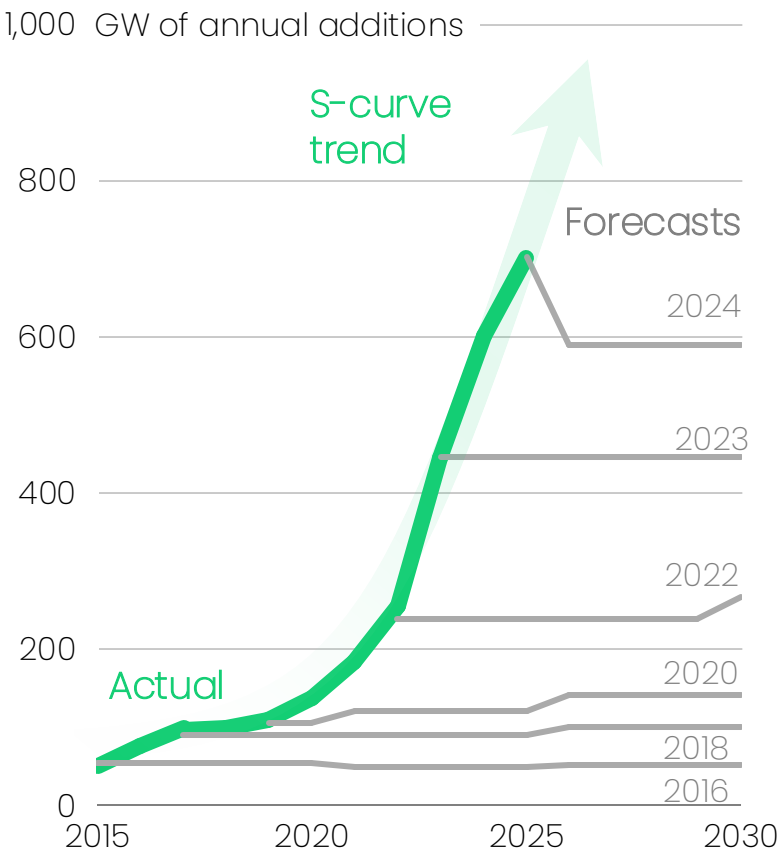
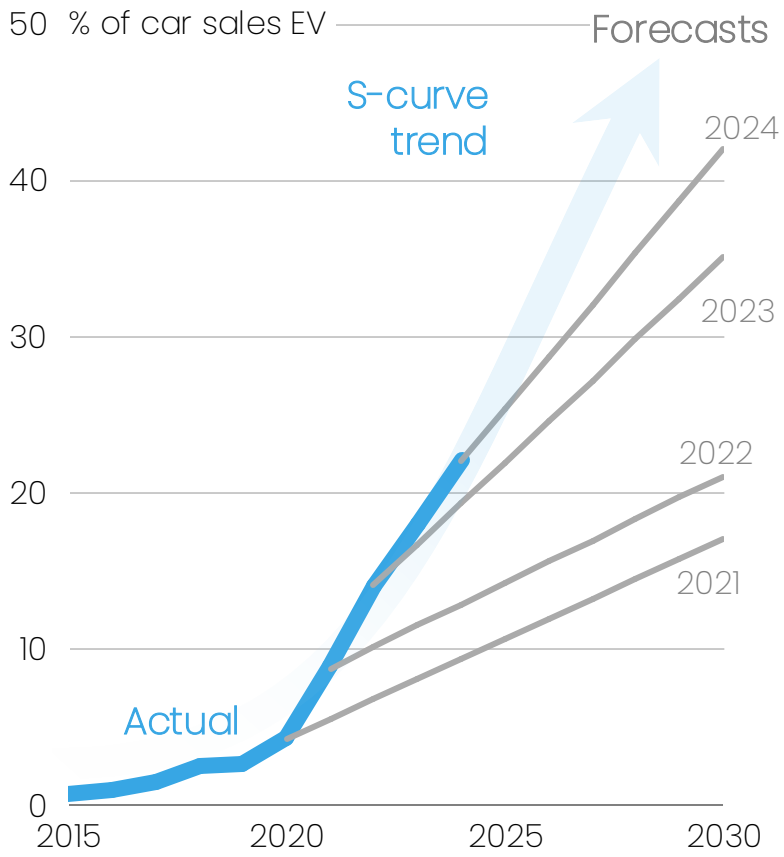
# Beware of the limits of old energy models

Complex models are missing the reality of exponential change

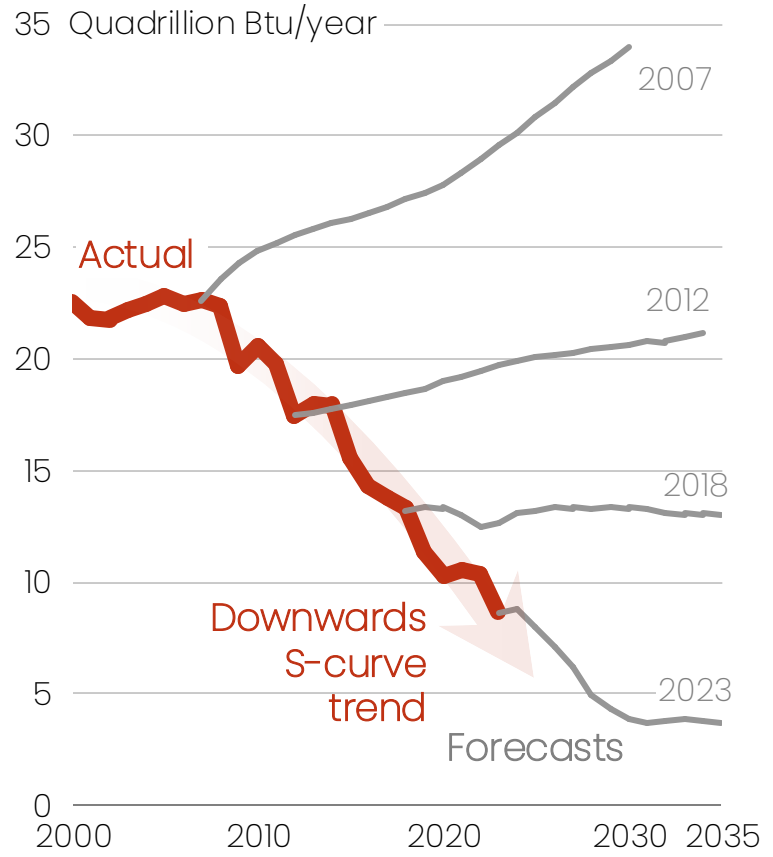
## New solar additions




## EV share of sales




## US coal demand






Sources: BNEF (solar actuals), IEA STEPS for WEO forecasts (solar & EVs), EIA via RethinkX (coal demand)

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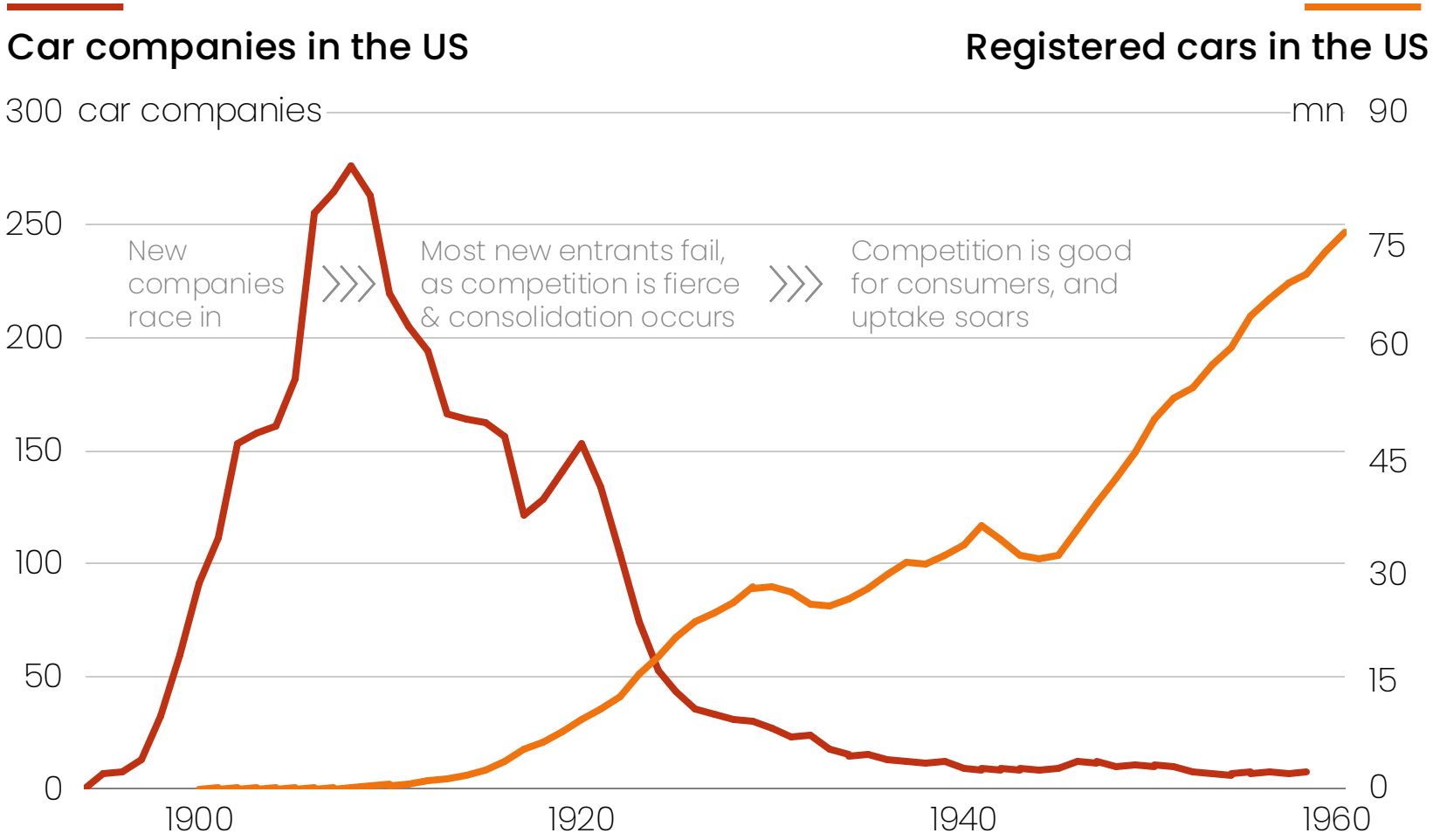
# Nobody said it was easy

Investing in technology revolutions is always risky




## Normal playbook

01 Brutal competition drives overcapacity and shakeouts

02 Most new entrants fail in the early stages

03 Companies and investors chase growth before profits

04 Market volatility is highest during the early phase

05 The winners win big

06 Failure at the firm level is a necessary part of advance-ment at an economy level



Source: US Department of Transport, Mazzucato & Semmer (1999)

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# Focus on the fundamentals

Three key questions to gauge new energy technology in times of peak confusion

## Physics

Does it make the energy system **more efficient?**

## Economics

Is it **small and modular**, so it can be manufactured at scale and **benefit from learning curves**?

## Geopolitics

Does it **enhance the independence and security** of its user?

# Pick technologies that have the wind in their back

Many popular solutions will struggle in the face of reality

| | **Physics**<br>Does it make the energy system more efficient? | **Economics**<br>Is it small and modular, so it can be manufactured at scale and benefit from learning curves? | **Geopolitics**<br>Does it enhance the independence and security of its user? |
|---|---|---|---|
| **CCS** | ✗ **No** | ✗ **No** | ✗ **No** |
| **Biofuels** | ✗ **No** | ✗ **No** | ✗ **No**<br>**unless you are Brazil** |
| **Green hydrogen** | ✗ **No** | ✗ **Not really**<br>**except for the electrolyser** | ✓ **Yes**<br>**unless imported** |
| **Electrotech** | ✓ **Yes** | ✓ **Yes** | ✓ **Yes** |



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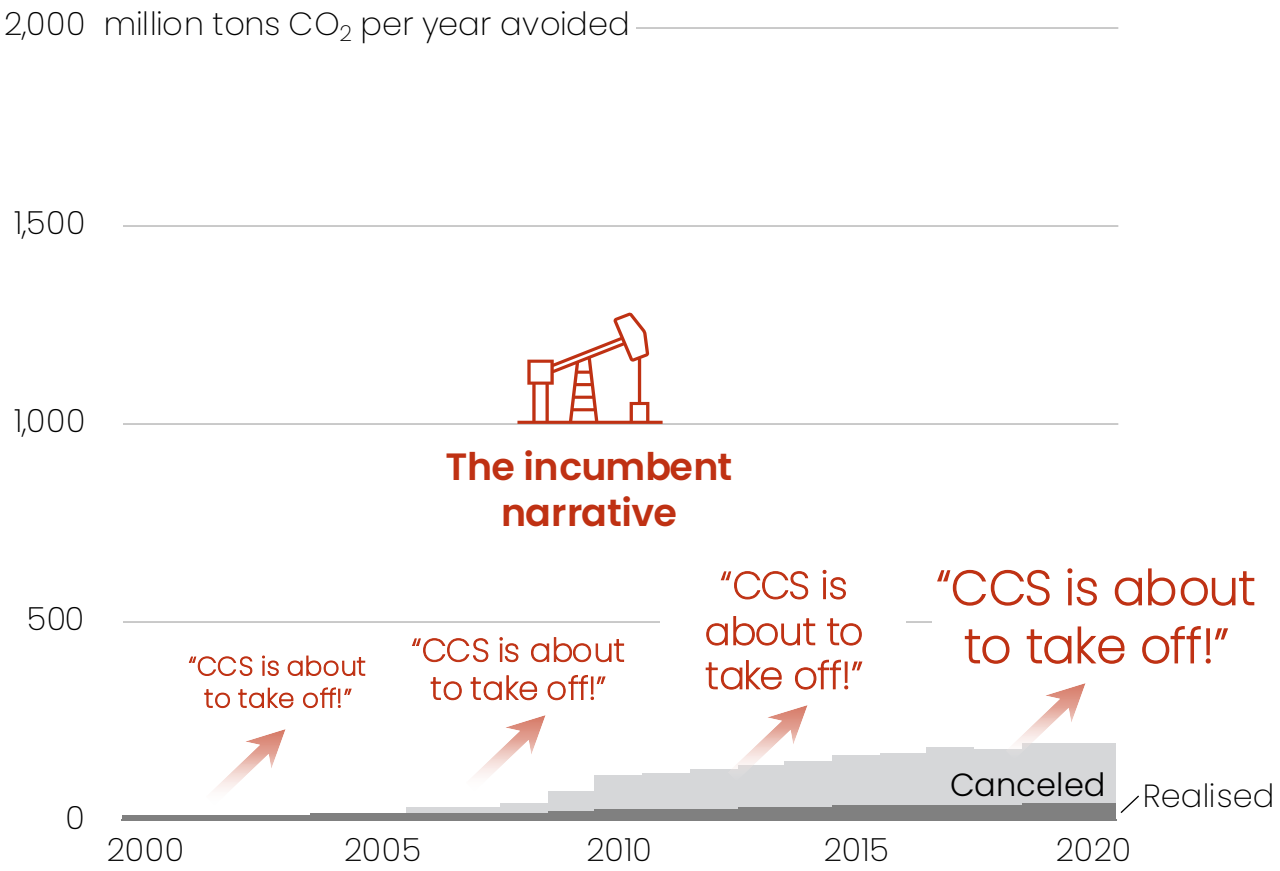
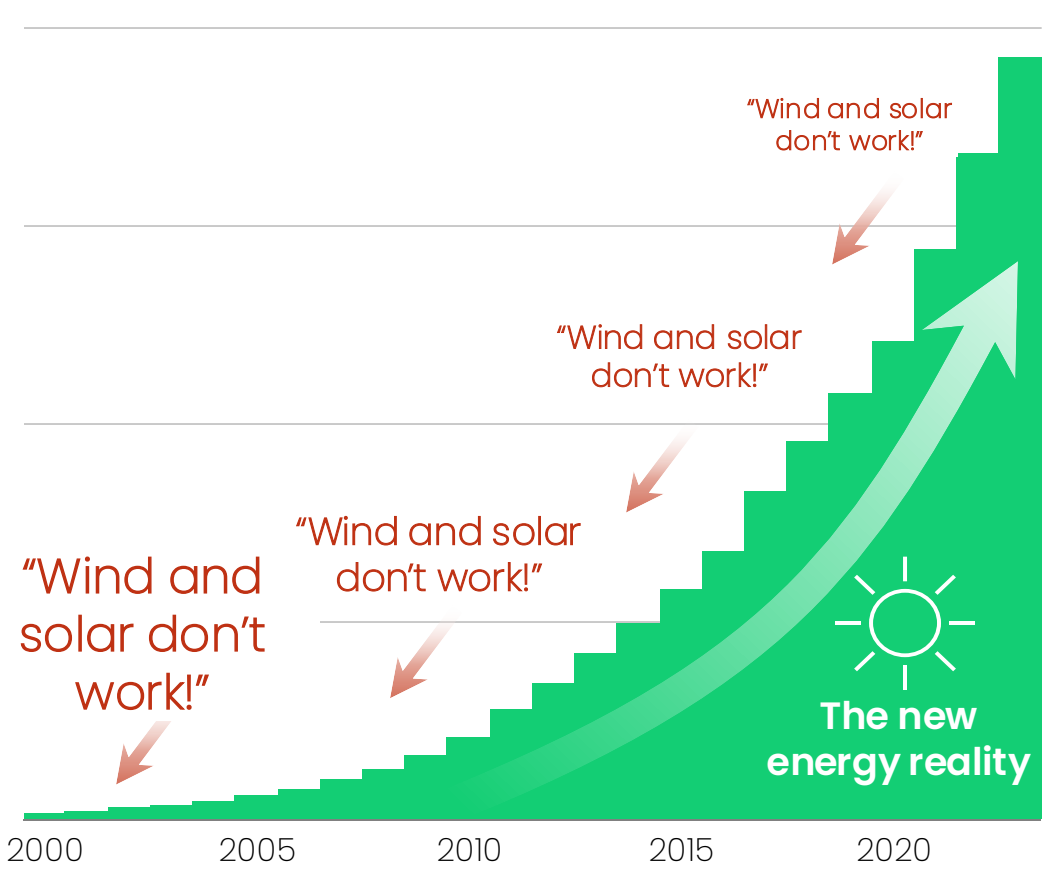
# Avoid the distractions

Some cleantech only gets louder; electrotech actually delivers

## Global installed CCS capacity




## Wind and solar avoided emissions






Sources: IEA, BNEF • Note: avoided emissions estimated based on average global grid emission intensity.

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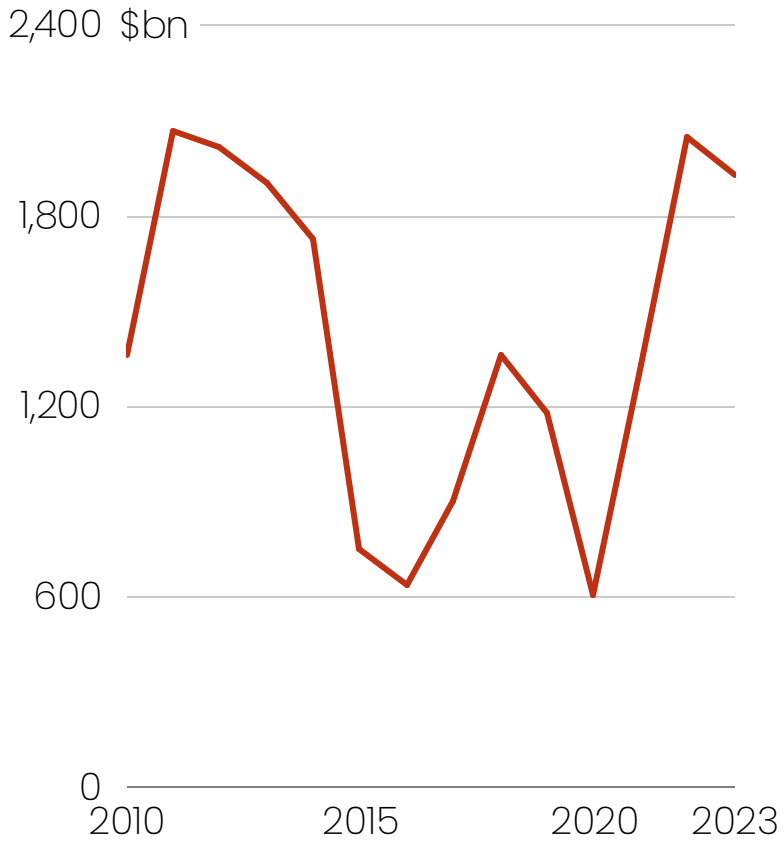
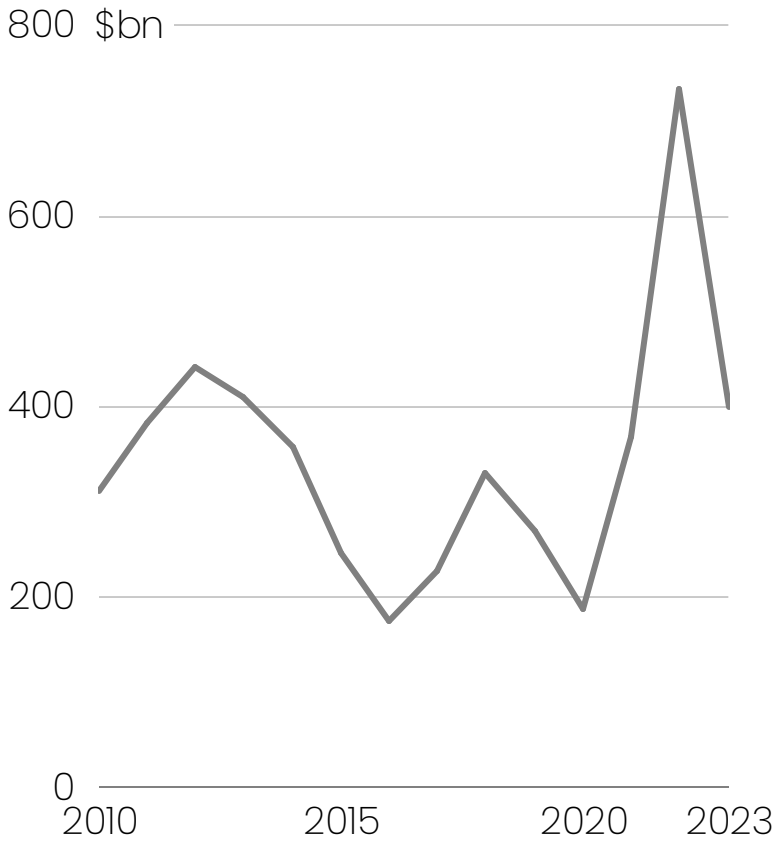
# Incumbents resist change because the status quo is so profitable

Governments need to decide what is in their country's best long-term interest

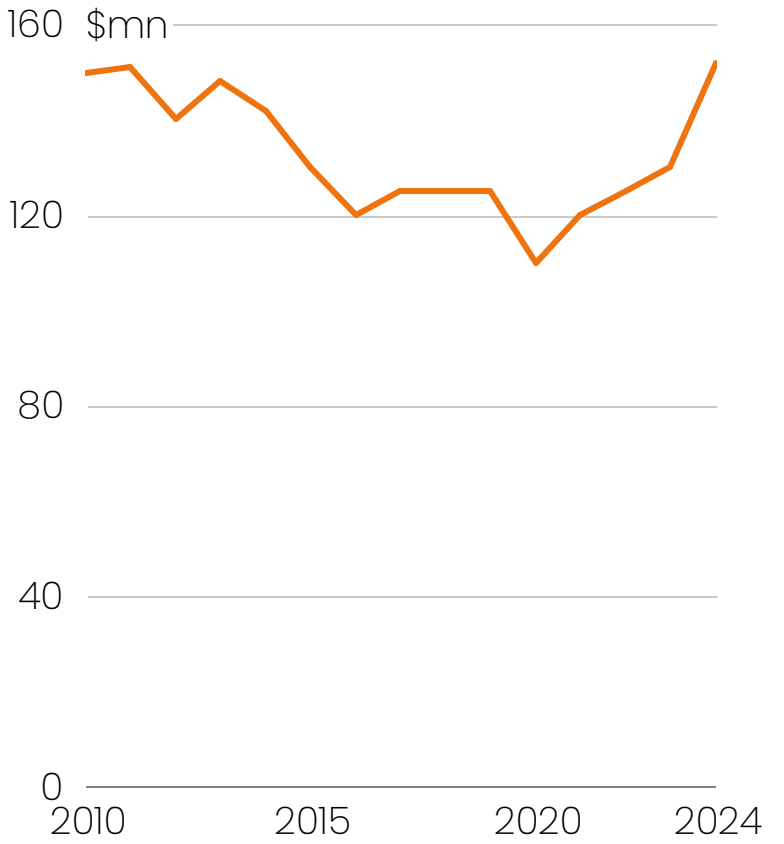
## Oil rents




## Fossil fuel subsidies




## Oil and gas lobbying in the US






Sources: World Bank, IEA, Open Secrets

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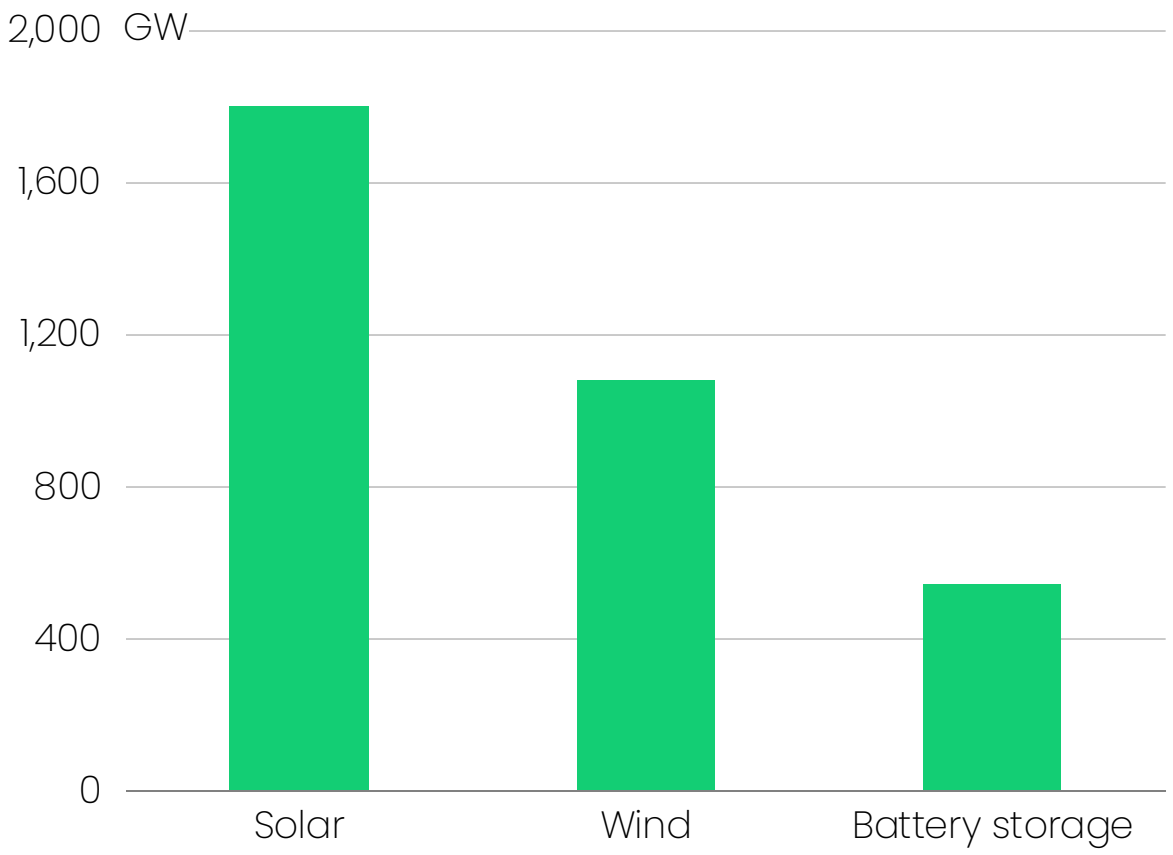
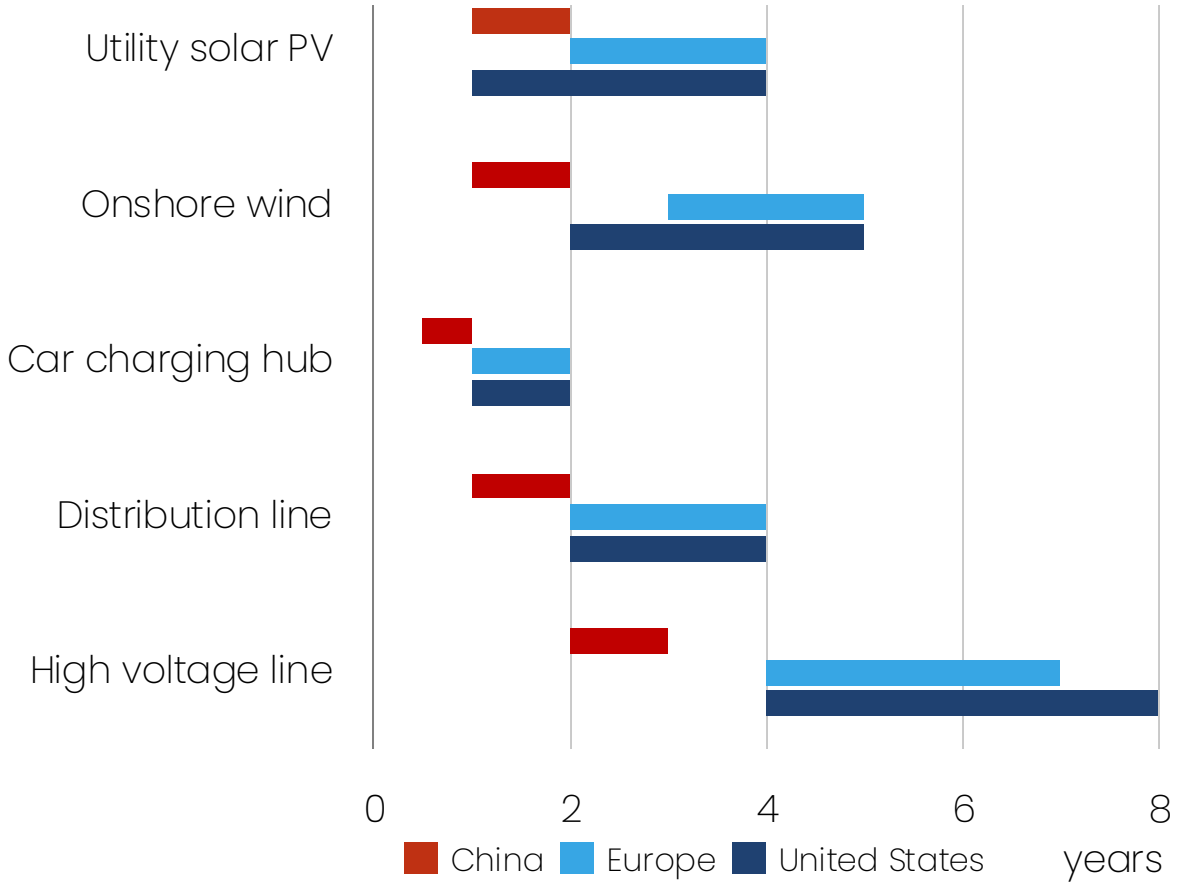
# Back the builders not the blockers

Unlock the queues of electrotech that want to come online

## Clean energy stuck in the connect queue




## Typical deployment time






Sources: IEA. Note: solar & wind queue is global; battery storage is in select markets only.

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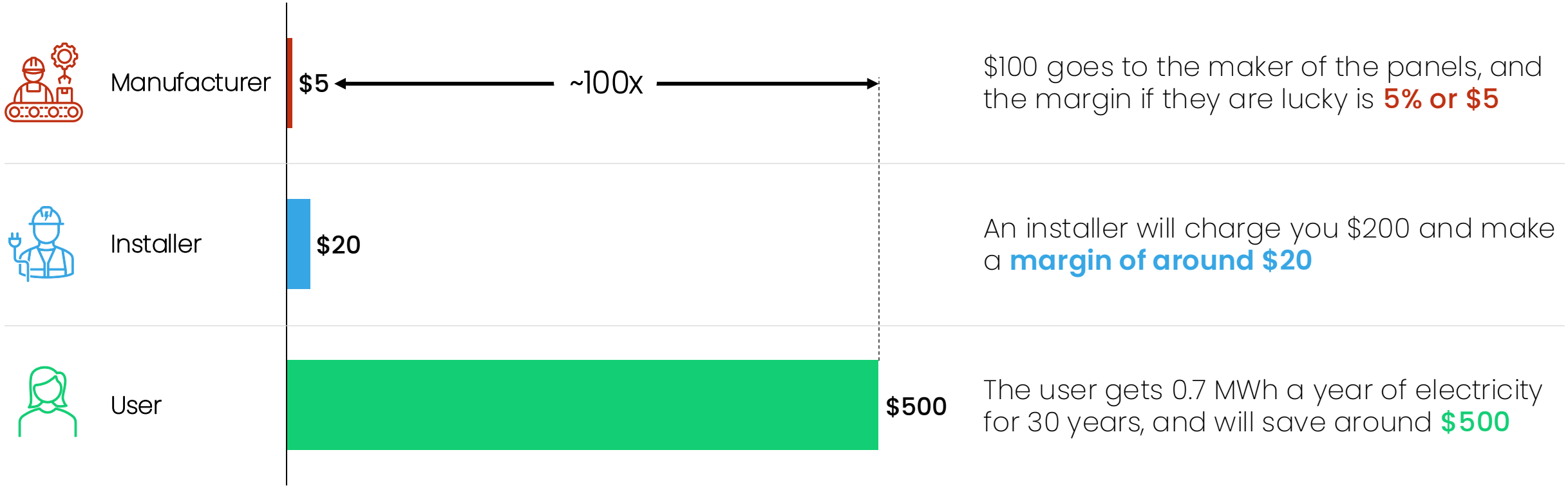
# It’s not all about manufacturing

The user benefits are 100x greater than the manufacturer profits

**The economics of putting up a couple of solar panels with 1kWp of capacity, UK example**

**Profits**




$100 goes to the maker of the panels, and the margin if they are lucky is **5% or $5**

An installer will charge you $200 and make a **margin of around $20**

The user gets 0.7 MWh a year of electricity for 30 years, and will save around **$500**

Sources: Alibaba for solar panel costs, Greenmatch for installation costs, NPV calculation for the net savings made by a retail consumer based on data from the Renewable Energy Hub and at a 7% cost of capital.



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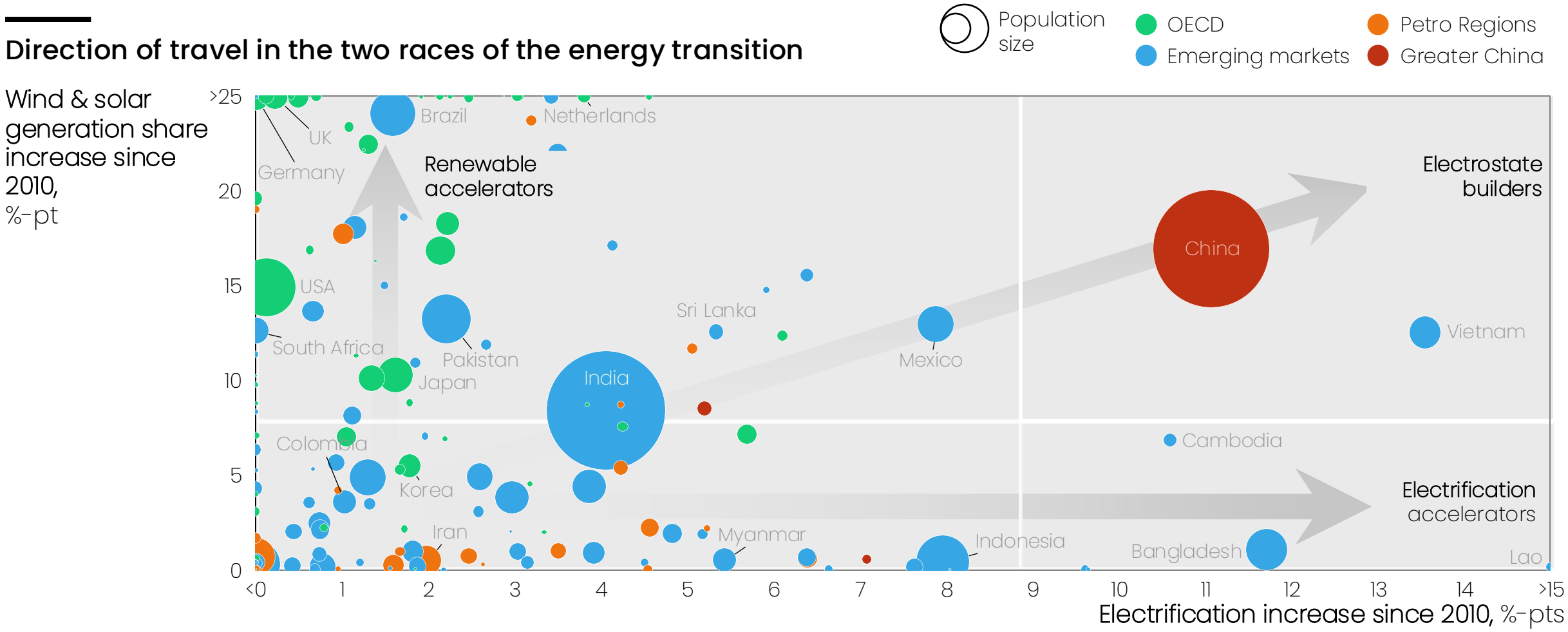
# The electrification imperative

Many countries are building renewables; few an electrostate

## Direction of travel in the two races of the energy transition






Sources: IEA WEB; Ember; Ember analysis • Note: Shown values cut off at 0-25% for wind & solar and 0-15% for electrification rates

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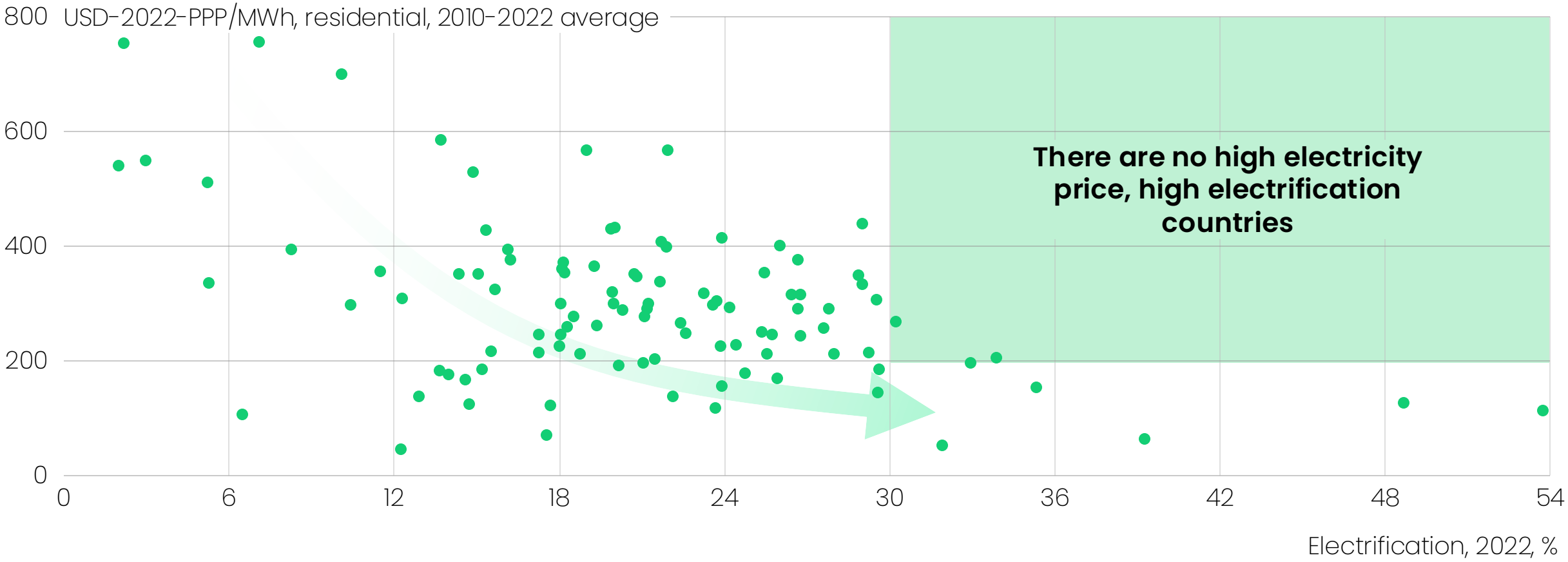
# Econ 101

Lower prices incentivise uptake

## Electricity price






Sources: IEA; Ember analysis

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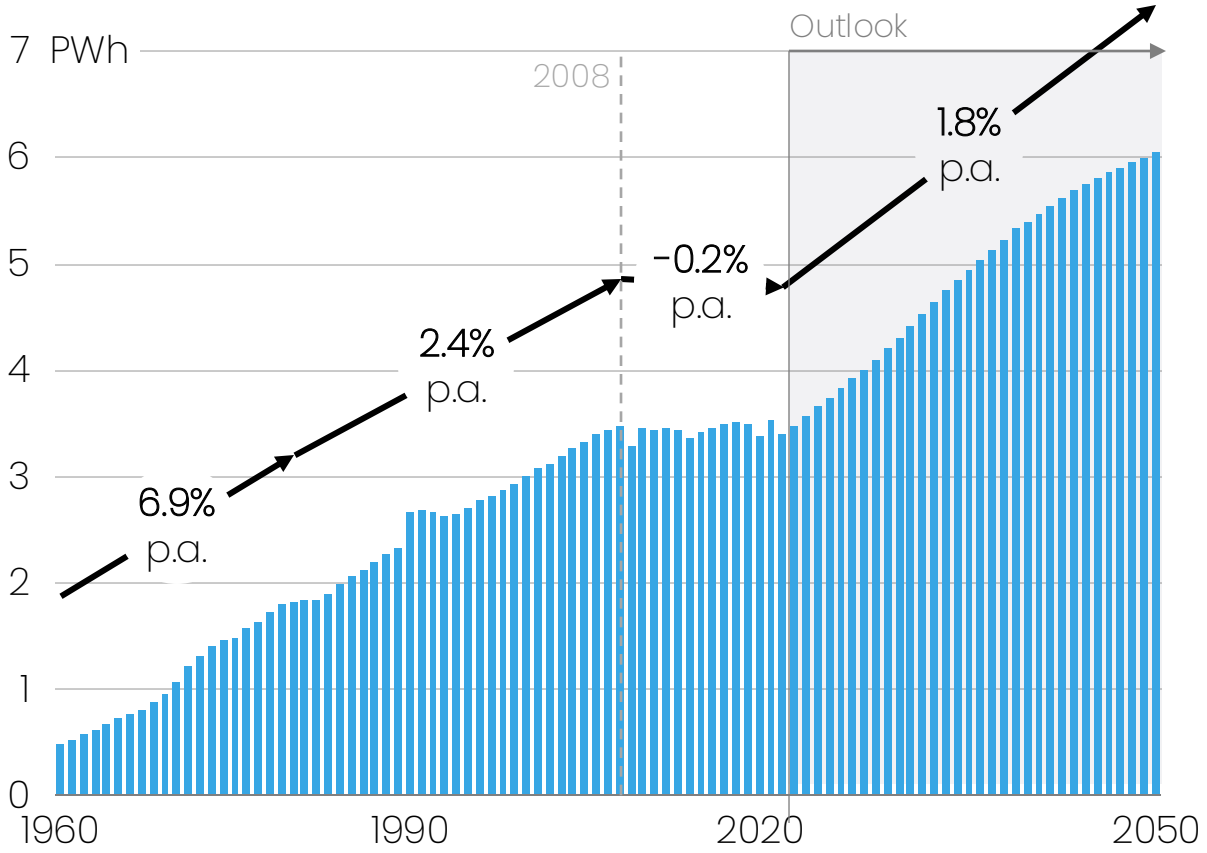
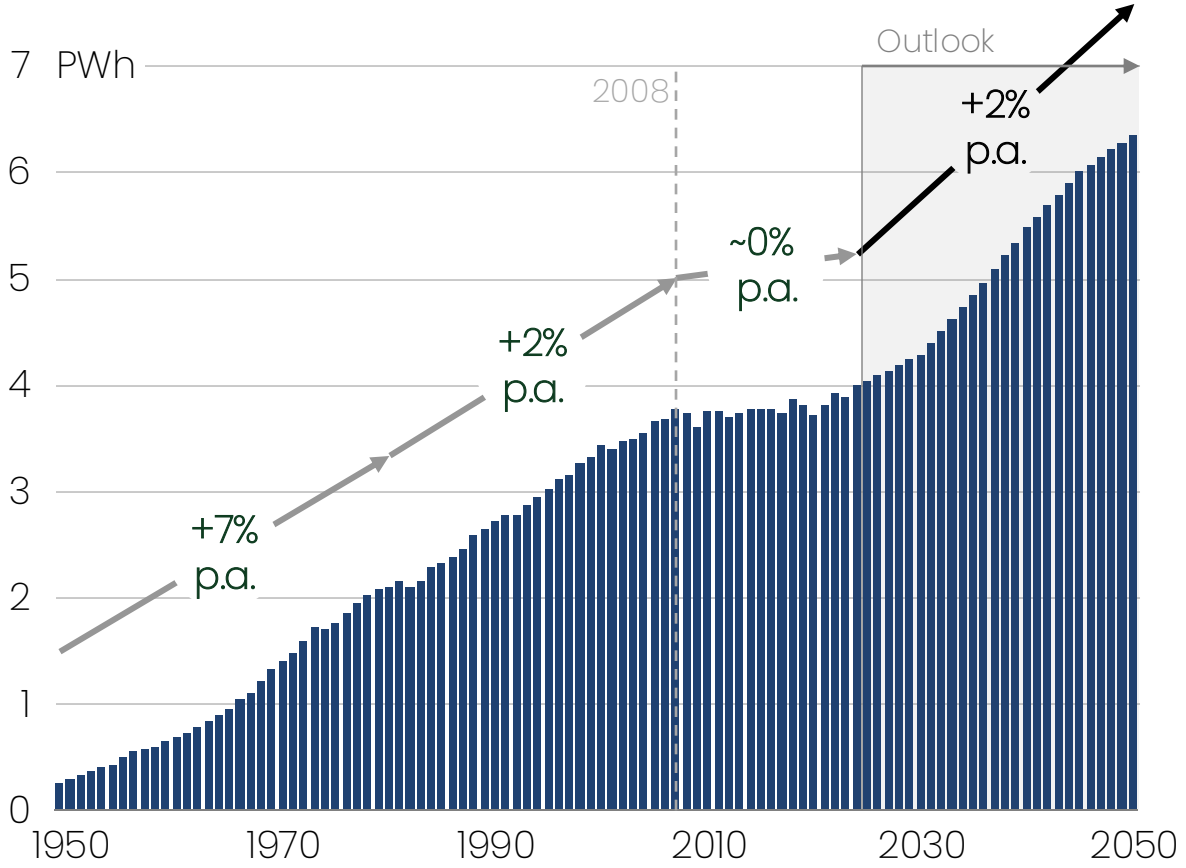
# The West can get back on track with electrification

Europe and the US were able to grow electricity demand rapidly for decades before 2008

## Europe electricity demand




## US electricity demand






Sources: IEA WEB; IEA APS; Ember analysis

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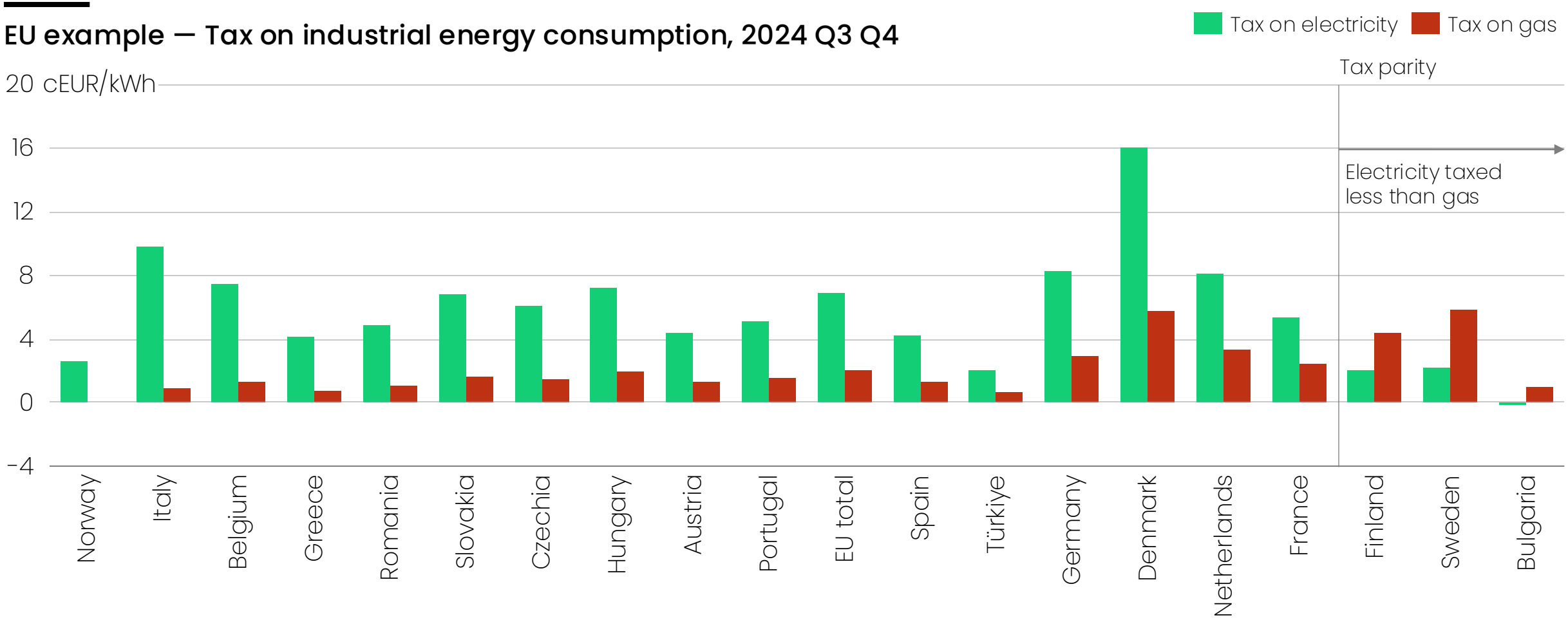
# Tax what you want to phase out

High taxes on electricity will only slow down electrification

## EU example — Tax on industrial energy consumption, 2024 Q3 Q4






Sources: Eurostat; Ember analysis — based on mid-sized industrial consumer

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# Experiment with policy and regulation

Just as we experiment with new tech, we should test new policies and regulations

| New electrotech | Different tech specs versus fossil incumbent | Example policies and regulations to experiment with to better match new tech | | |
|---|---|---|---|---|
| Utility-scale wind & solar | Variable with weather; available everywhere; zero marginal cost | Regional pricing | Nodal/local battery tenders | Power price-setting reform |
| Rooftop solar & microgrids | Consumers become prosumers; power flows two ways | Connection fast tracking | Locational tariffs | Microgrid resilience payments |
| EVs and heat pumps | Loads get more local, mobile, and can be flexed sub-hourly; availability varies by user behavior and season | TOU and availability pricing | Storage buffer incentives | Interoperability / API sandbox |
| Industry electrification | Very large, shiftable electricity demand for some sites; hard baseload for other sites | Zonal demand tenders | Flexible industrial contracts | CfD for offtake prices |
| Grid upgrades & advanced sensing | New sensors and controls give fast, local visibility and automated options | Dynamic line rating | Performance-based payments | Private power lines |

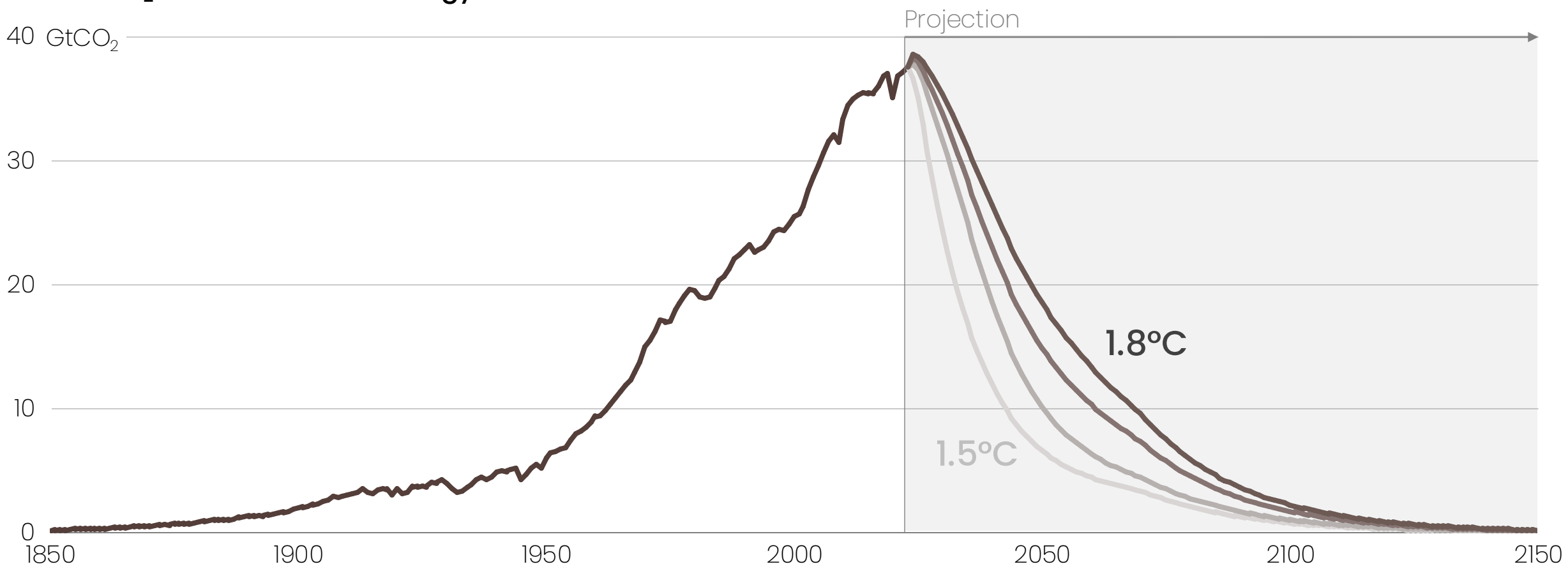


Sources: Systemiq analysis for the ETC; Ember

# Falling emissions are a consequence of the Electrotech Revolution

The faster electrotech grows, the faster emissions will fall

## Global $CO_2$ emissions from energy






Sources: Global Carbon Project, OWID (1850-2023), Rystad Energy to 2023-2070; RMI illustrative onwards.

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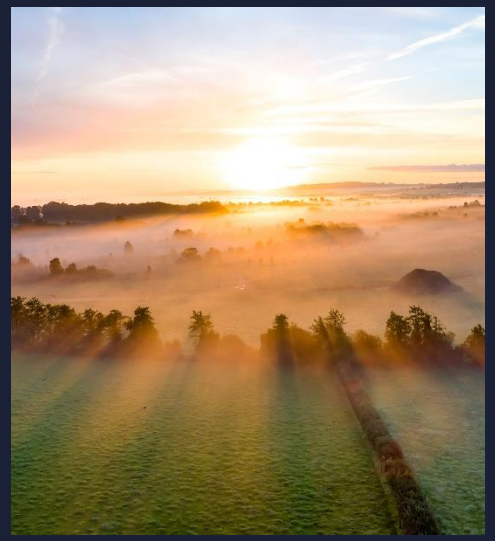
# The time is now

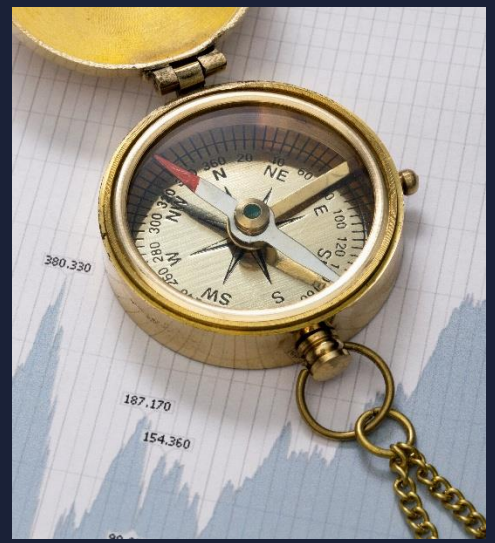


## 01

For the first time in history, we can harness the exceptional power of the sun through electrotech

## 02

After a century of evolution, electrotech is now coming together in a decade of revolution; surging globally, replacing fossil fuels, and powering emerging economies



## 03

Change is driven by the fundamental forces of of physics, economics and geopolitics, not just climate action

## 04

This revolution will come faster and go further than most think, stranding more than just energy assets, and reshaping global leadership

## 05

This is the decisive decade. Surf the electrotech wave or be dragged under



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## About Ember

Ember is an independent energy think tank that aims to accelerate the clean energy transition with data and policy. Its vision is a world with a safe climate, powered by a clean, electrified energy system for all.

## About Ember Futures

This report is the first annual pitch deck from Ember Futures, a new research initiative established to help leaders navigate the rapid rise of electrotech and the decline of fossil fuels, and what this transition means for energy, financial markets, and geopolitics.


## Acknowledgements

Data visualisation: Chelsea Bruce-Lockhart, Reynaldo Dizon.
Data: Sam Hawkins, Euan Graham, Nicolas Fulghum.
Strategy: Phil MacDonald, Harry Benham, Bryony Worthingon, Dave Jones, Kostantsa Rangelova, Richard Black.
Communications: Hannah Broadbent, Ardhi Arsala Rahmani, Rashmi Mishra, Rini Sucahyo.
Asia team: Aditya Lolla, Muyi Yang, Dinita Setyawati, Ruchita Shah.

With thanks to: Arthur Downing, Assaad Razzouk, Amory Lovins, Bill McKibben, Bruce Douglas, Chris Goodall, Freya Newman, Greg De Temmerman, Hannah Ritchie, Hauke Engel, Jon Hansen, Jules Kortenhorst, Kate Bassett, Leonardo Buizza, Liza Rubinstein, Mark Campanale, Maria Pastukhova, Michael Collins, Michael Seckler, Mike Hemsley, Nigel Topping, Paul Dickinson, Tom Steyer.

Cover image: NanoStockk, Getty images



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