

The Electrotech Revolution

The shape of things to come

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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-term 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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Seize the opportunity



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

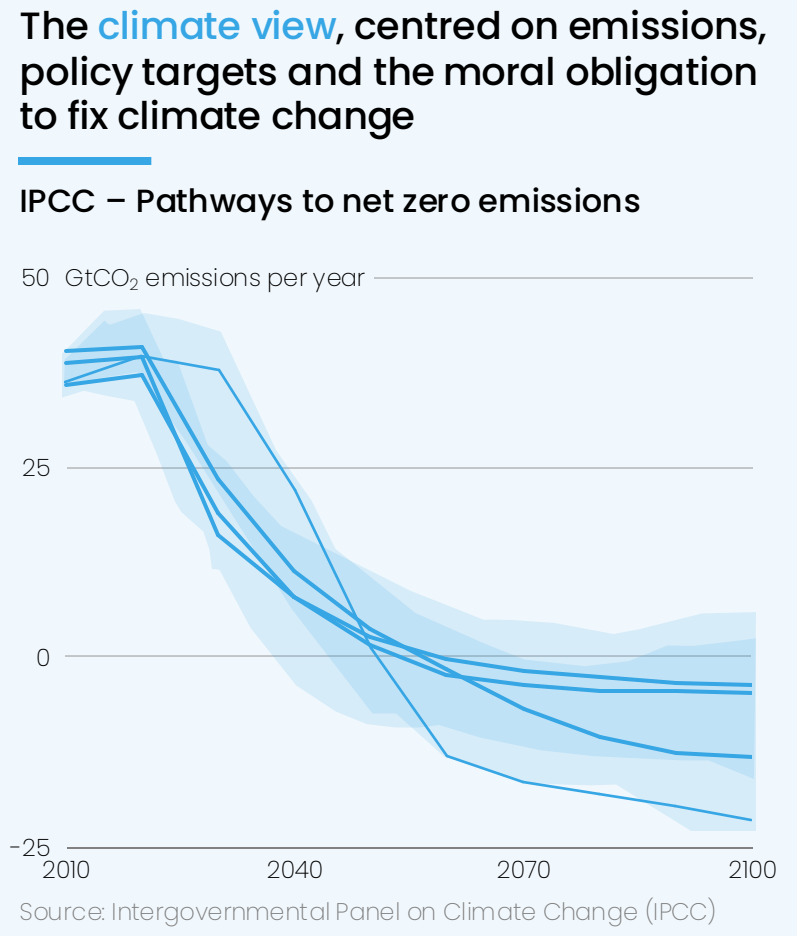
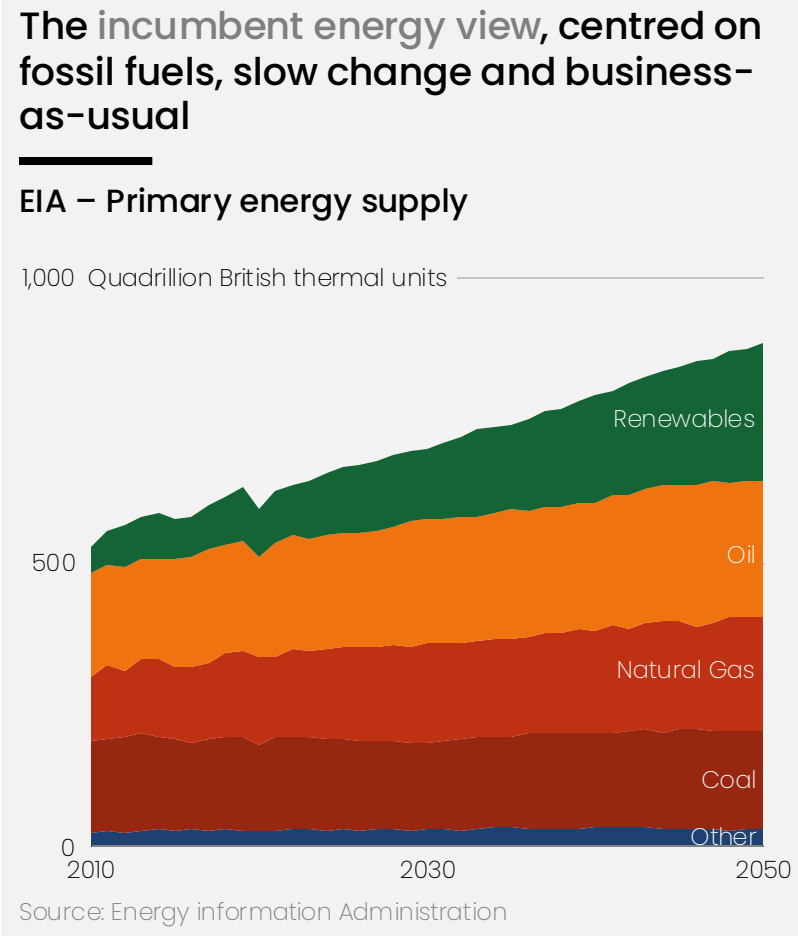
Electrotech enables us to harness the sun's enormous energy resources. The sun supplies Earth with as much energy every five days as all fossil fuel reserves combined. This makes possible a new energy era.

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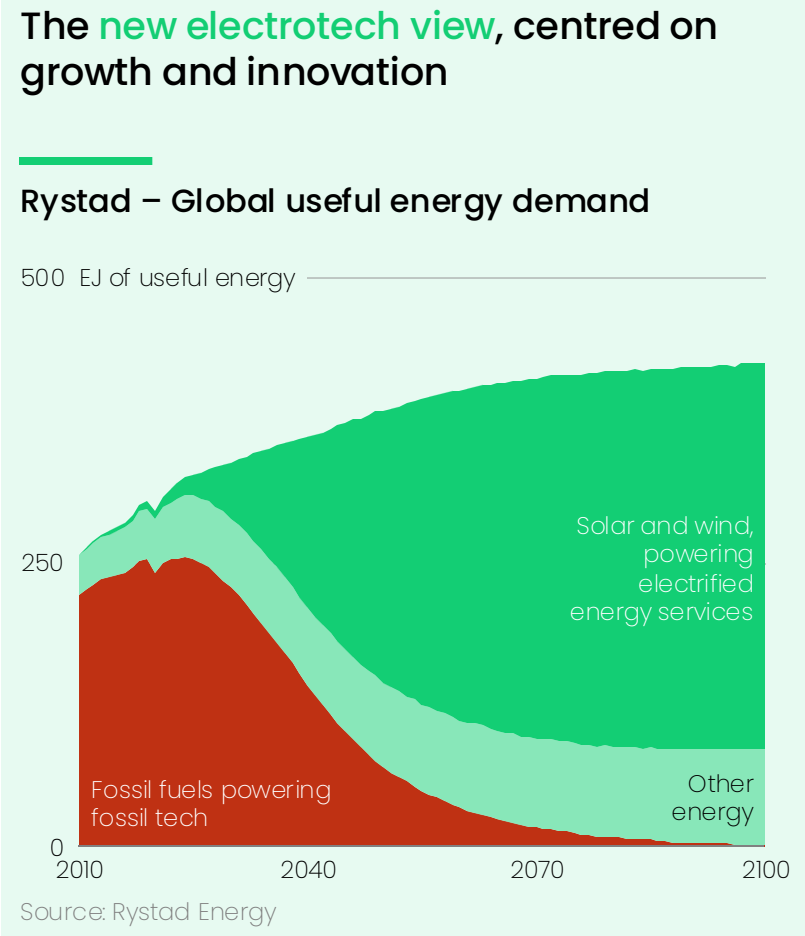


Two views on energy dominate the conversation. We propose a third

The dominant energy views in the energy debate today



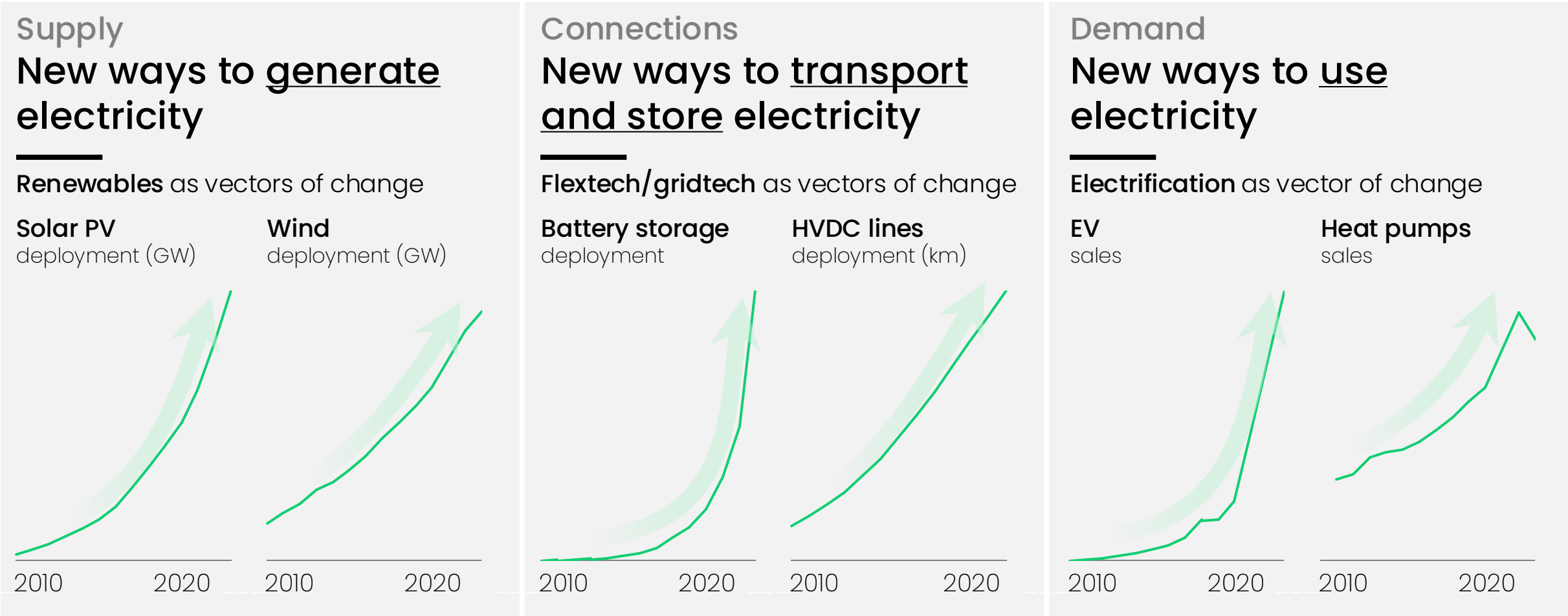
A third way: the electrotech view





This is a technology revolution in energy

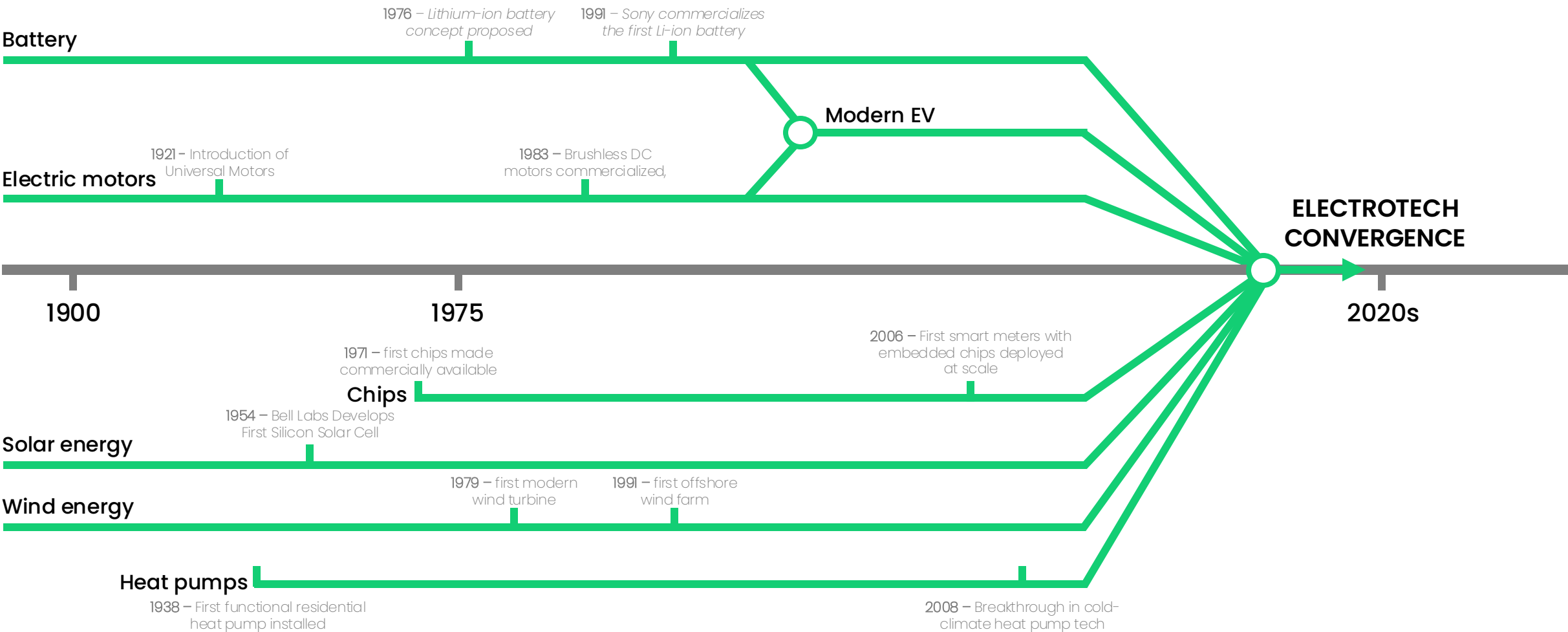
Electrotech is technology that revolutionises the supply, connection and demand of electricity



A century of evolution is converging into a decade of revolution

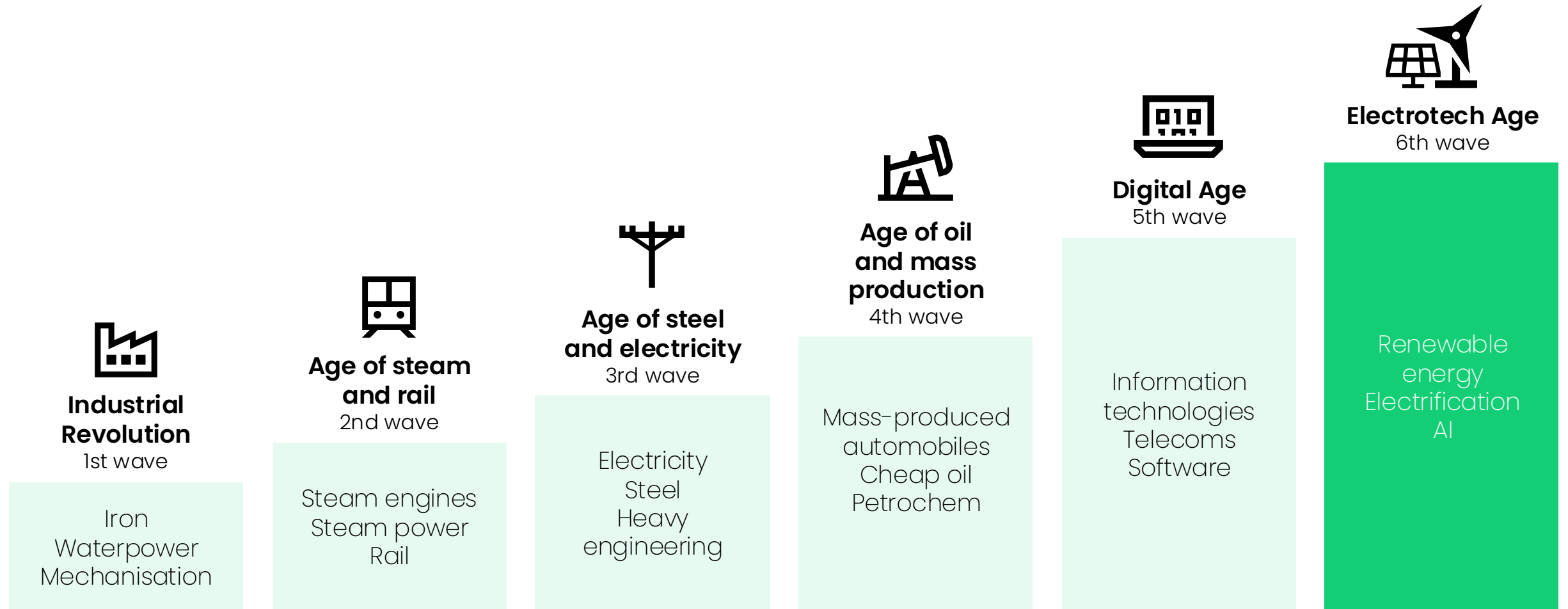
The 2020s mark a great technology convergence

ILLUSTRATIVE



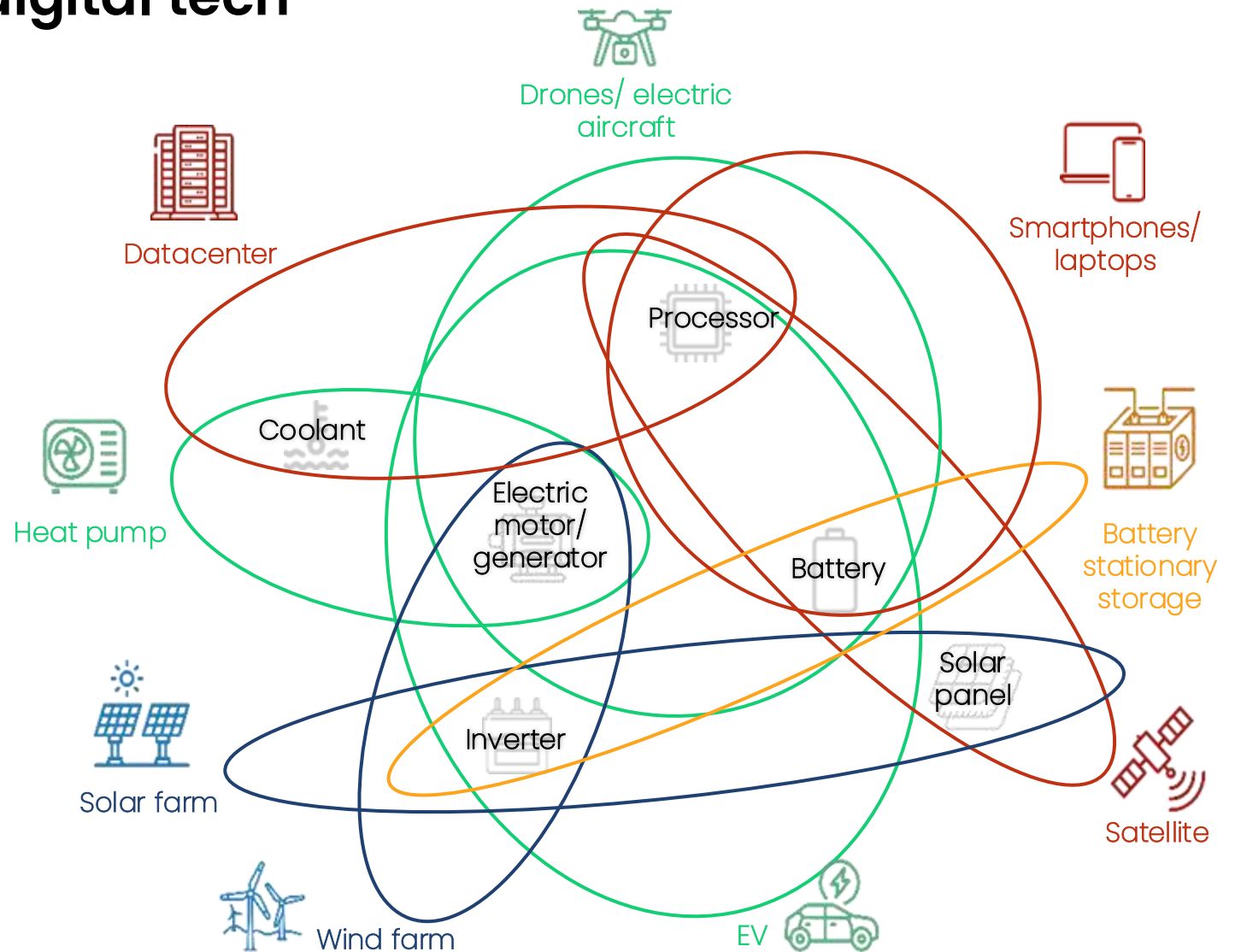
This is the age of electrotech

It is the latest in a long line of technology shifts



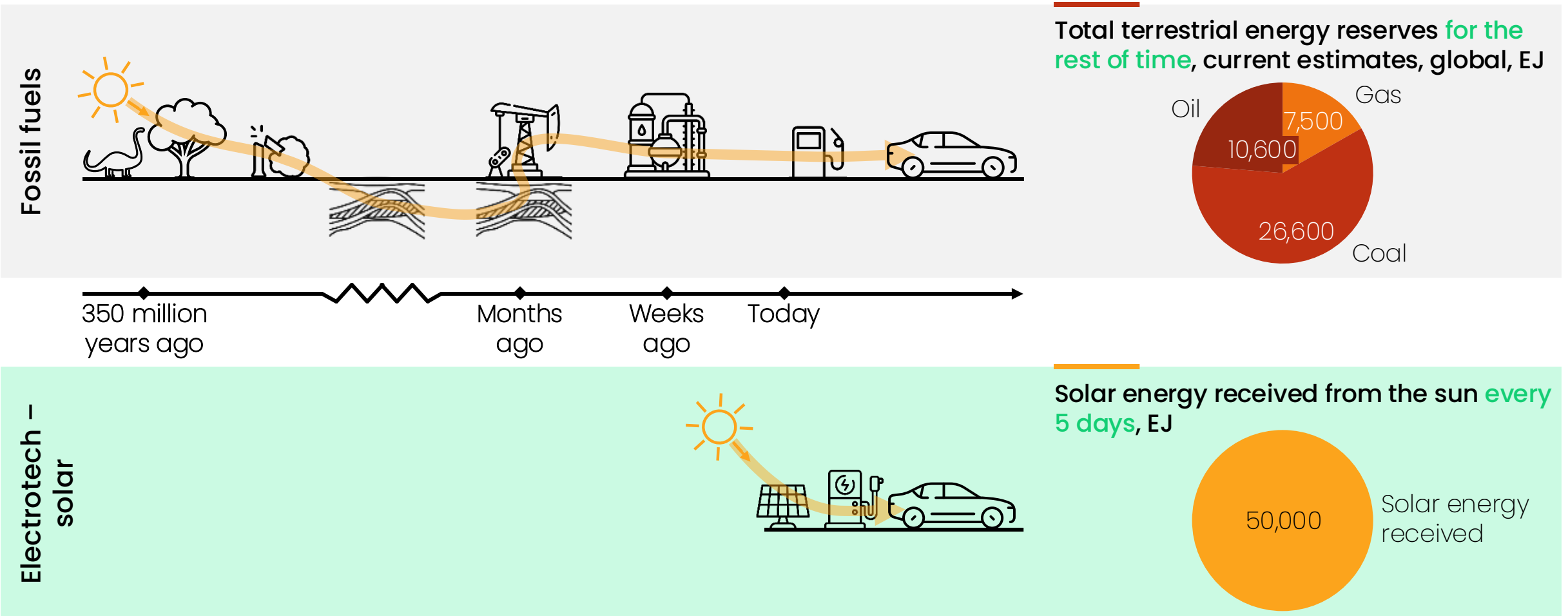
Electrotech is the child of digital tech

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



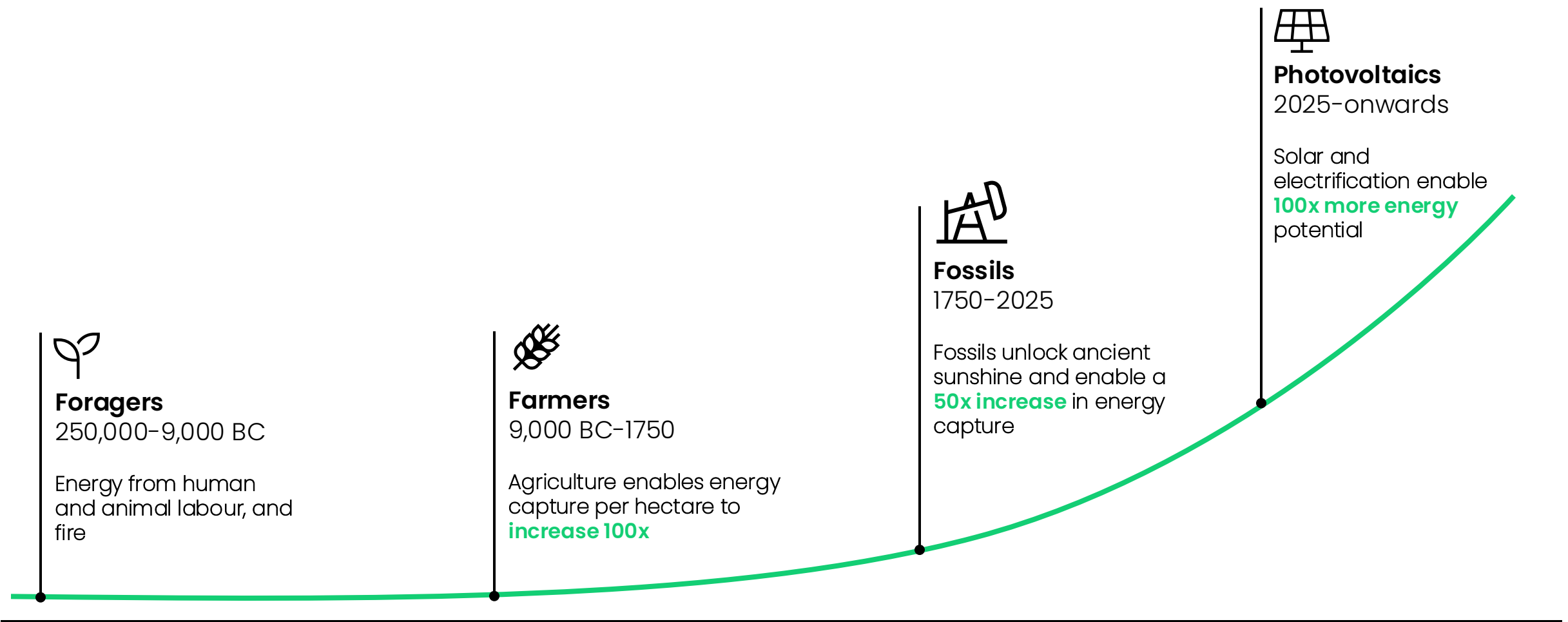
From burning old sunshine to using it real-time

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



Foragers, Farmers, Fossils, Photovoltaics

Electrotech enables another 100x leap in energy abundance



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.

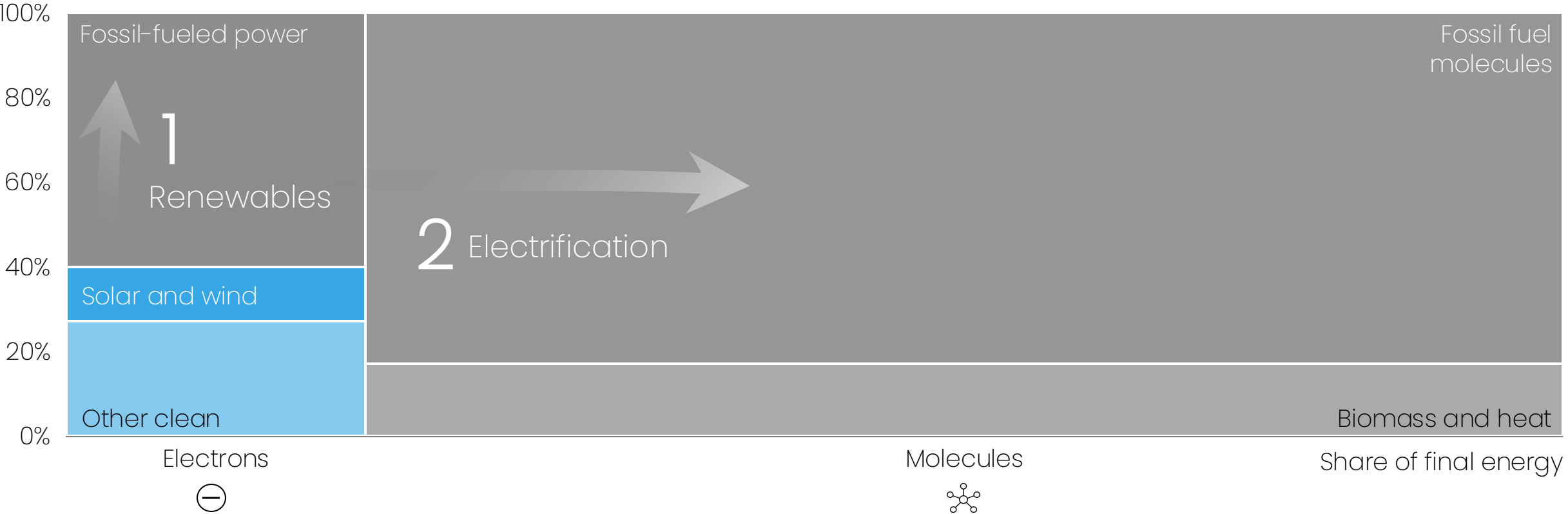
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The two vectors of the energy transition

Renewables replace fossil electricity; electrification replaces fossil molecules

Global final energy demand in 2023

Share of final energy



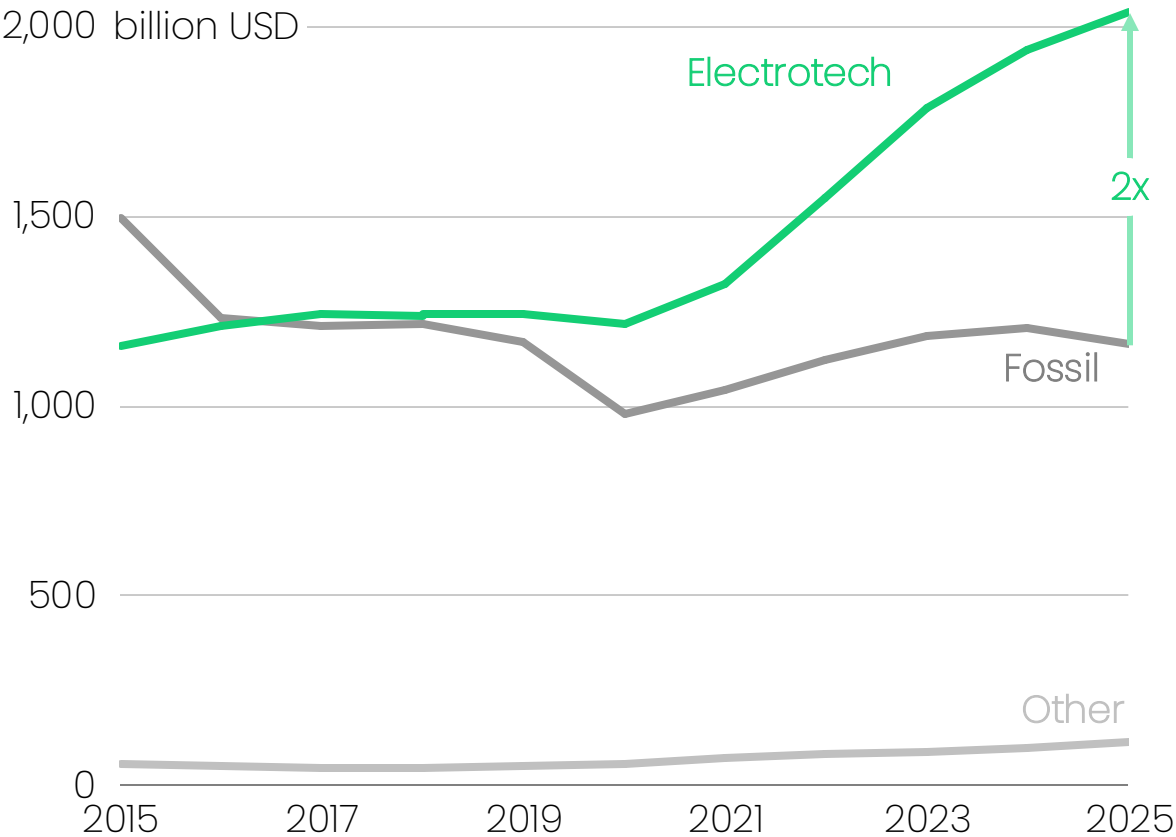


Electrotech investment is twice as big as fossils

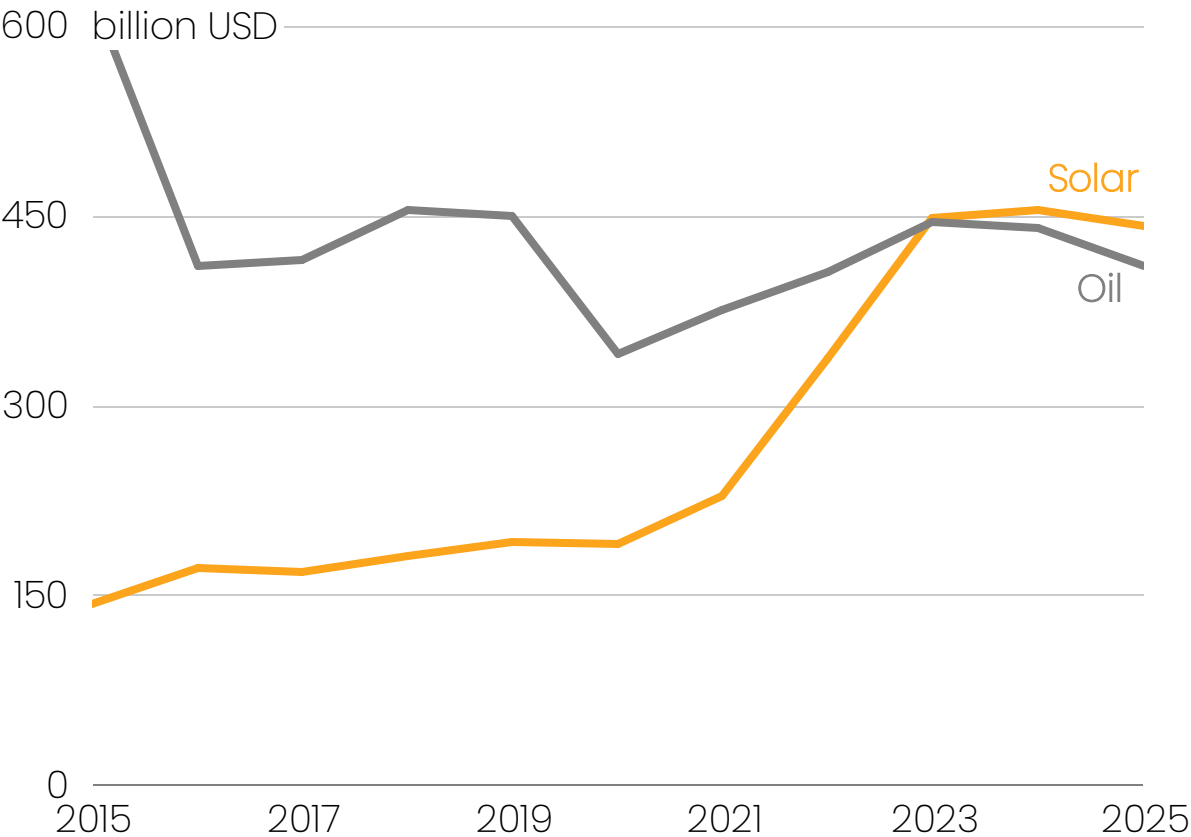
And we spend more on solar capex than on oil



Energy investment by category



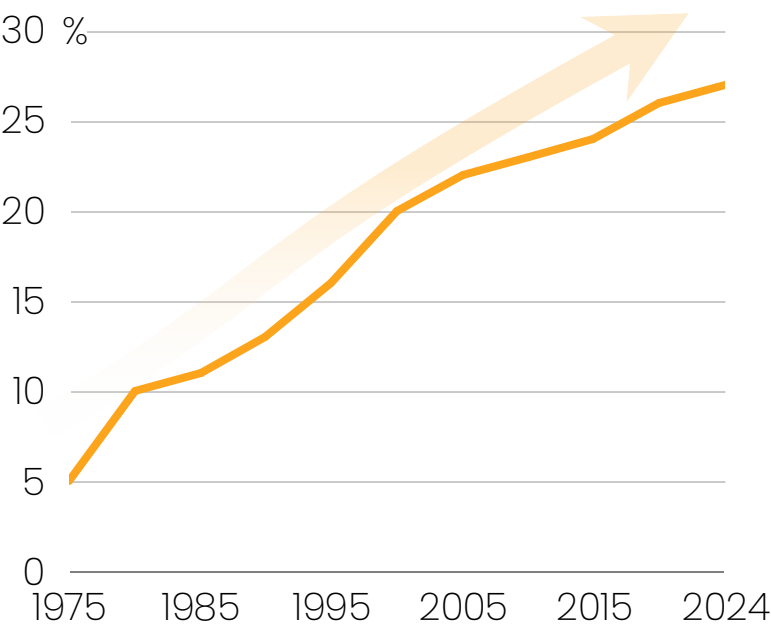
Solar and oil investment



Electrotech keeps getting better

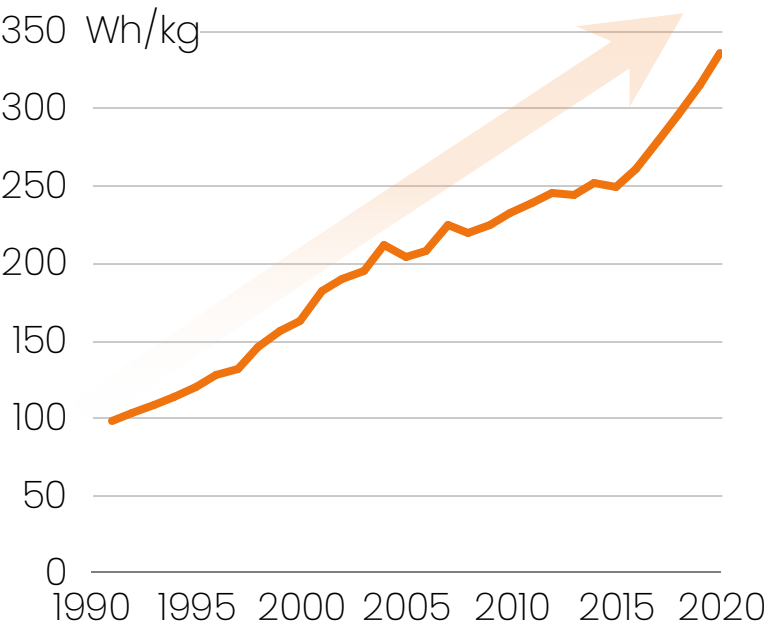
Decade after decade of innovation raises the ceiling of the possible

Solar cell efficiency



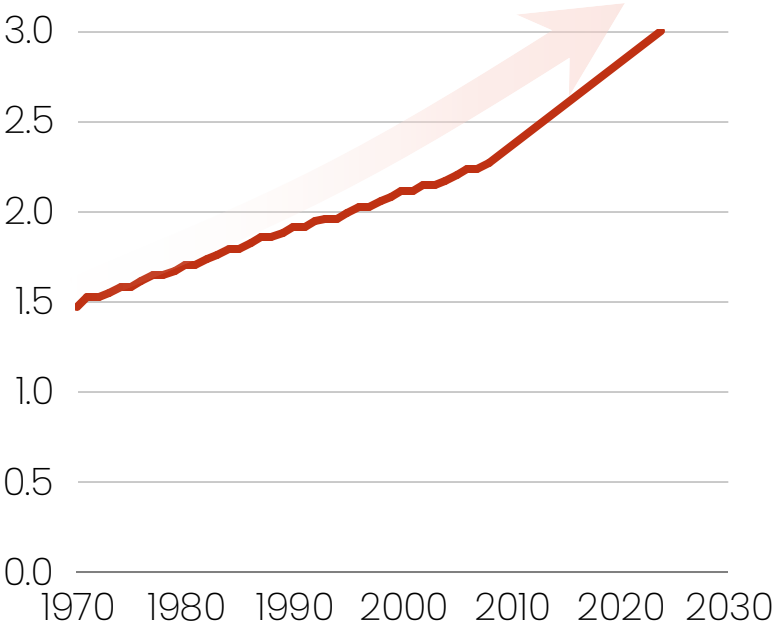
More efficient solar cells mean more space and material efficiency and lower cost

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

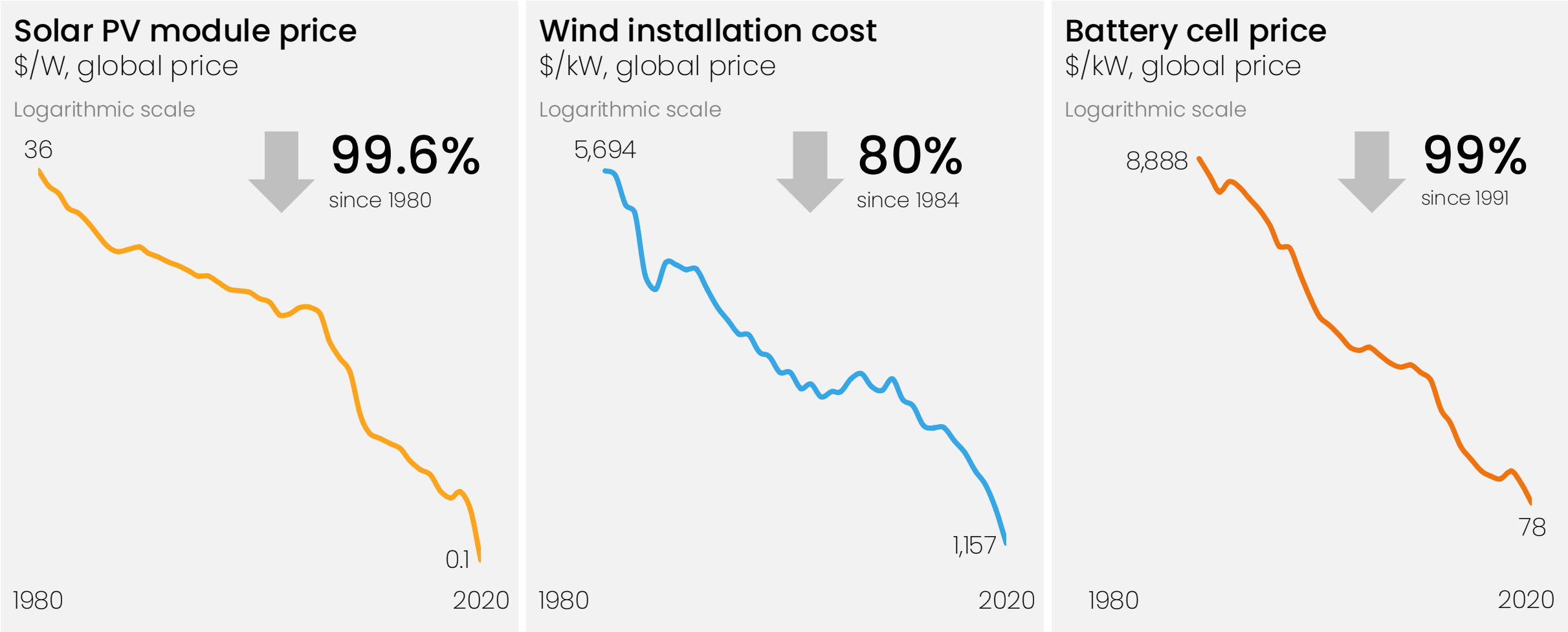


Higher COP means a more efficient and powerful heating system



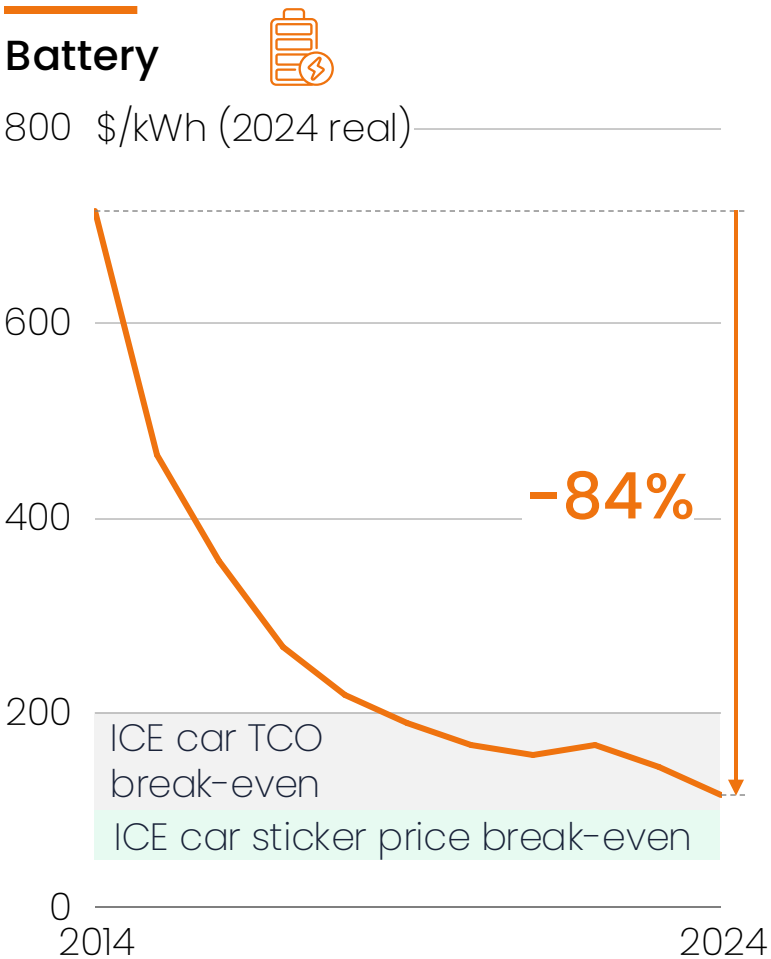
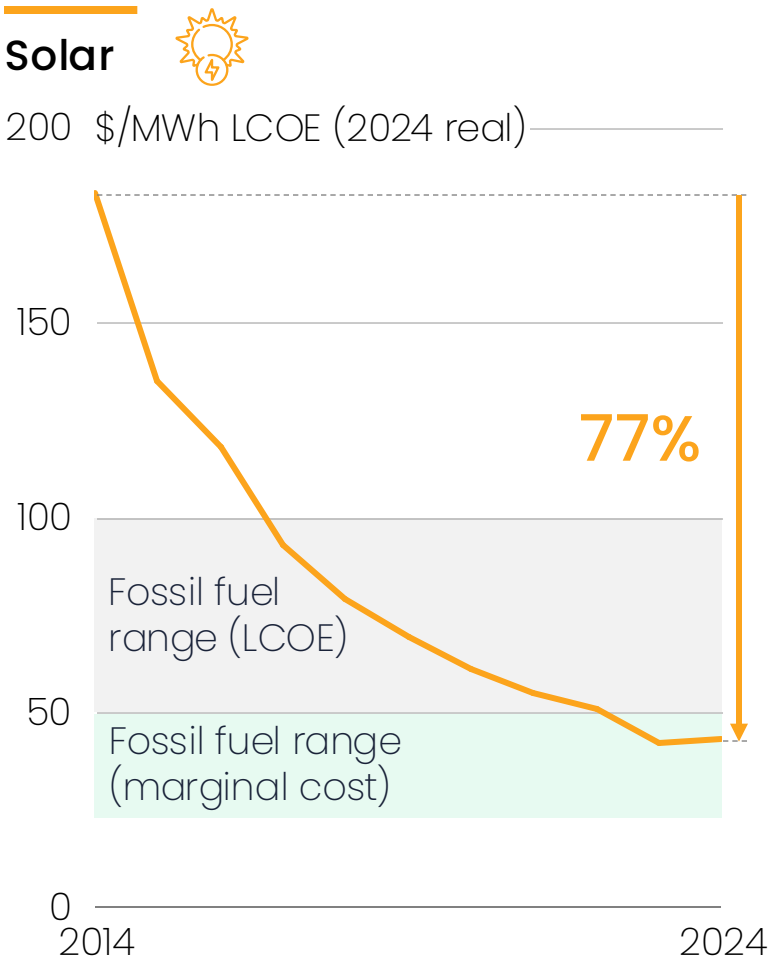
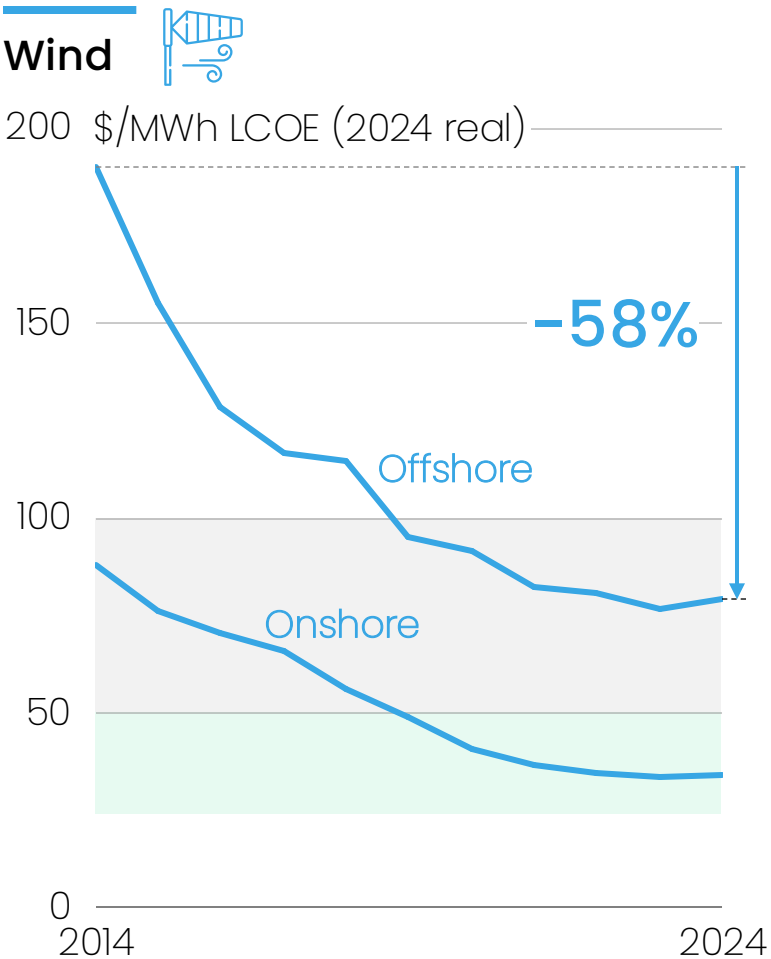
Costs have been falling for decades on learning curves

Decades of steady cost innovation improved electrotech economics



Cheap enough to challenge incumbents

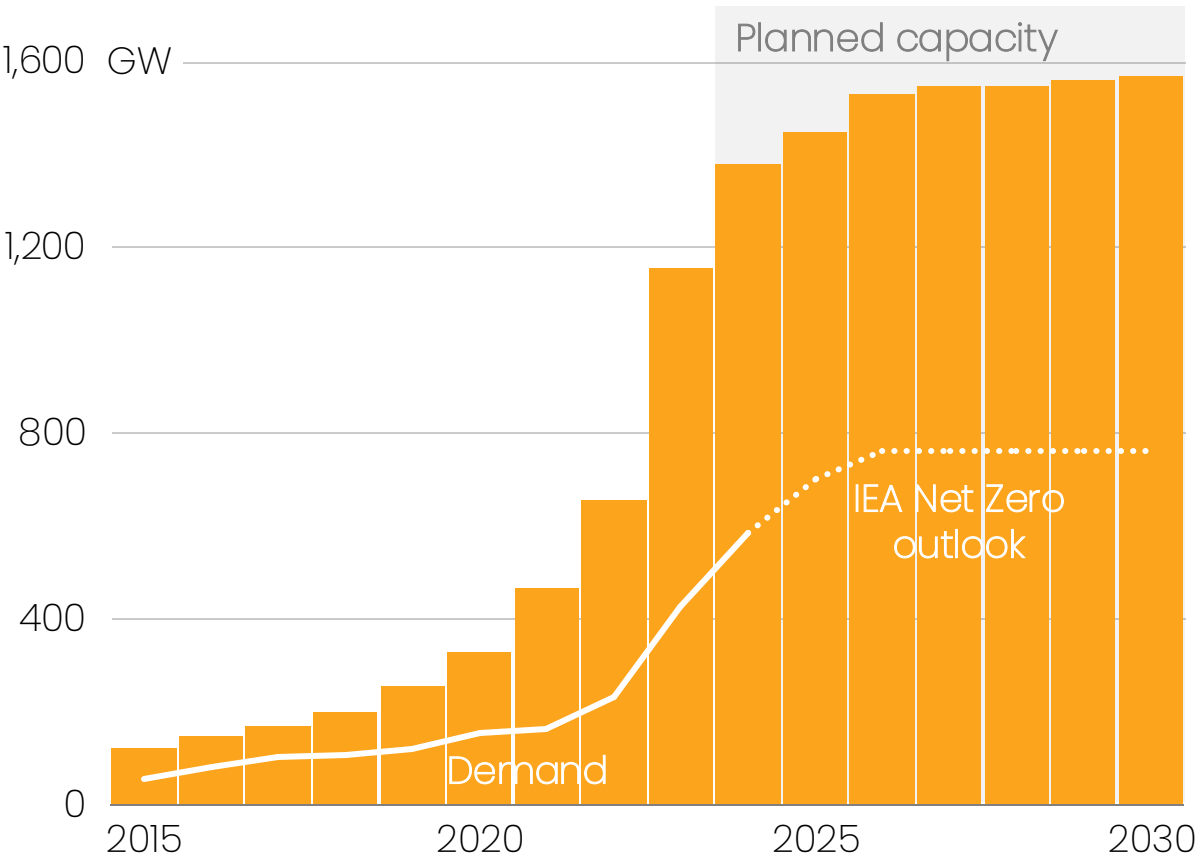
After decades of cost innovation electrotech is now cheaper than fossils



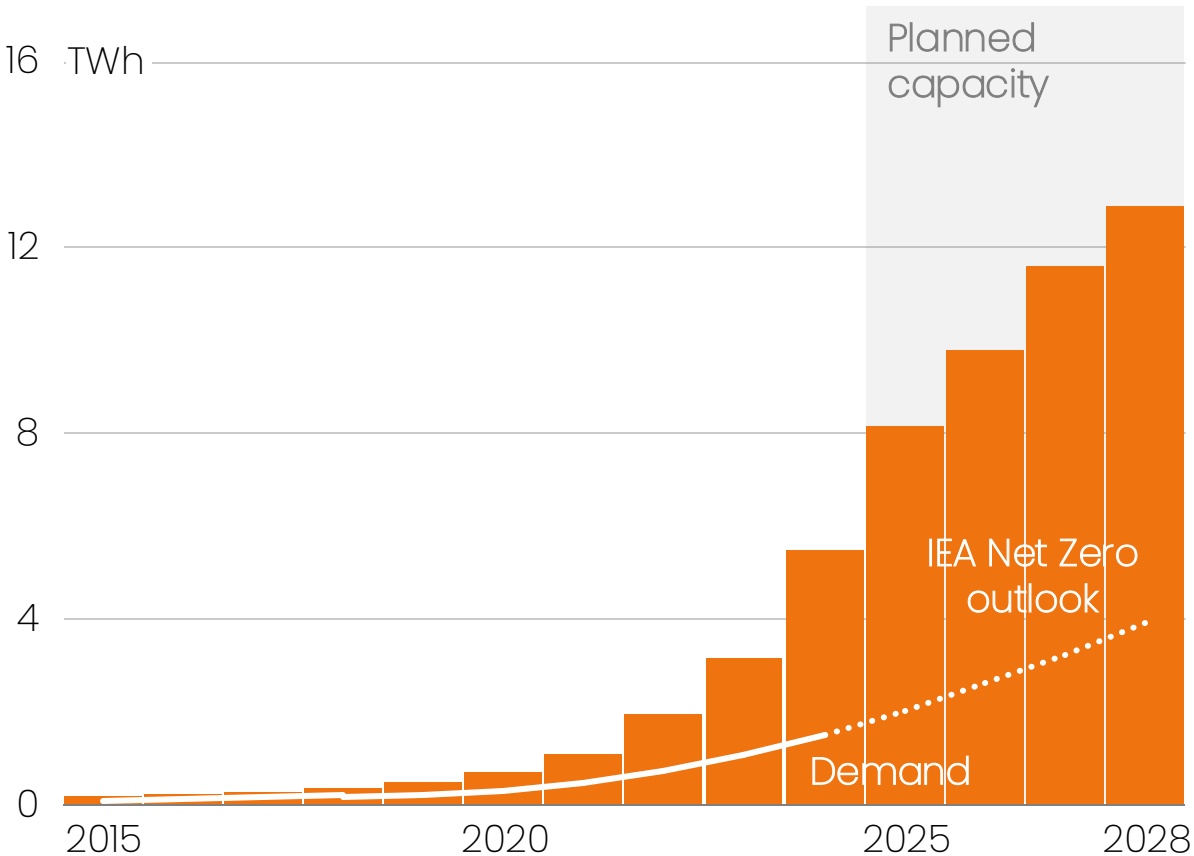
The manufacturing capacity is in place

Outpacing projected demand of even net zero scenarios

Solar PV manufacturing capacity



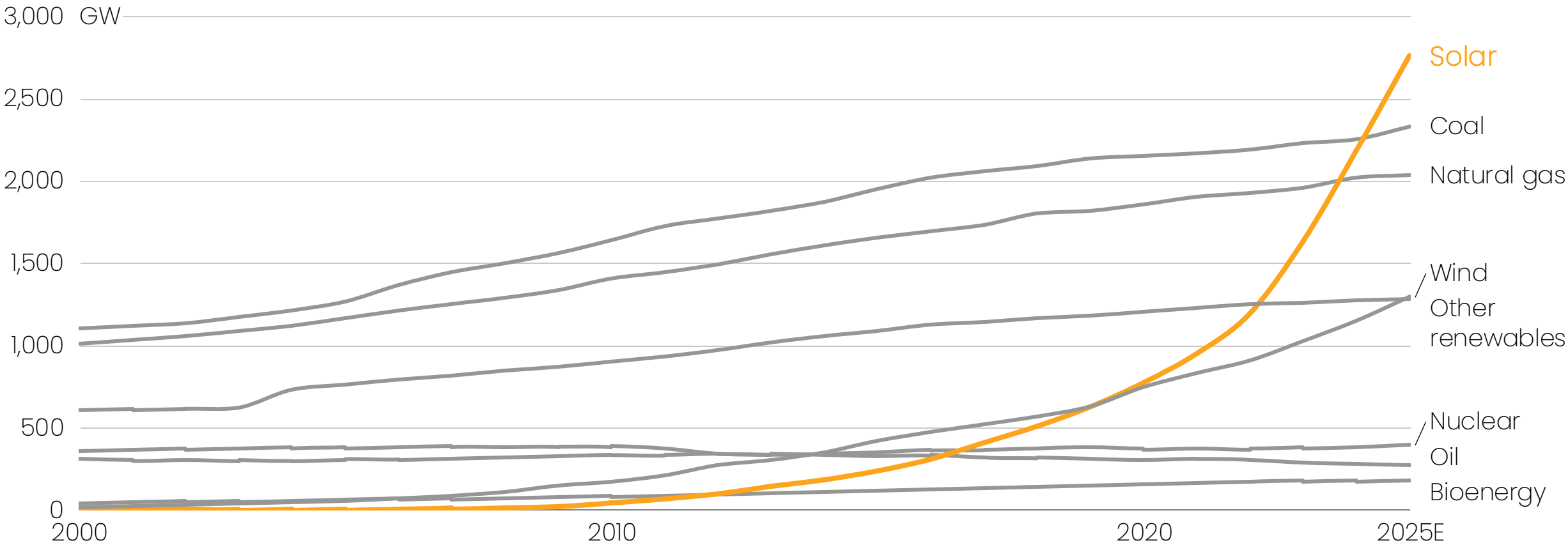
Battery manufacturing capacity



Sunrise

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

Global installed electricity capacity

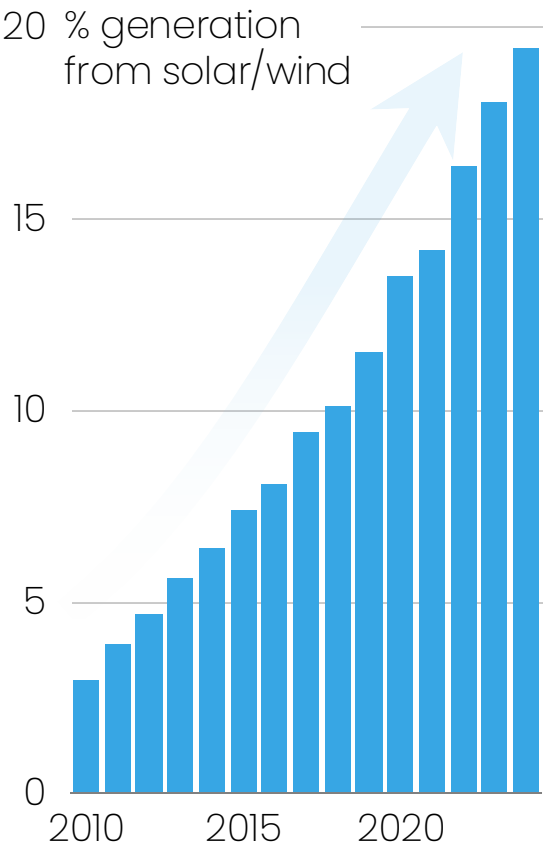




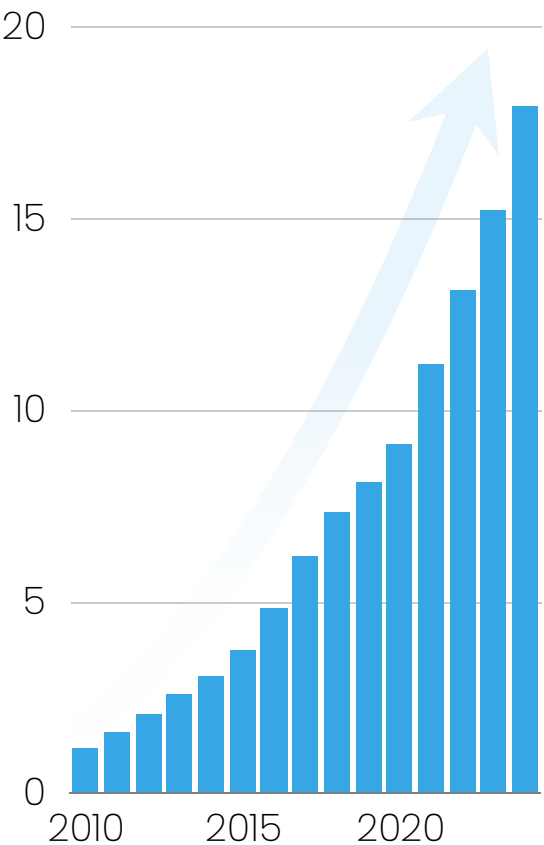
Solar and wind deployment is a global story

From mature economies to emerging markets

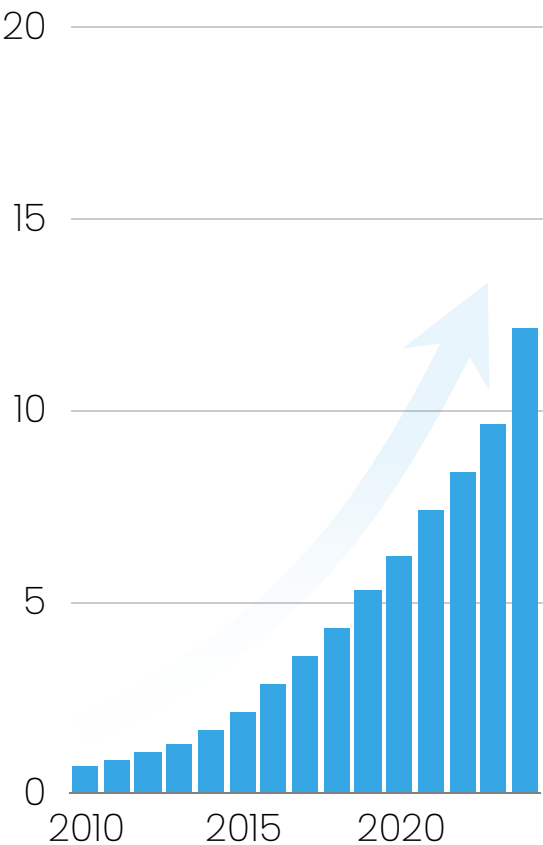
Mature markets



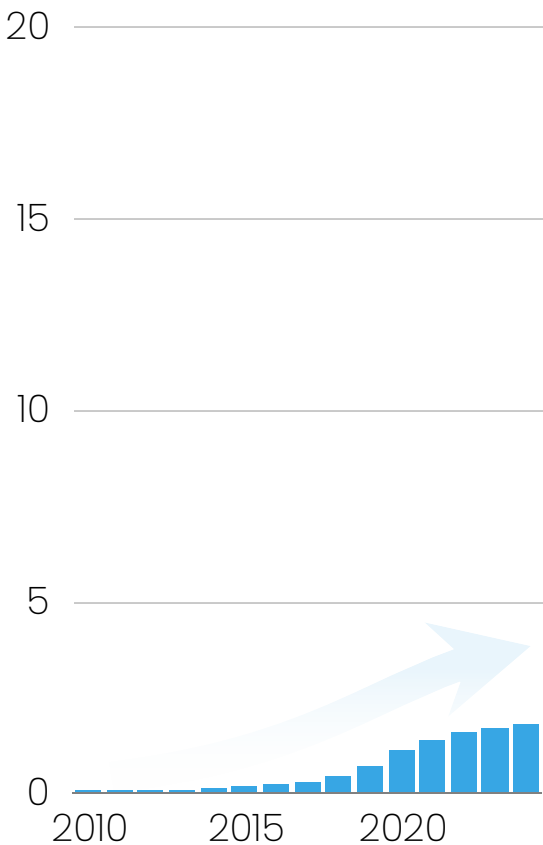
Greater China



Emerging markets



Petroregions

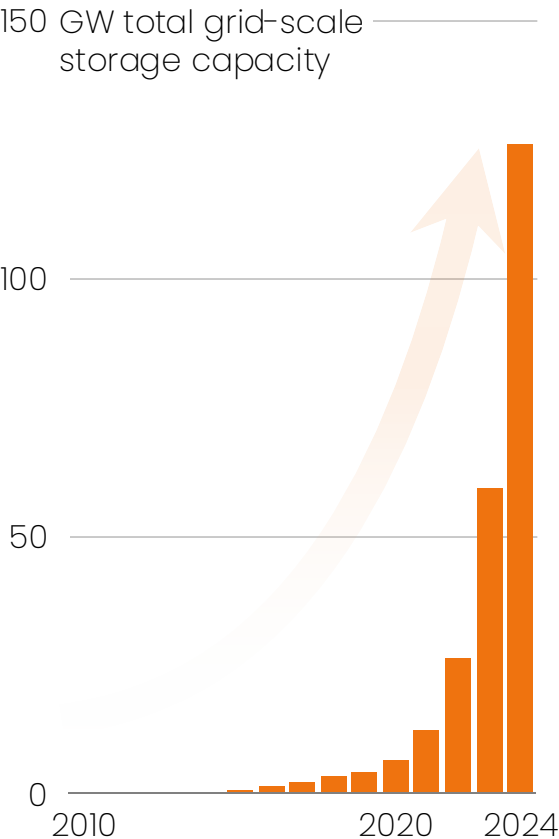


Sources: Ember. Note: Emerging markets include Latin America, Africa, South Asia and Southeast Asia; Petroregions include the Middle East and Eurasia.

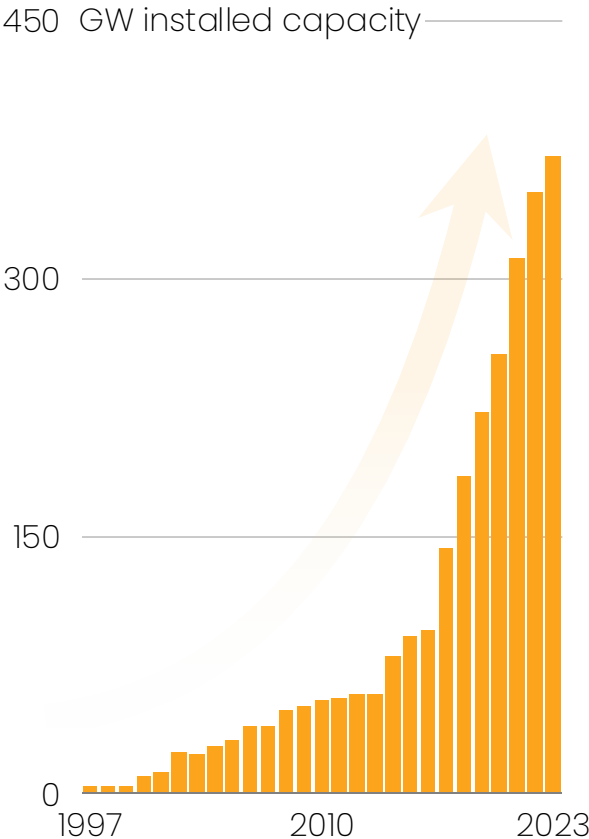
The rise of new connections

Flextech and gridtech smartly connect supply and demand

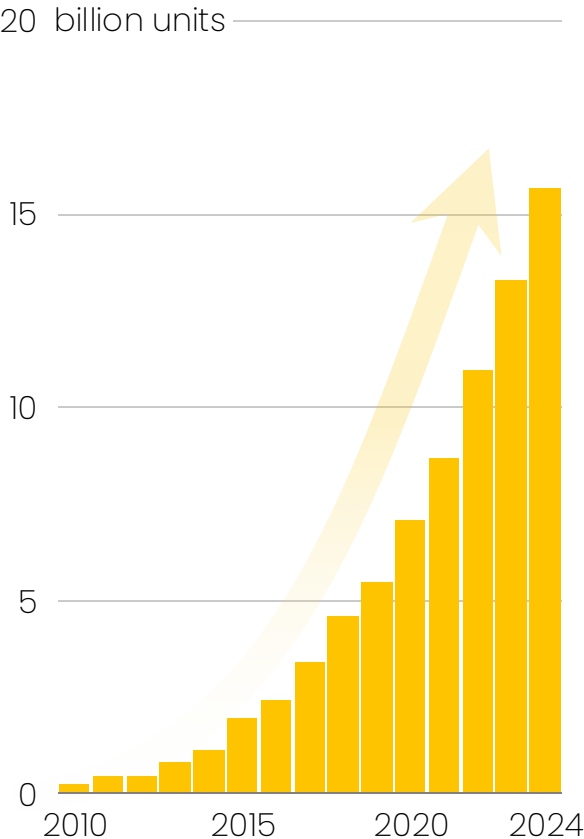
Battery storage capacity



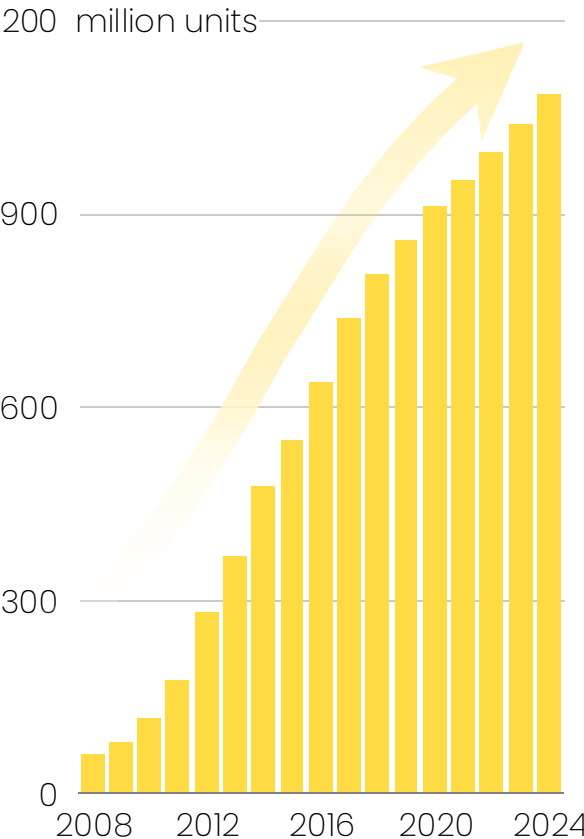
High voltage DC transmission



Internet connected devices



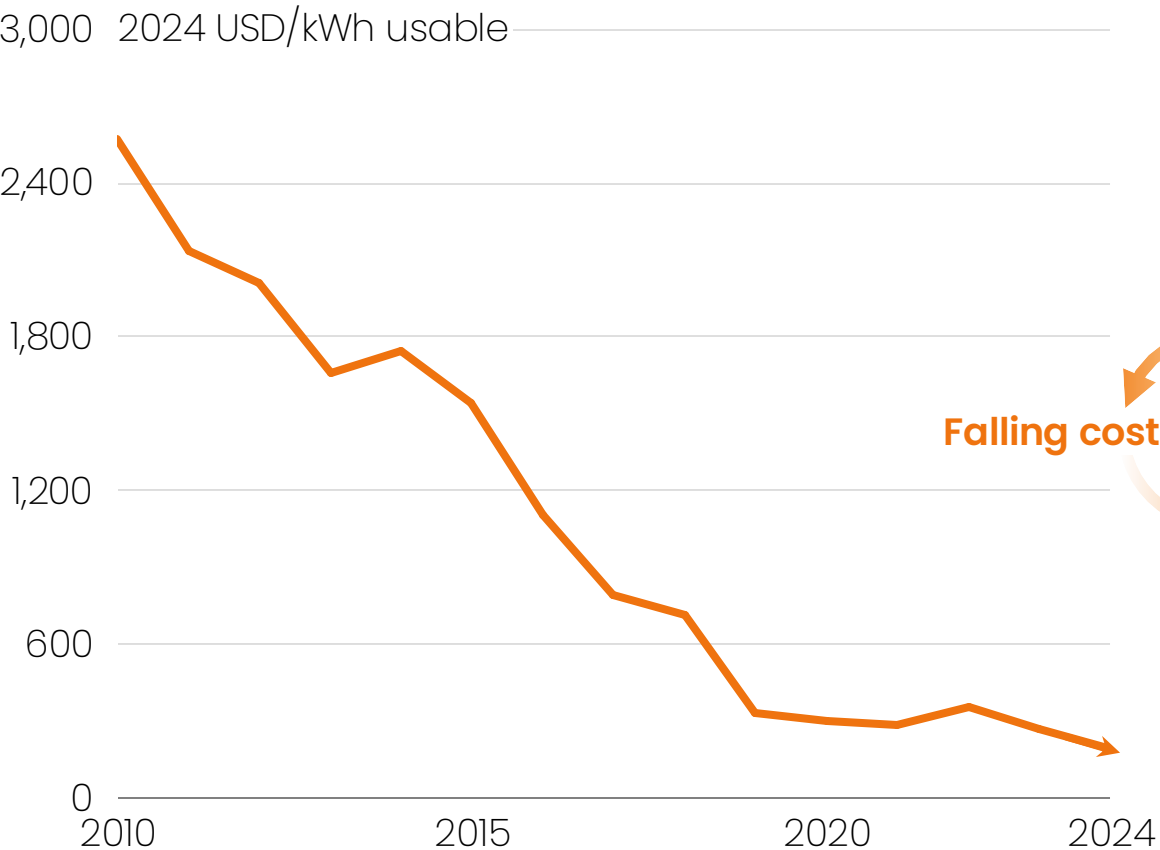
Smart meters installed



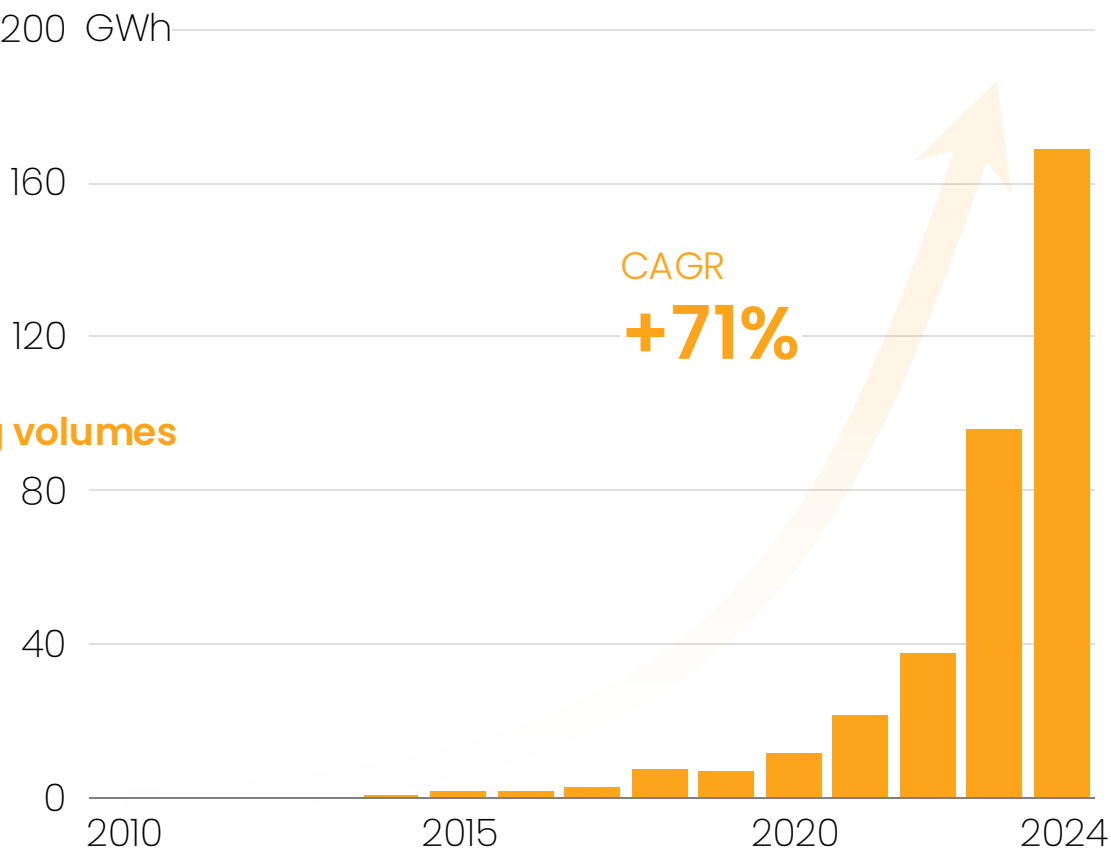
The cheaper it gets, the faster it goes

The virtuous cycle between cost and volume is self-sustaining

Utility-scale energy storage cost, global



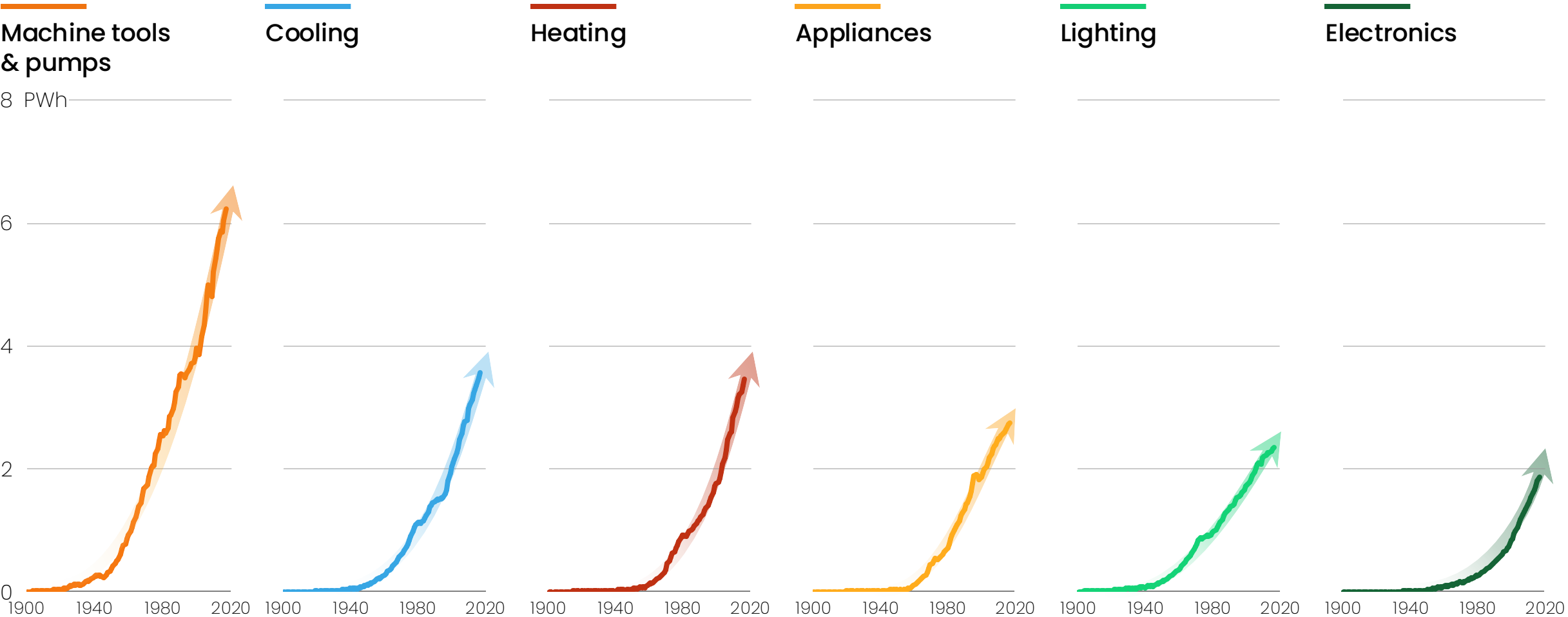
Utility-scale energy storage sales, global





The long march of electrification

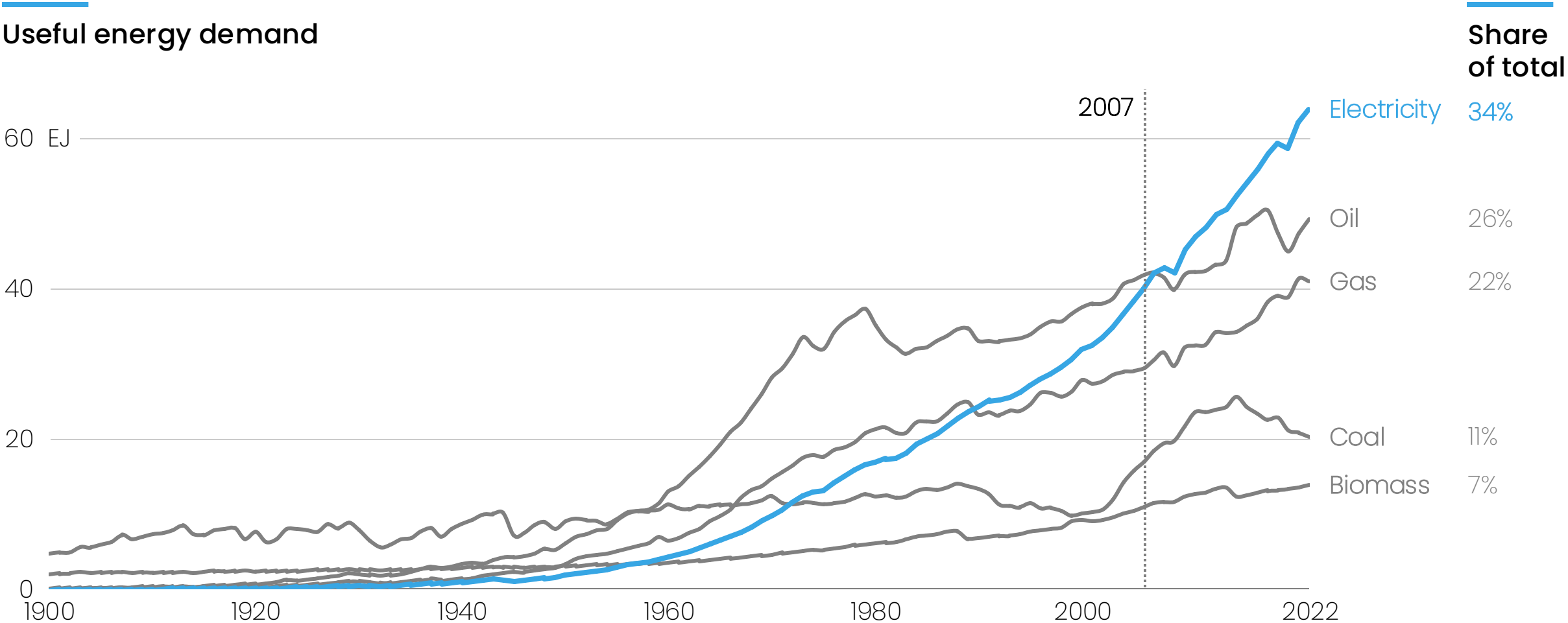
We've been electrifying the global economy for over a century



Electricity is the king of energy

Electricity overtook oil as largest supplier of useful energy in 2007

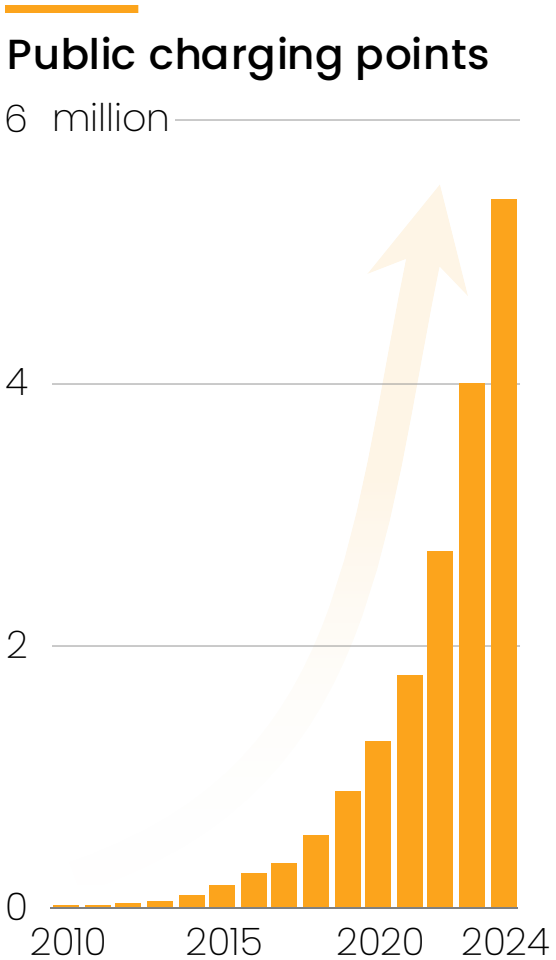
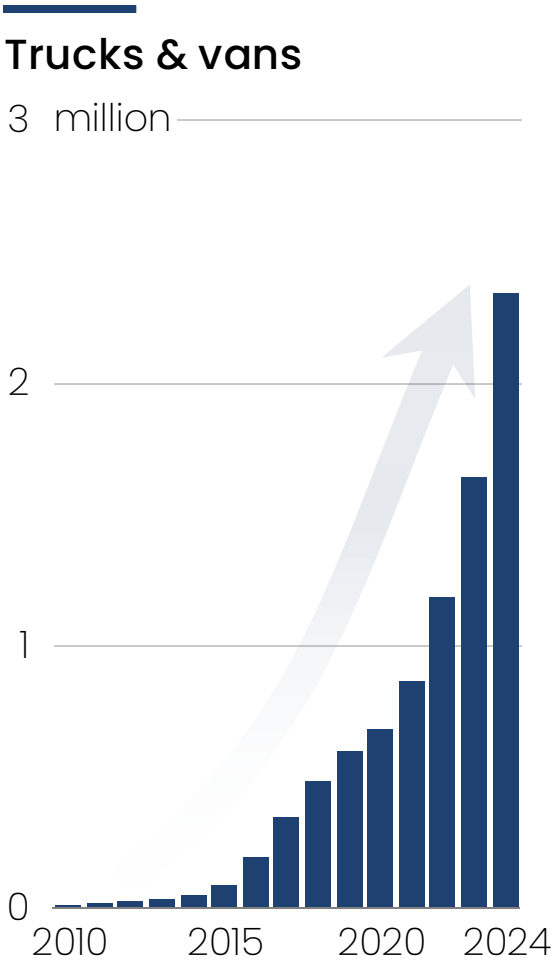
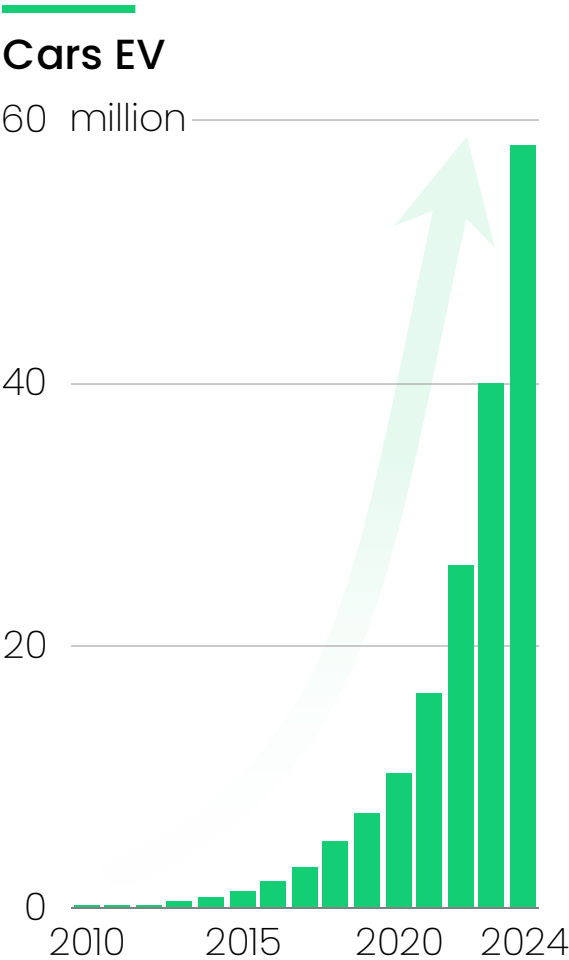
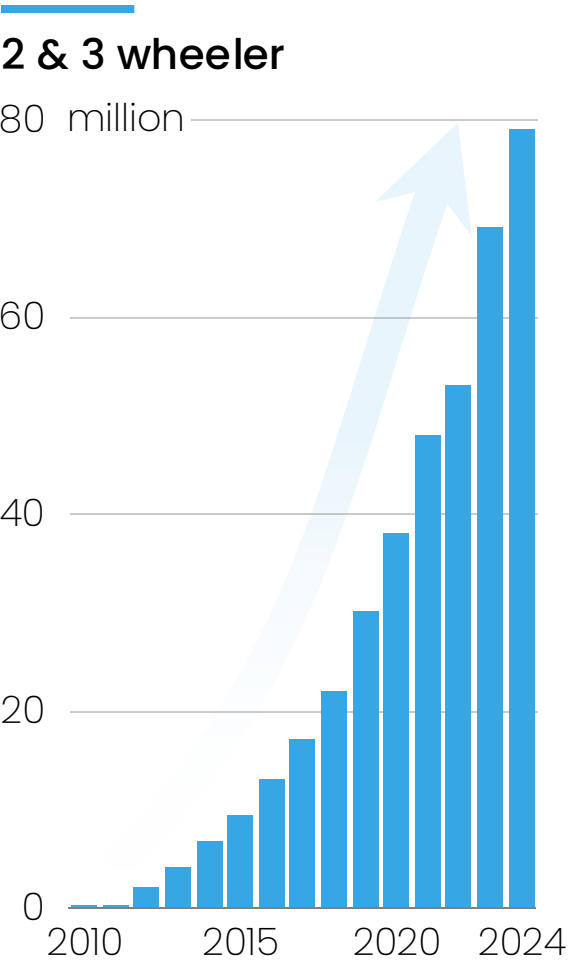
Useful energy demand





The EV revolution is taking off

Electric mobility is growing exponentially across vehicle sizes

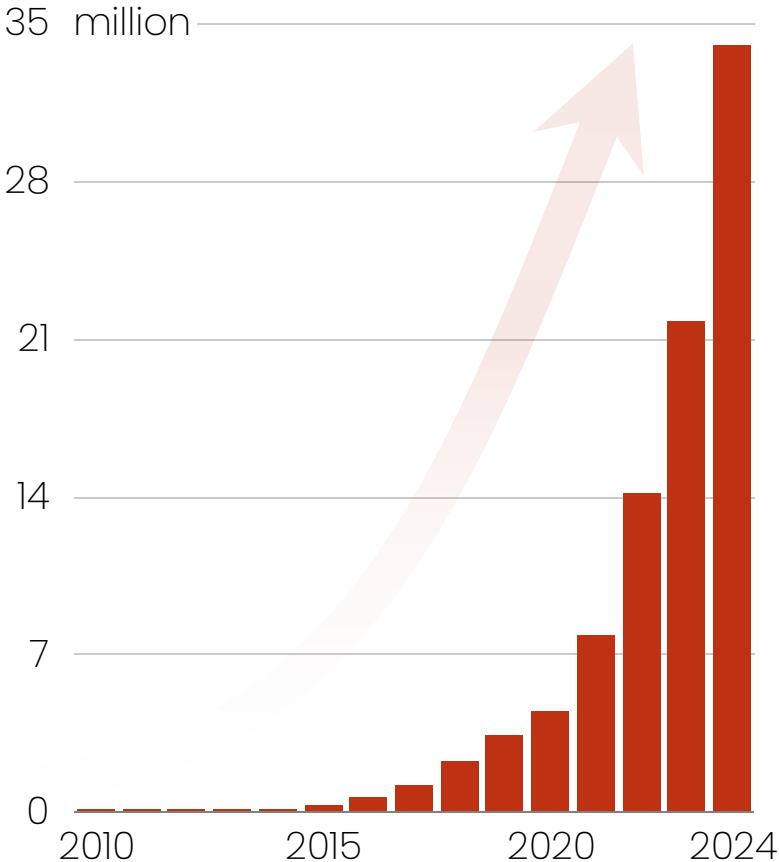




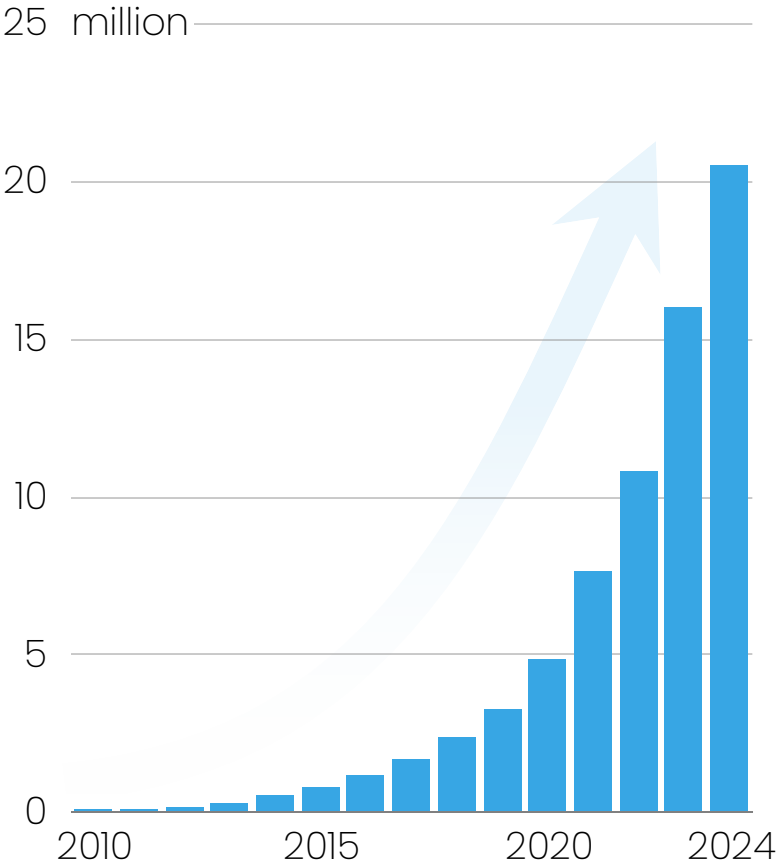
EV deployment is growing exponentially

Double digit growth across the world

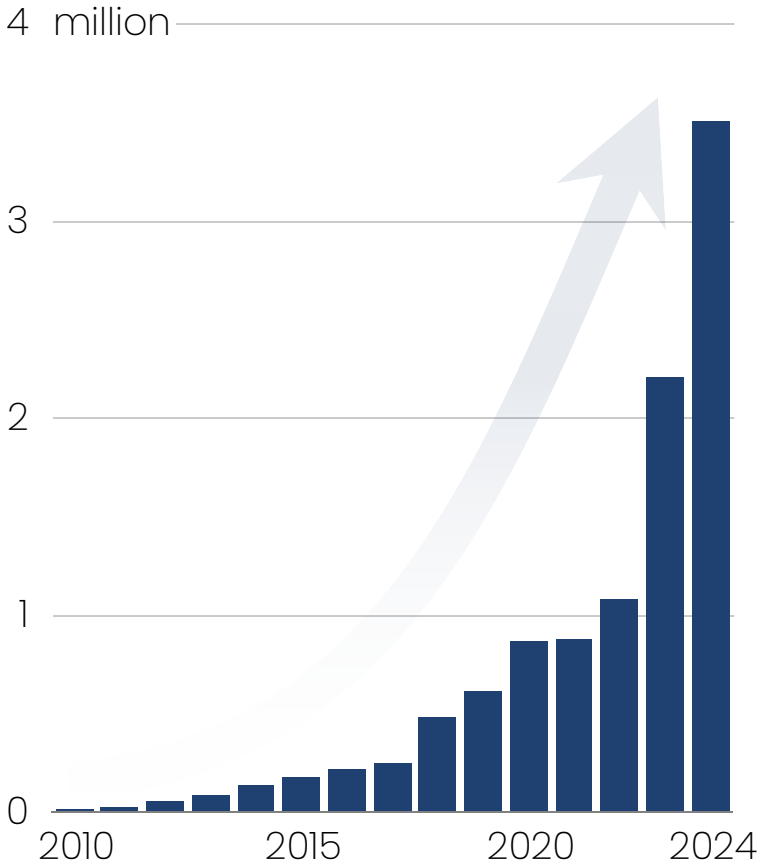
China



North America & Europe



Rest of World

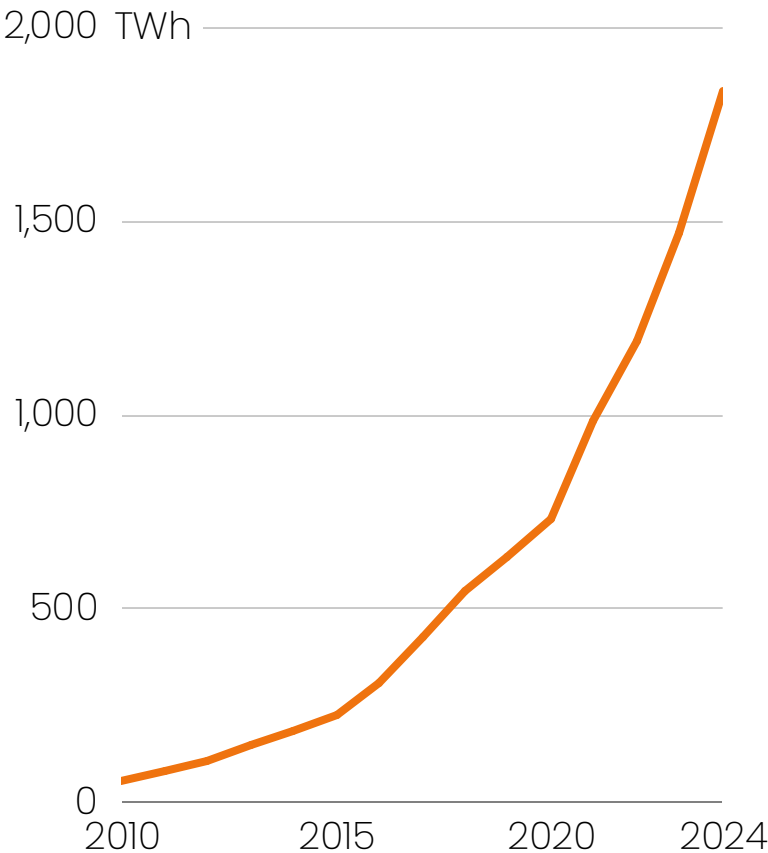




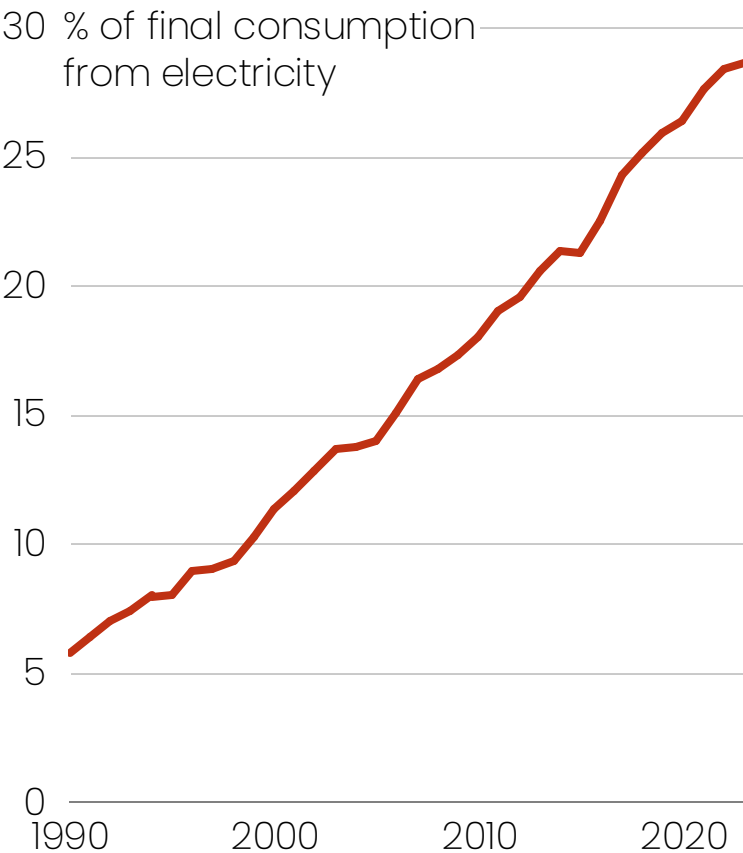
China is moving at lightning speed

Across renewables and electrification

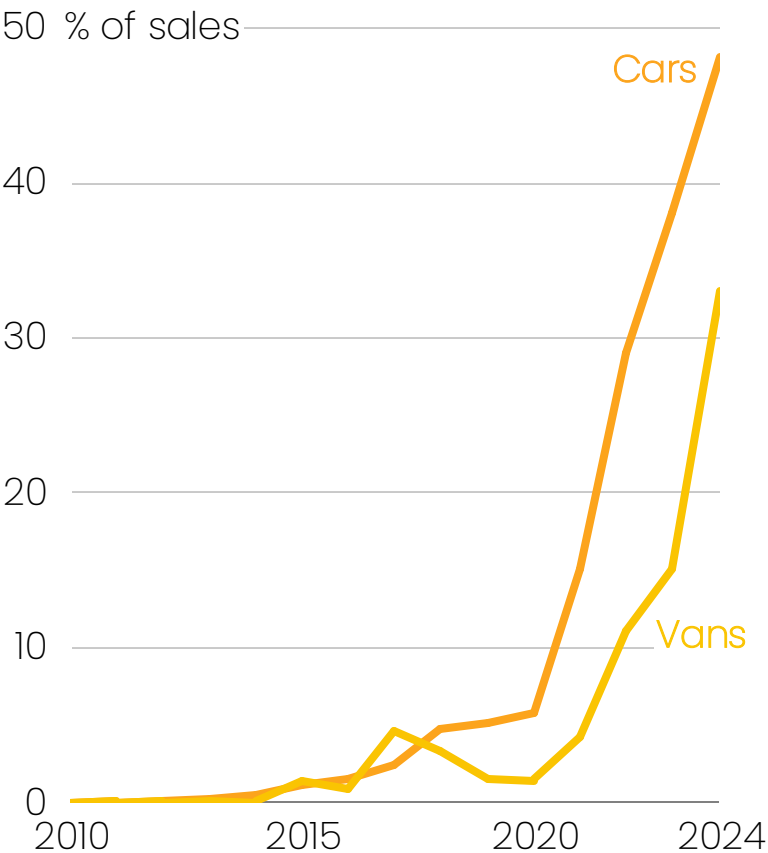
Solar and wind generation



Electrification

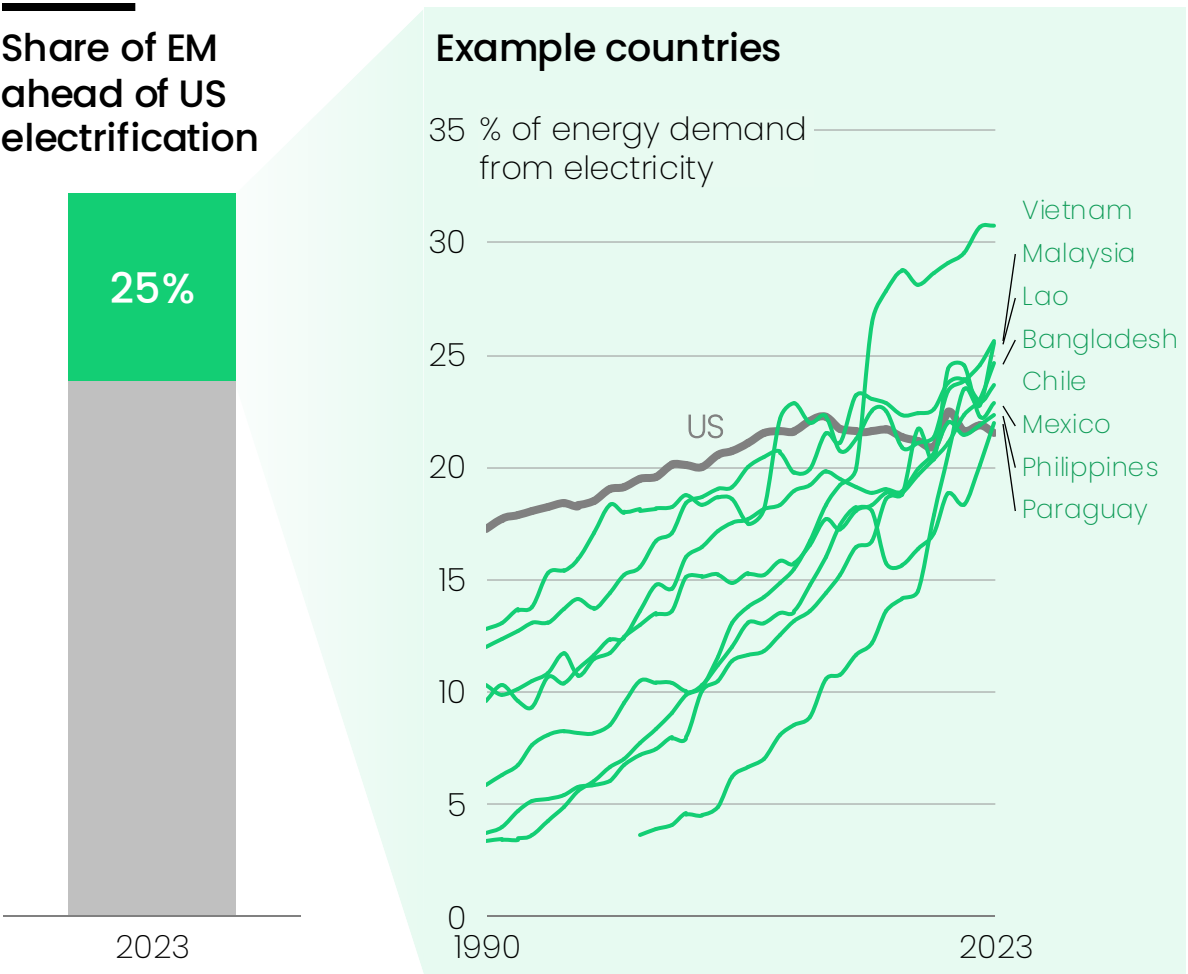
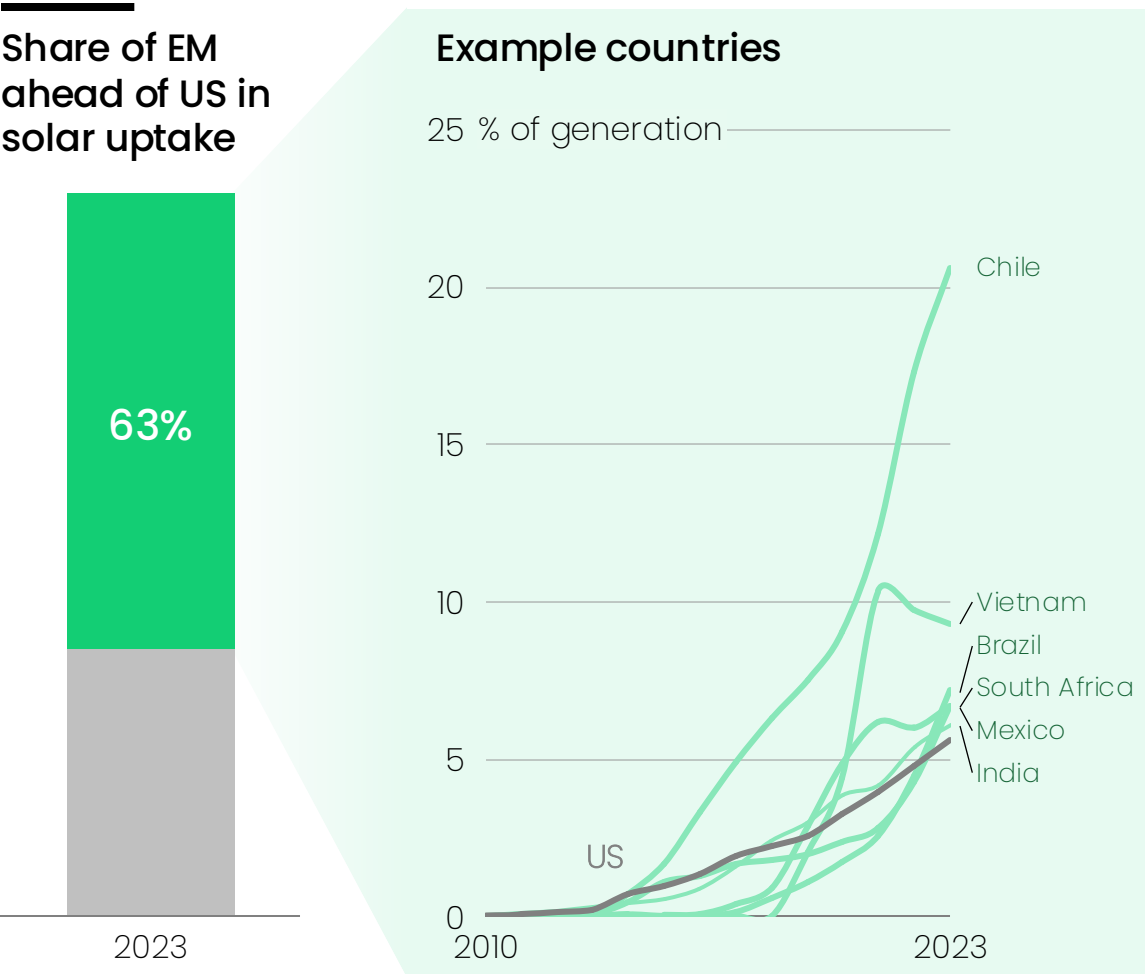


Electric vehicles



Emerging markets are leapfrogging

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





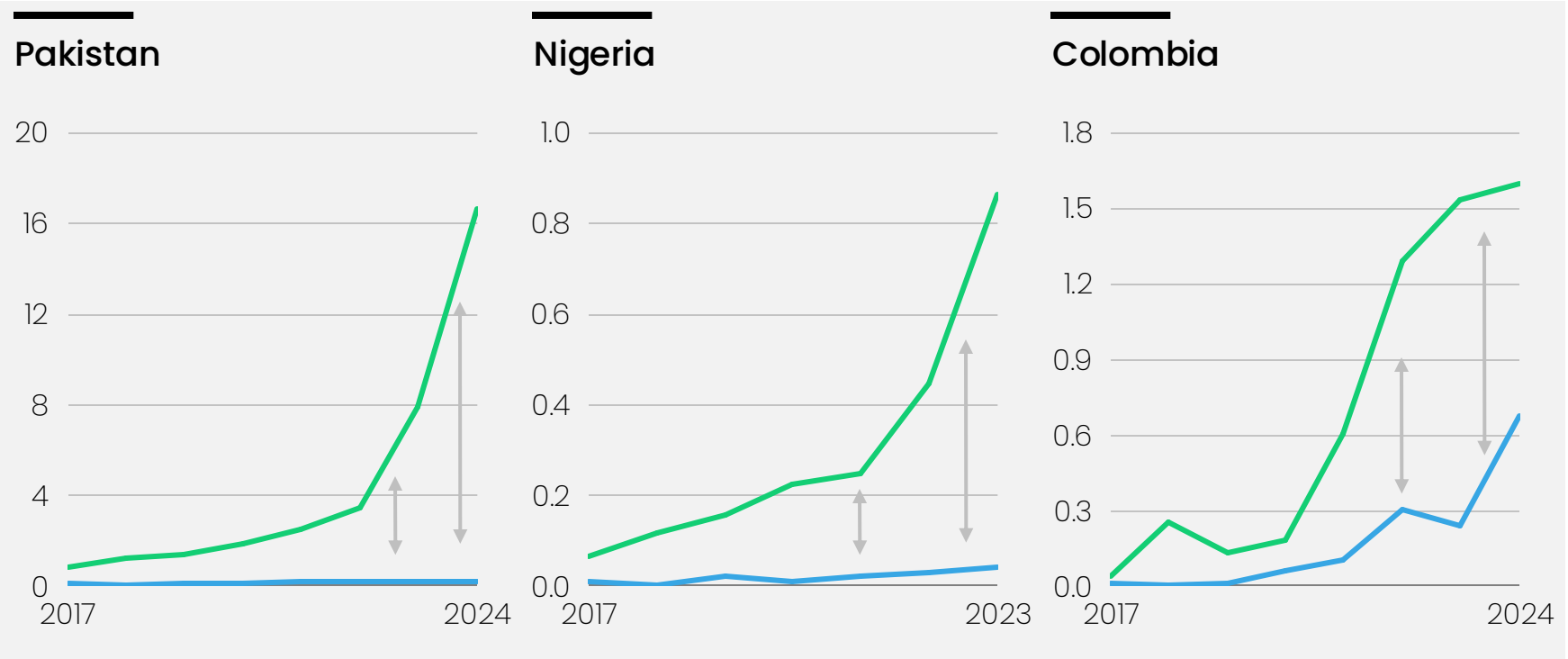
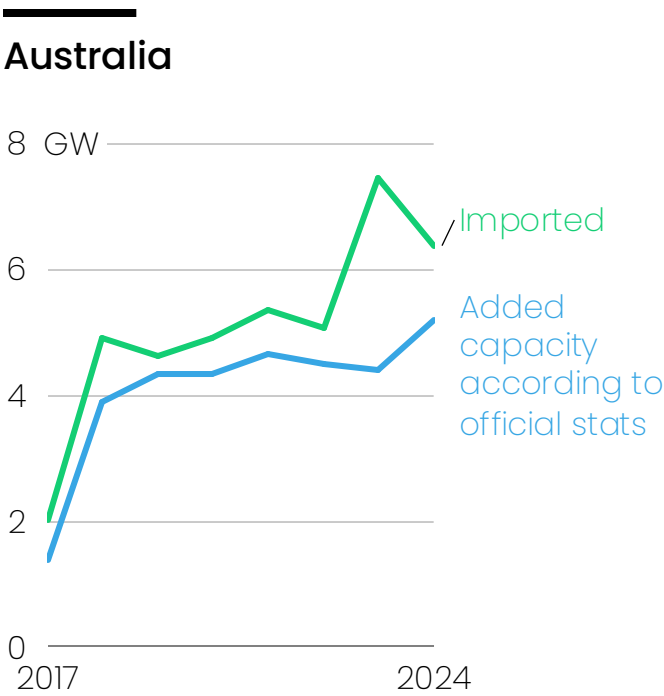
Change is happening faster than it can be recorded

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.

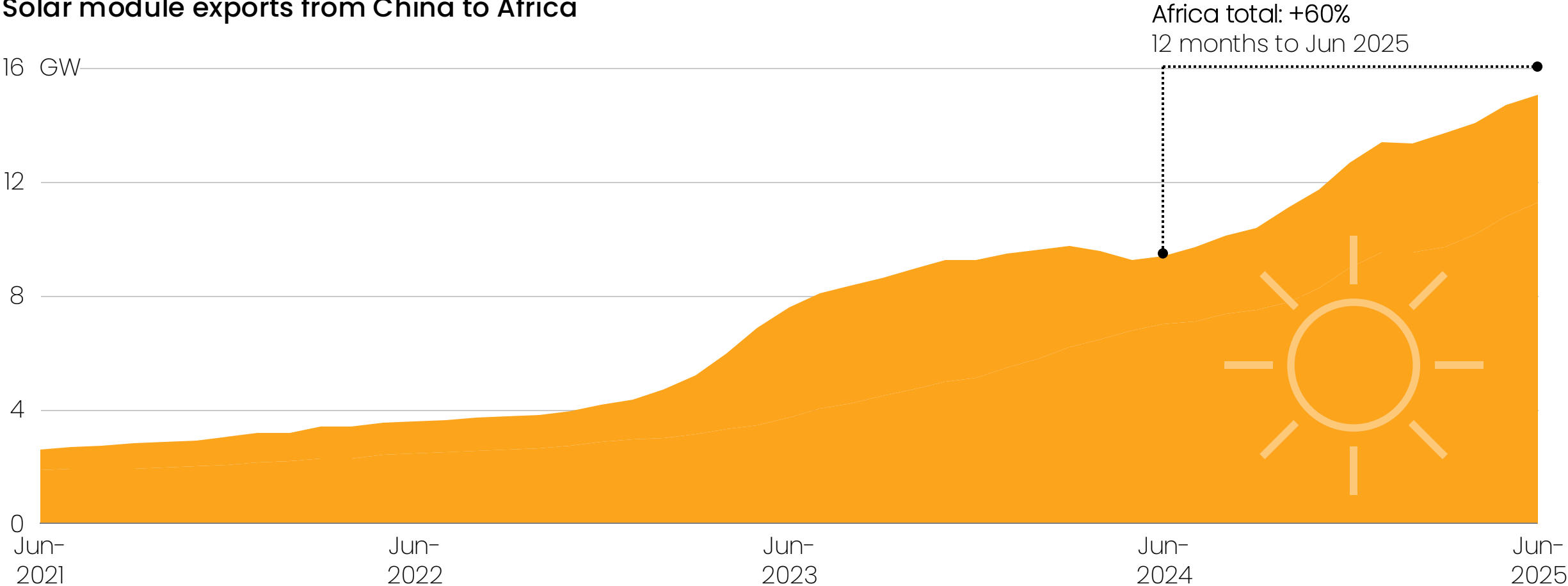




Africa is turning to the sun

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

Solar module exports from China to Africa



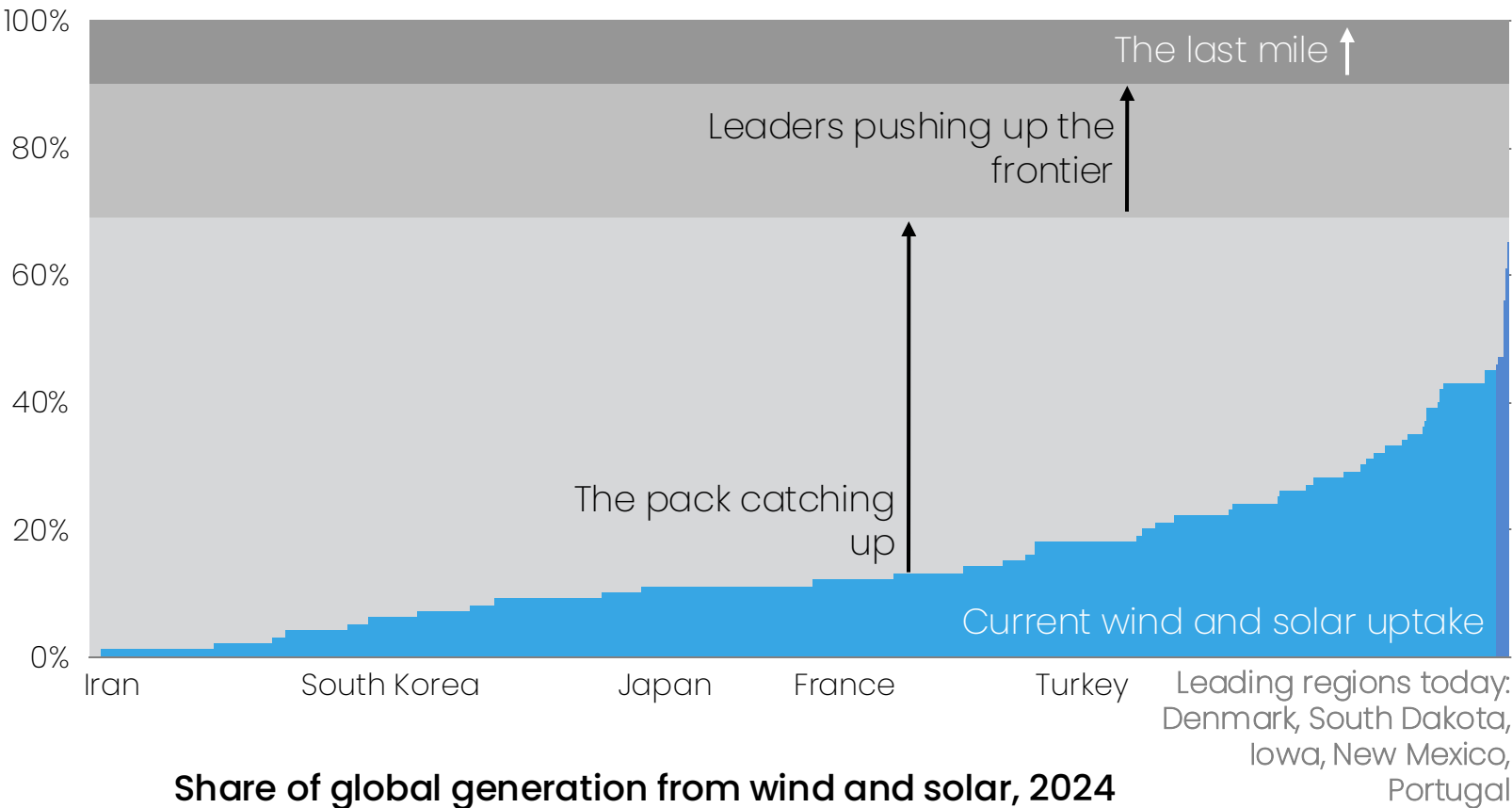


The renewables ceiling is high and rising

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



Wind and solar share of generation



6 solutions to manage variability

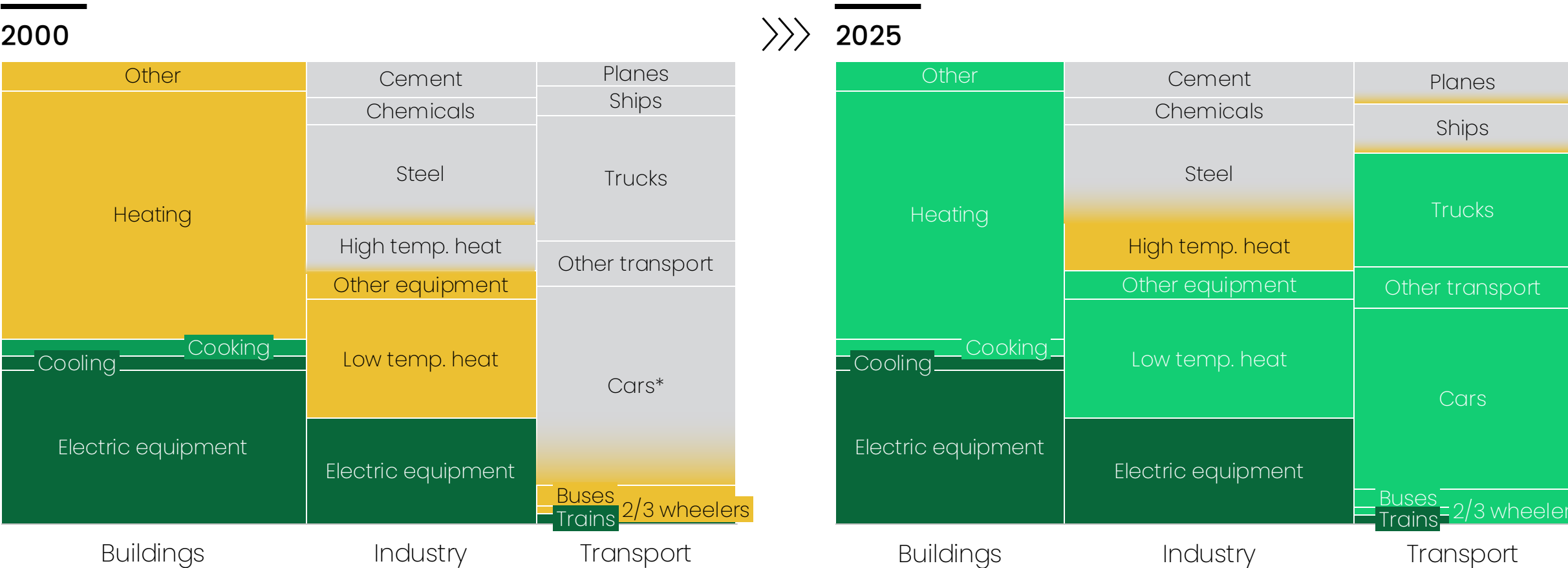
	Demand side flexibility
	Flexible generation
	Smarter grids
	Bigger grids
	Energy storage
	Overbuild solar & wind

The electrification ceiling is high and rising

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

- Already (largely) electrified
- Can be electrified technically
- Can be electrified economically
- Still under development

Share of final energy demand by subsector and electrification potential (%)

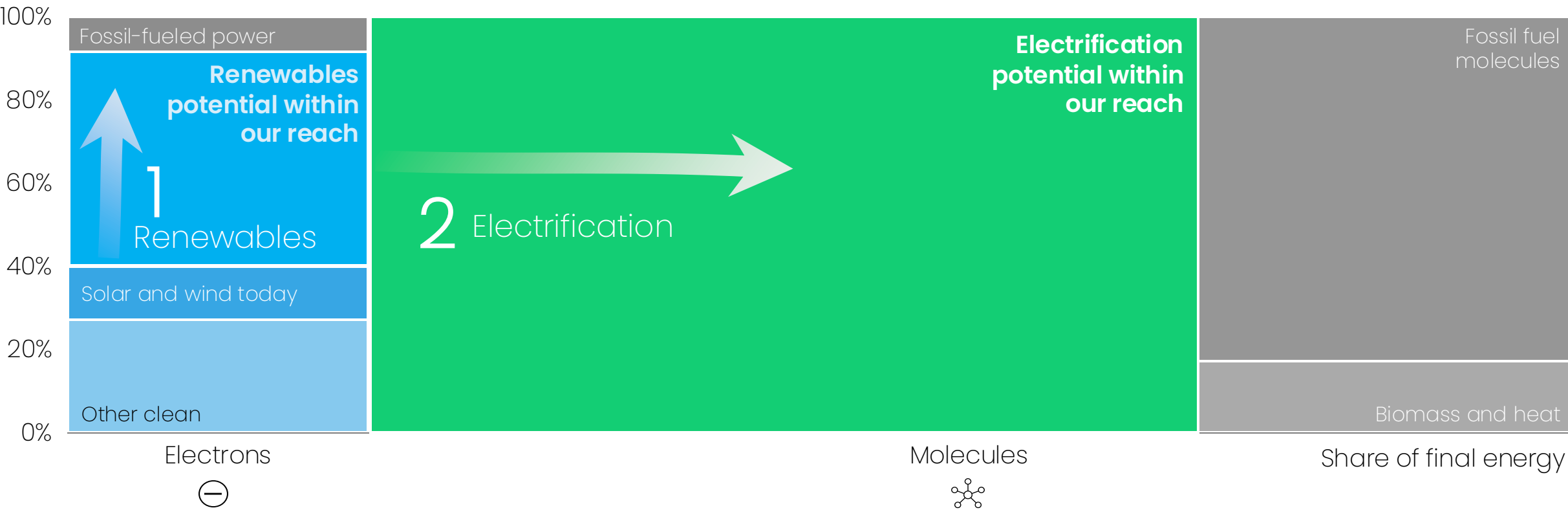


The majority of the energy system is within reach

Renewables and electrification can triple

Global final energy demand in 2023

Share of final energy



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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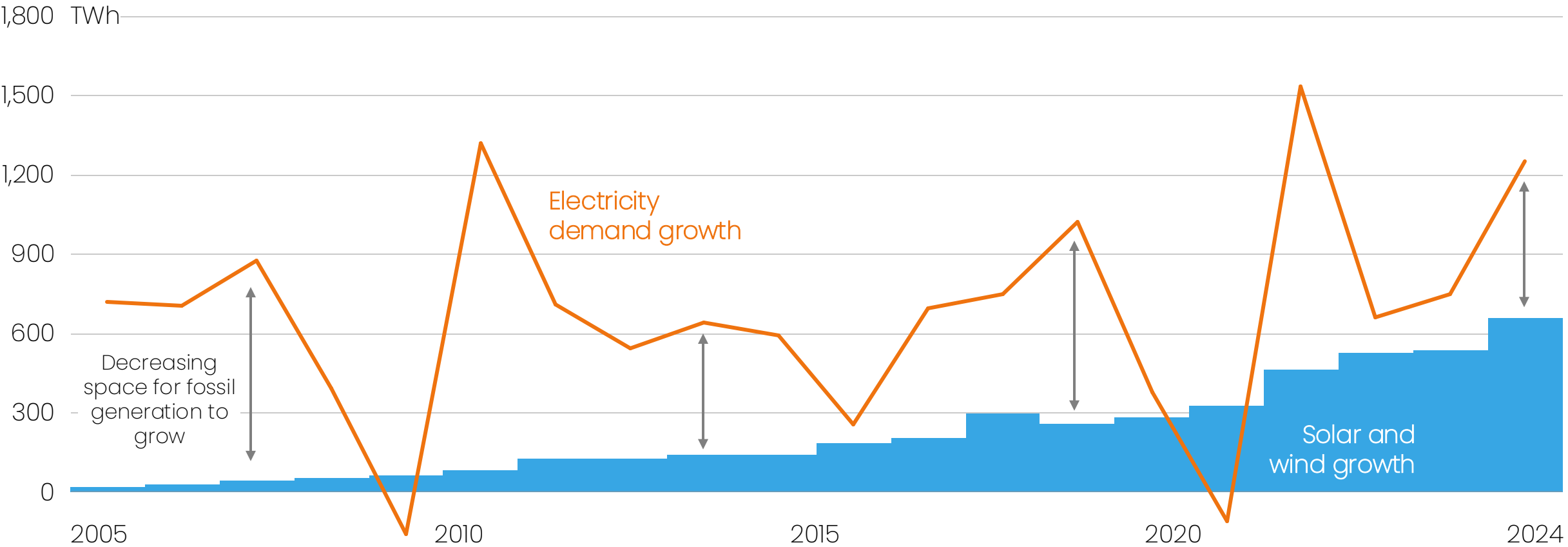


No space for fossils to grow in electricity

Solar and wind are about to take all the growth



Annual change in electricity generation



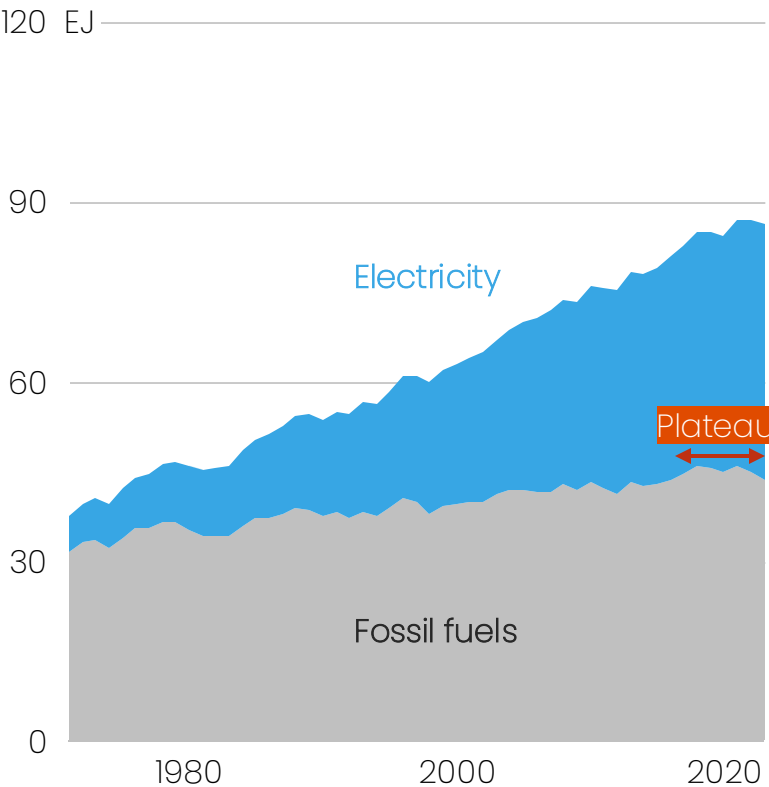


Electricity is taking all the growth in final demand

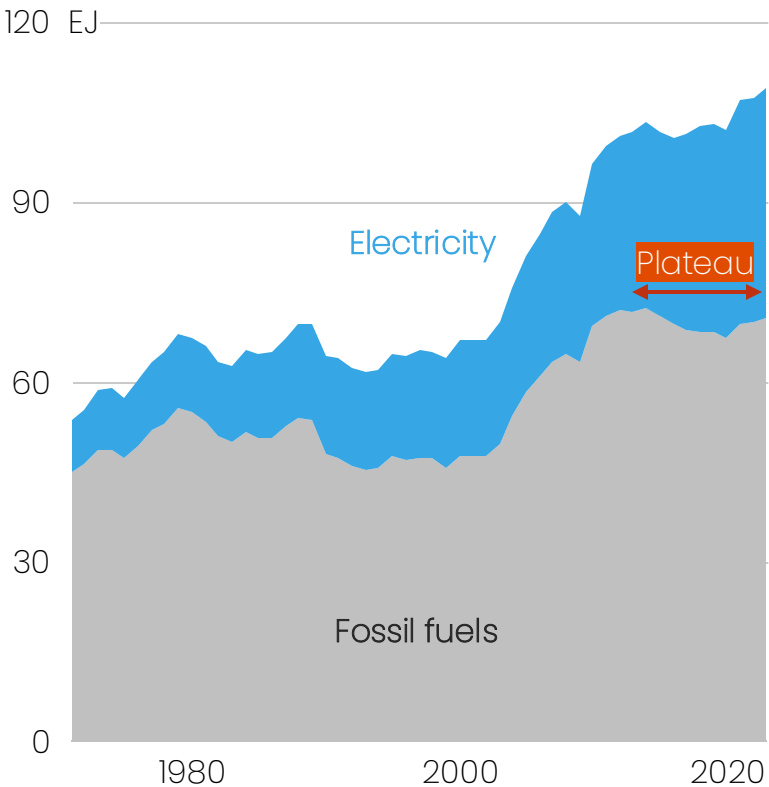
Peak fossils in industry was 2014 and in buildings was 2018

Final energy demand by sector

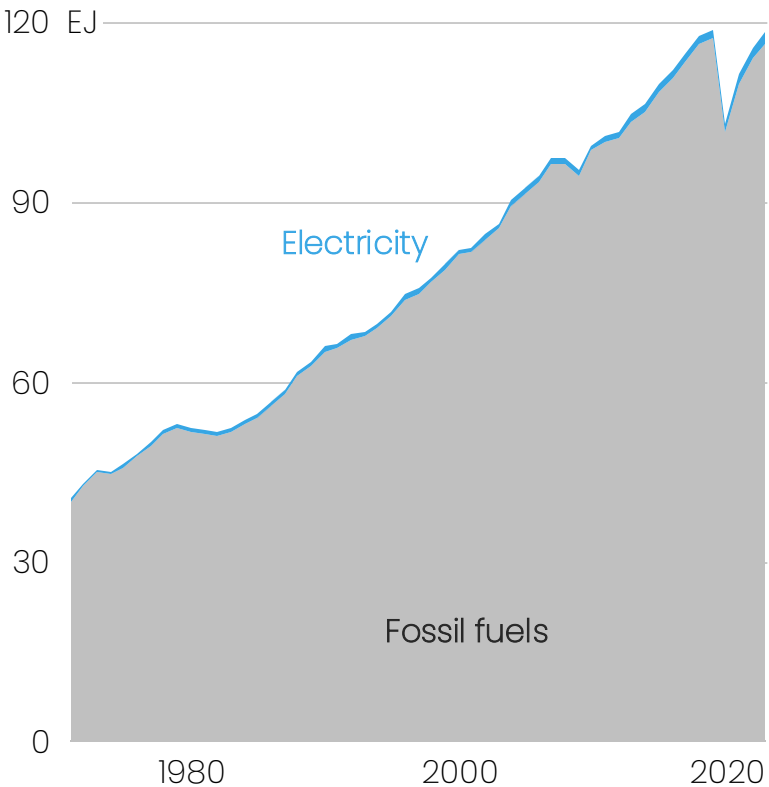
Buildings



Industry



Transport

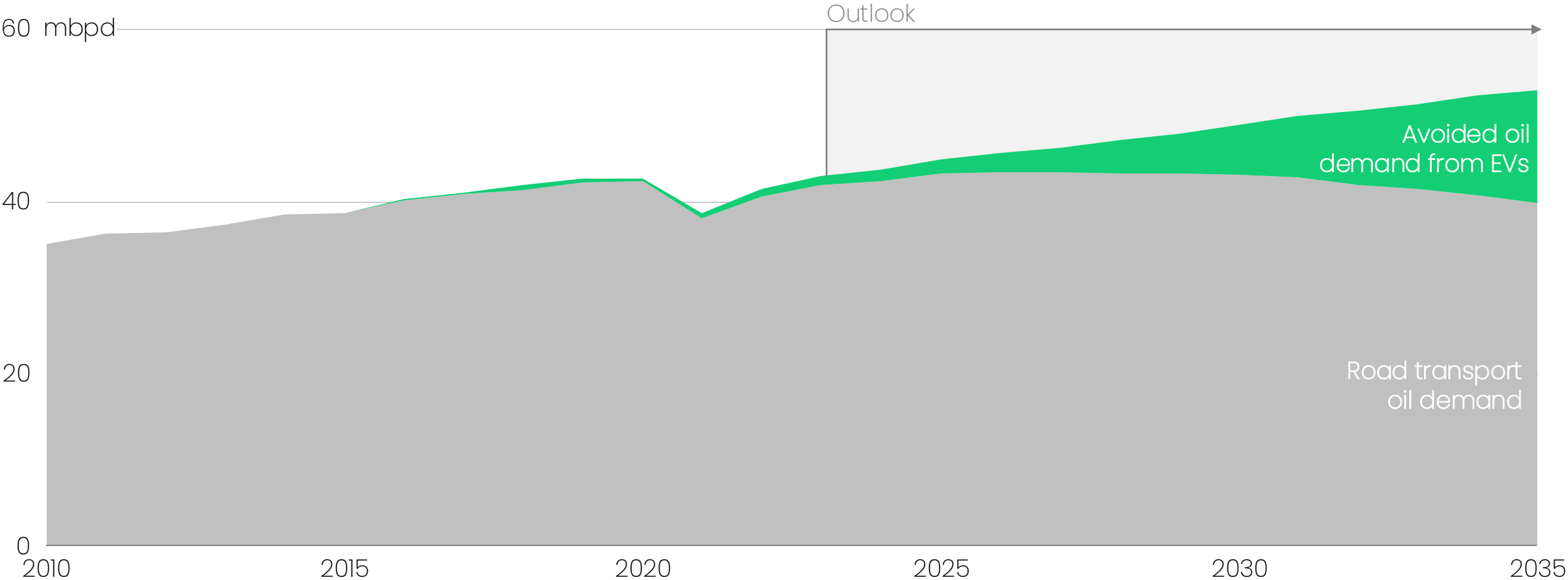




EVs are driving a plateau in road transport

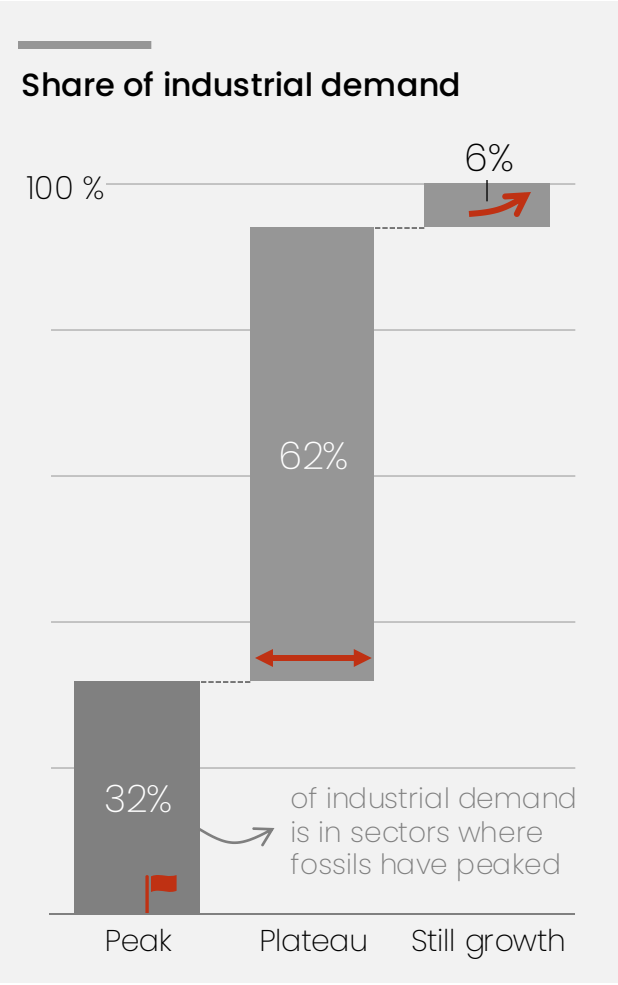
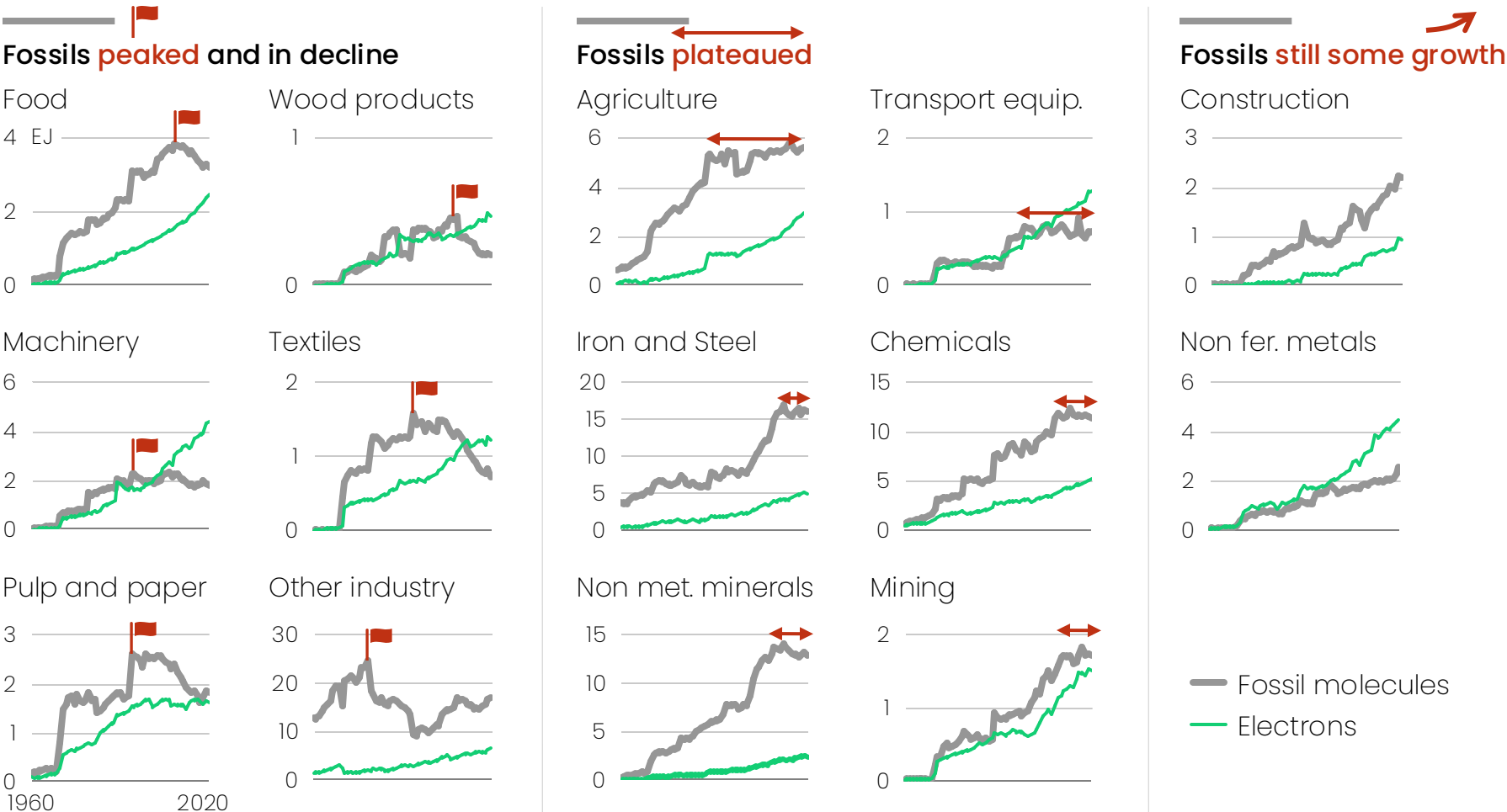
And road transport is 75% of transport energy demand

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



Industrial peaks everywhere

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

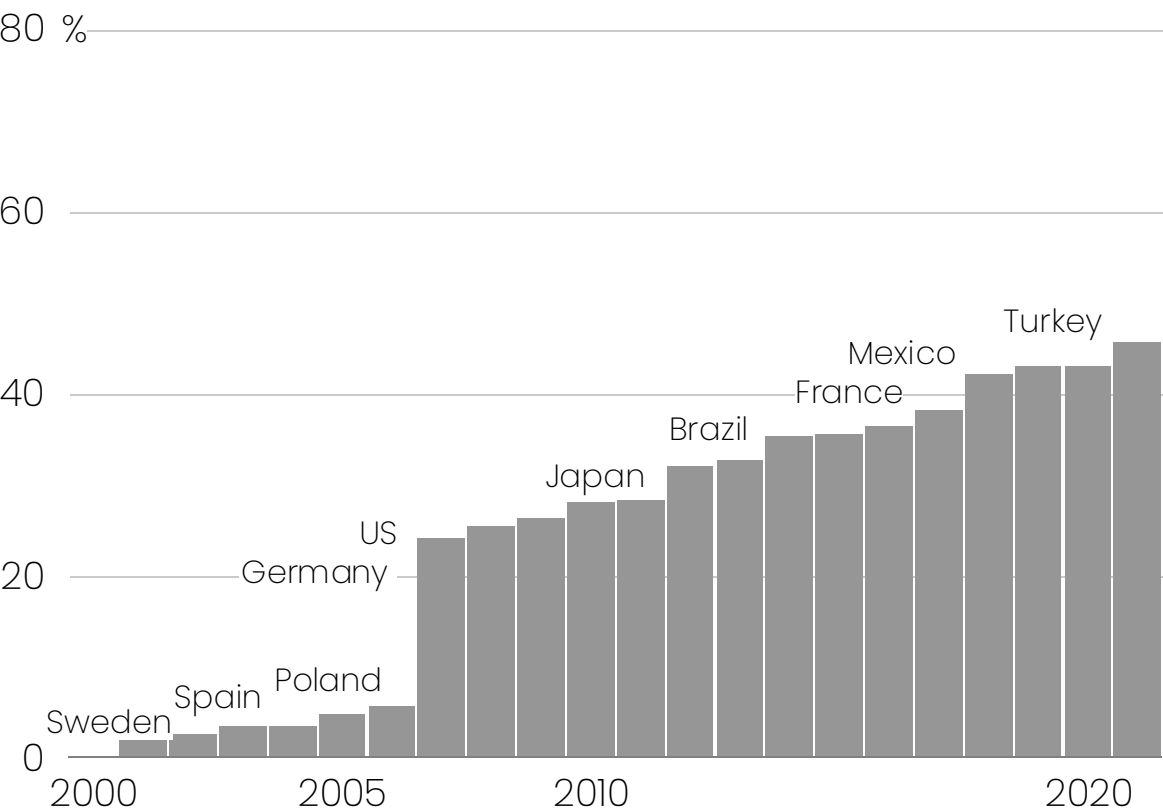


Most of the world is past peak fossil fuels

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

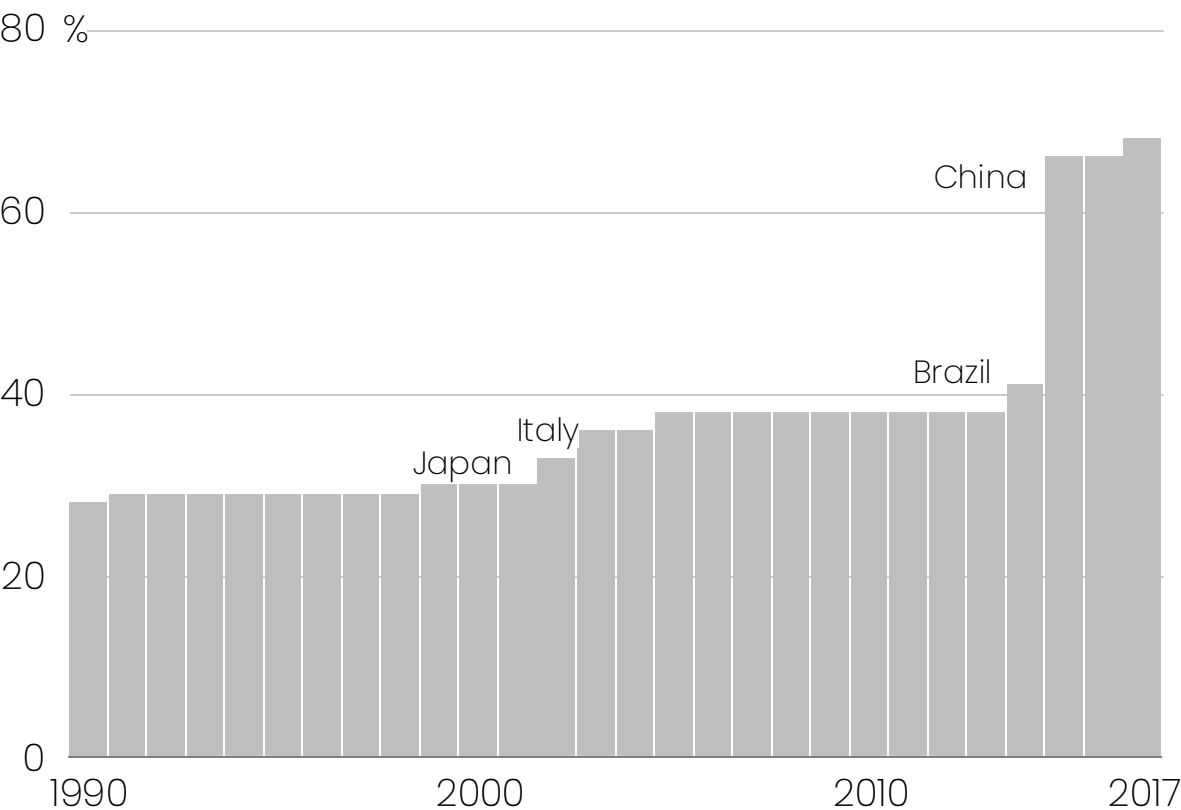
Share of the world past peak fossil demand for electricity

Driven by clean power and efficiency



Share of the world past peak final fossil energy demand

Driven by efficiency and electrification



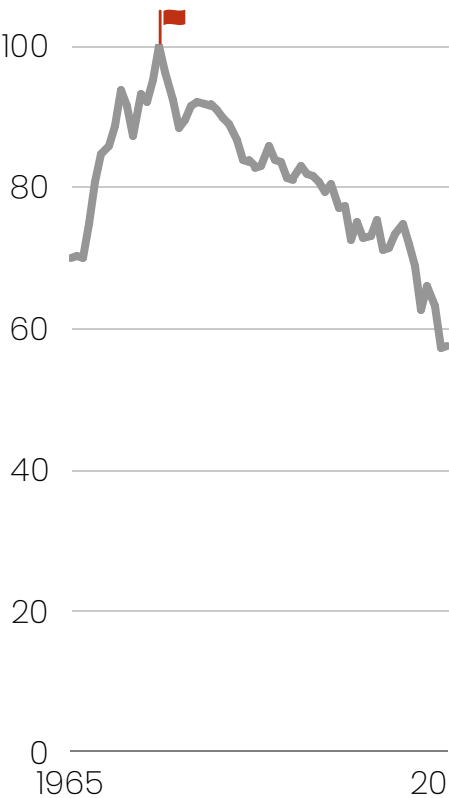


After the peak comes the fall

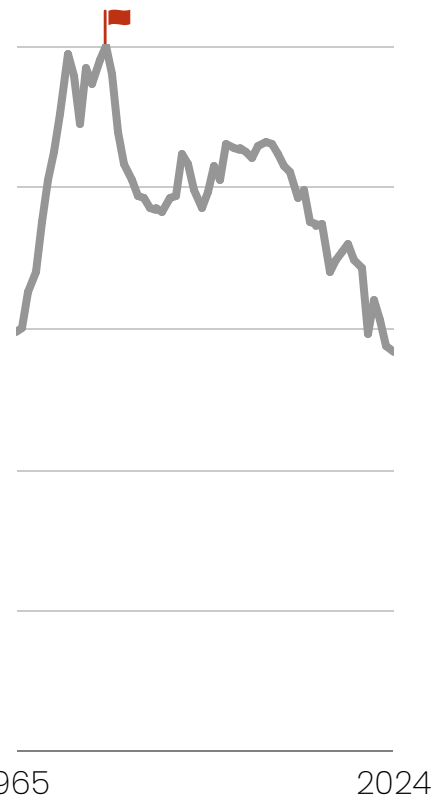
Countries don't have long plateaus although the world does

Fossil fuel demand, peak = 100

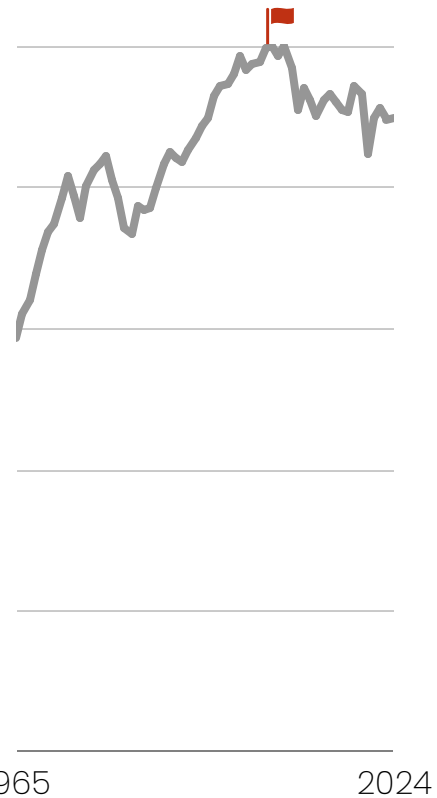
Germany



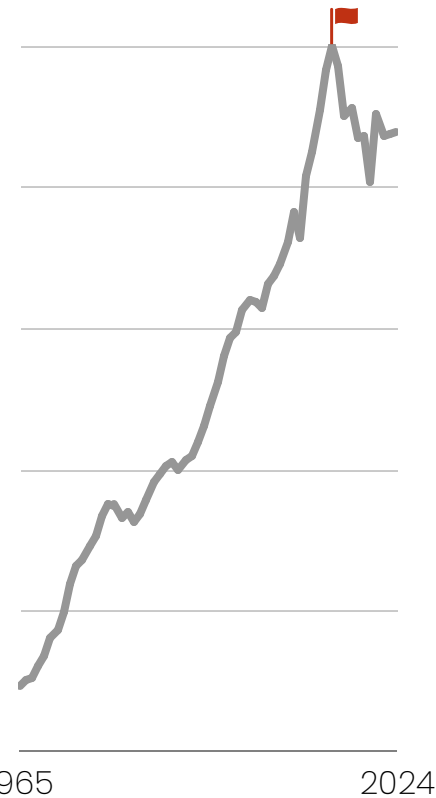
France



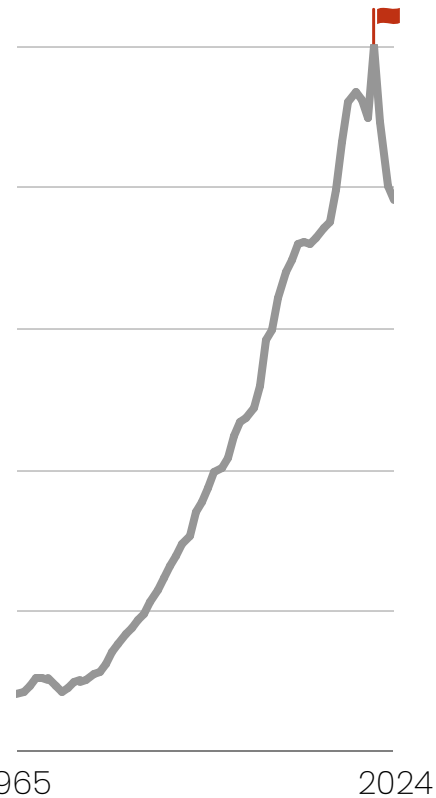
United States



Brazil



Pakistan

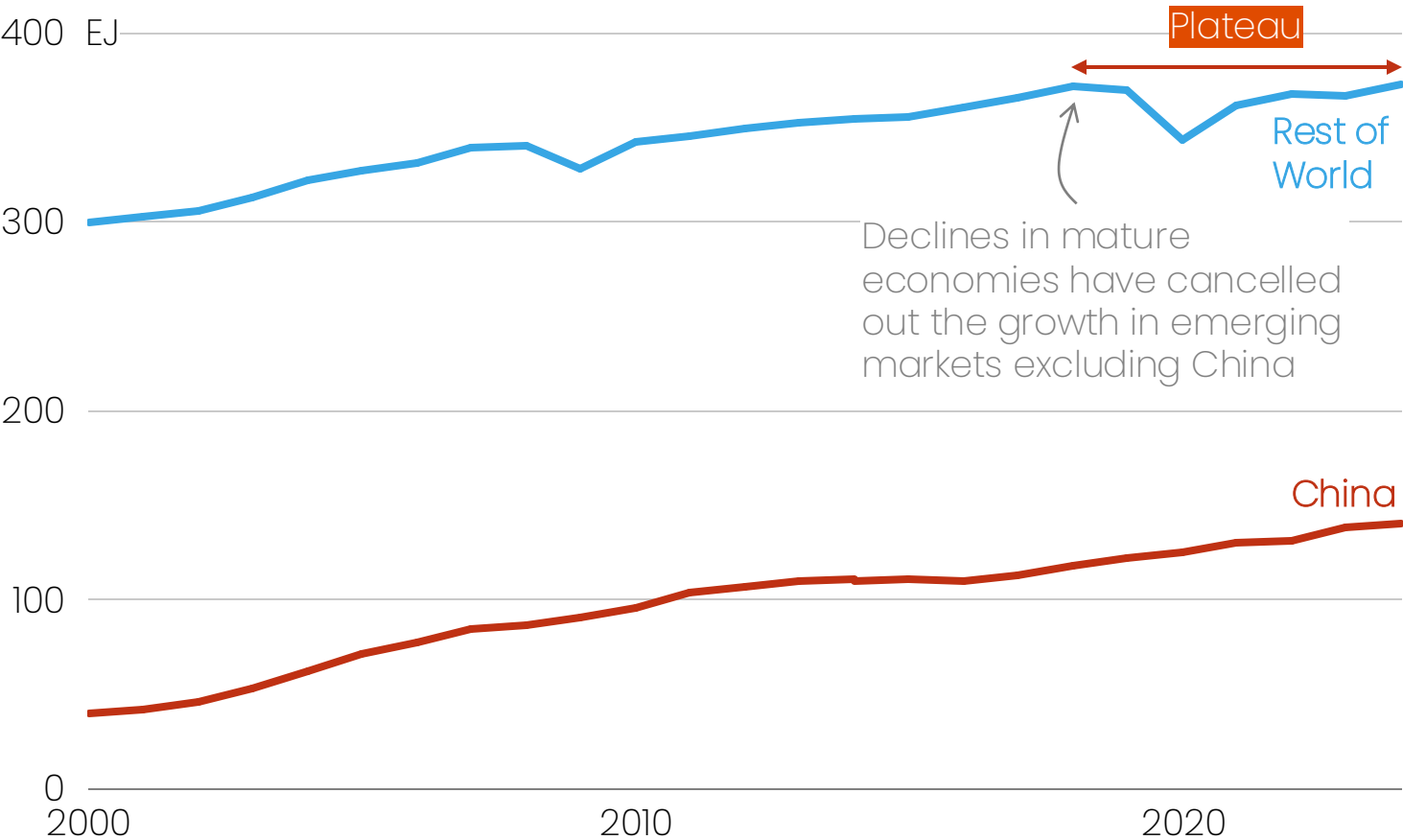




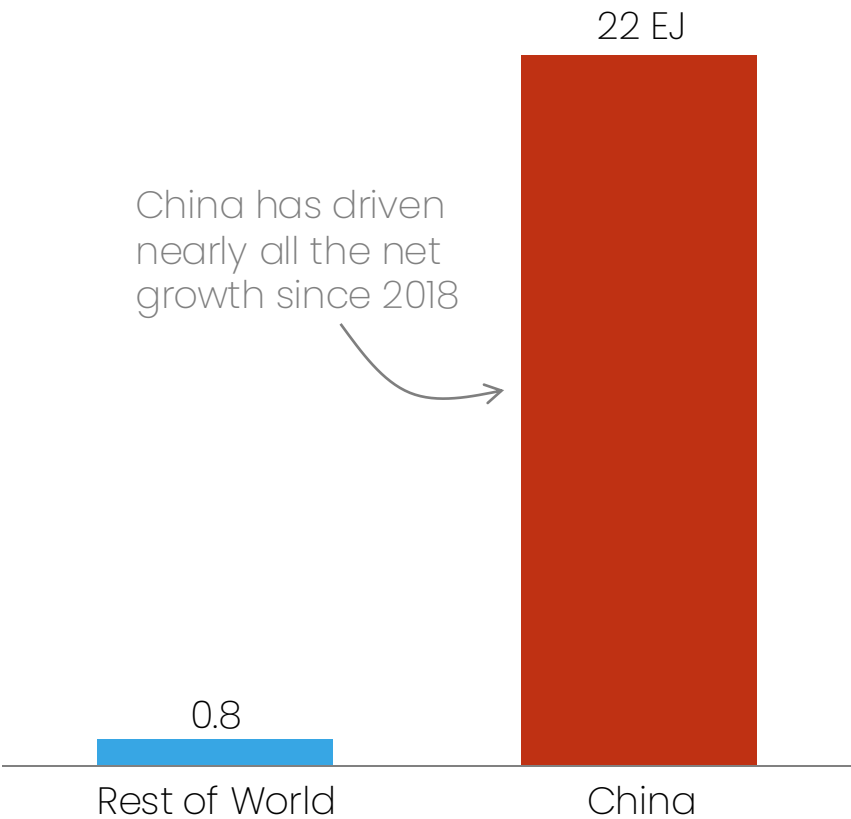
China is the pivot nation

Fossil fuel demand has already reached a plateau outside China

Primary fossil fuel demand



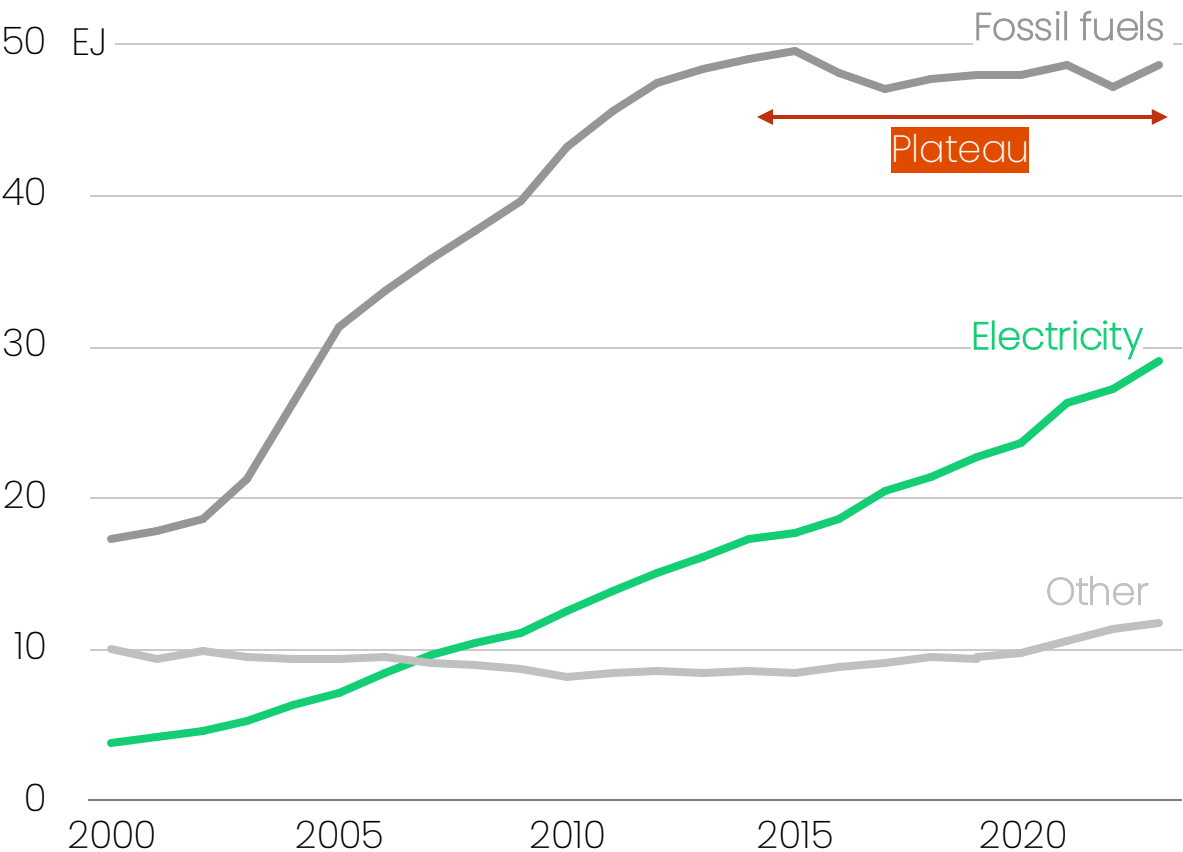
Change in fossil fuel demand 2018-2024



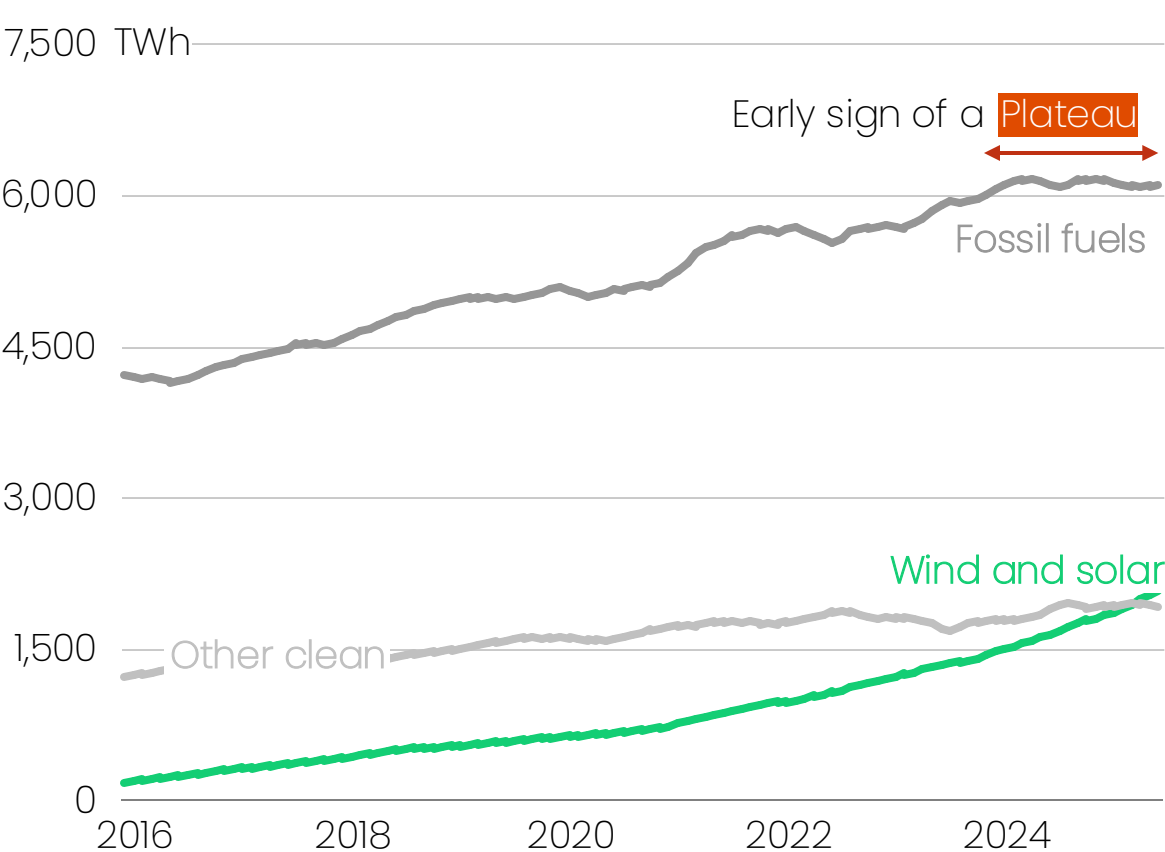
Fossil fuel demand is peaking in China

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

Final energy consumption



Electricity generation, 12-month rolling sum



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

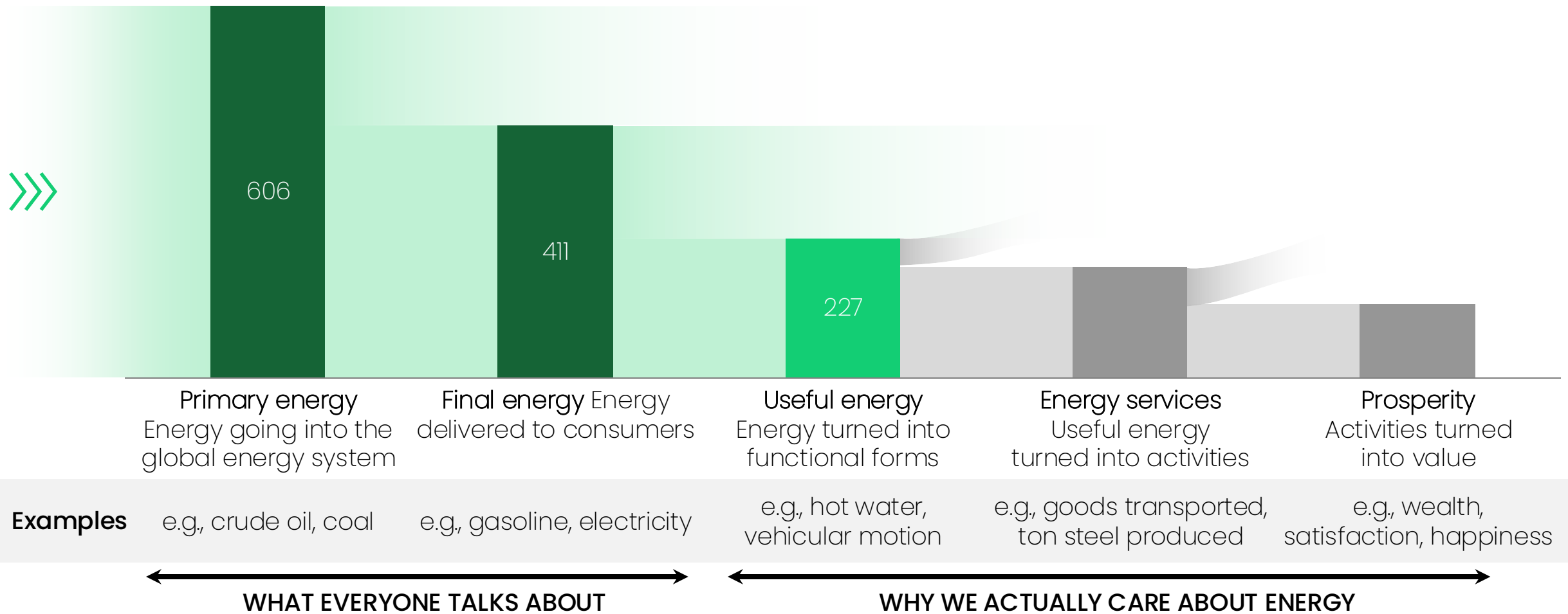
Electrotech beats the rest of cleantech

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

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Energy is all about efficiency

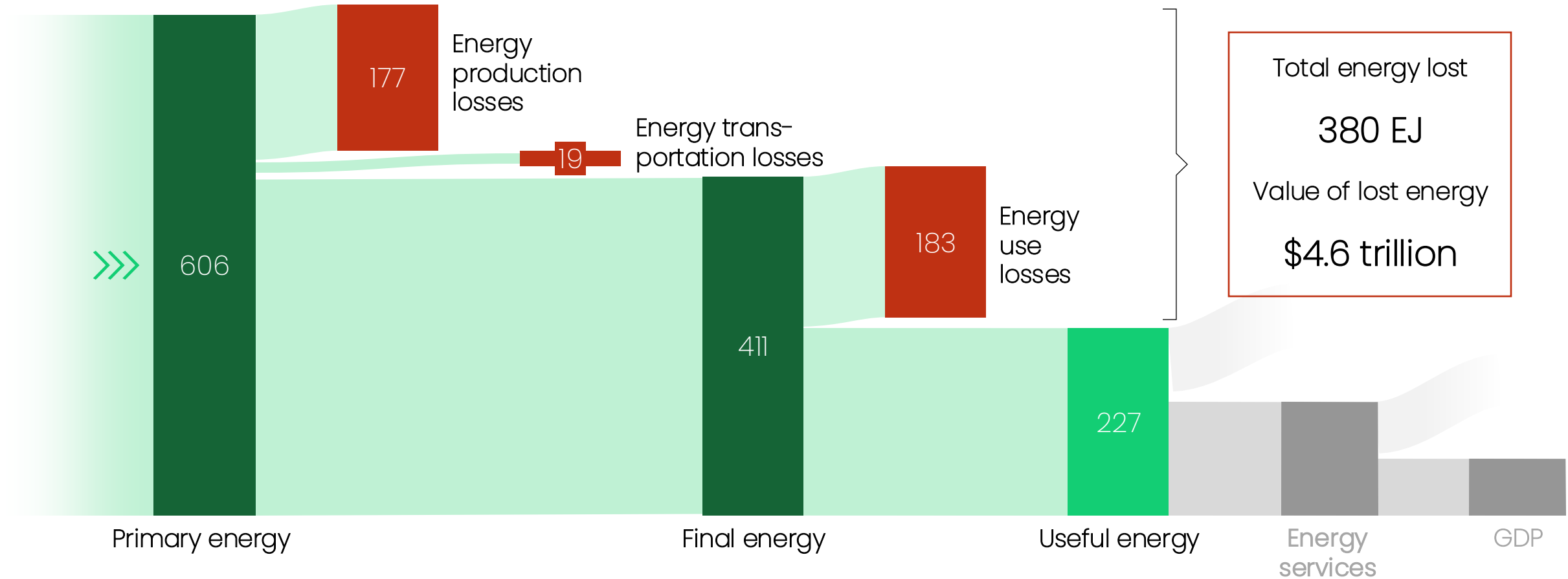
At its core, the energy system is about converting energy into useful forms as efficiently as possible



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



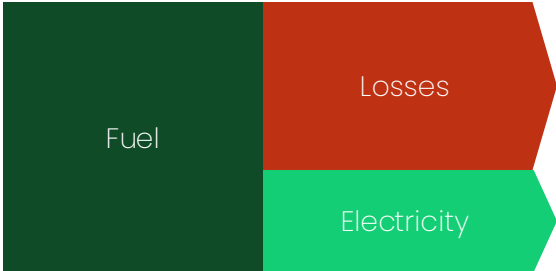
Electrotech is 3x more efficient

It offers a leap in energy efficiency across the economy

Supply

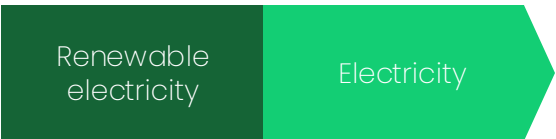
Electricity generation

Fossil thermal



30-40% efficiency

Wind & solar



100% efficiency

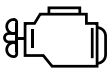
2-3x

as efficient

Demand

Transport

Internal combustion engine



25-40% efficiency

Electric vehicles



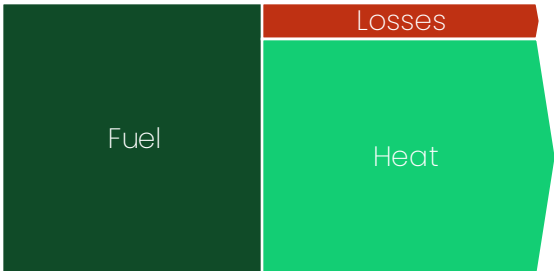
80-90% efficiency

2-4x

as efficient

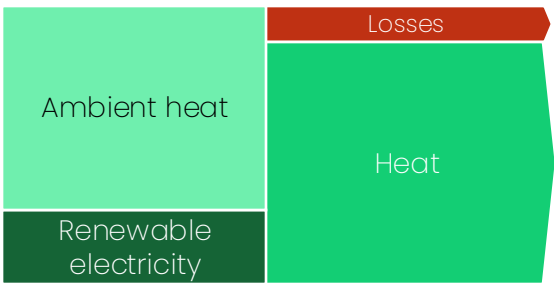
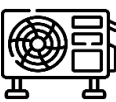
Heating

Gas boiler



85% efficiency

Heat pumps



300-400% efficiency

3-4x

as efficient

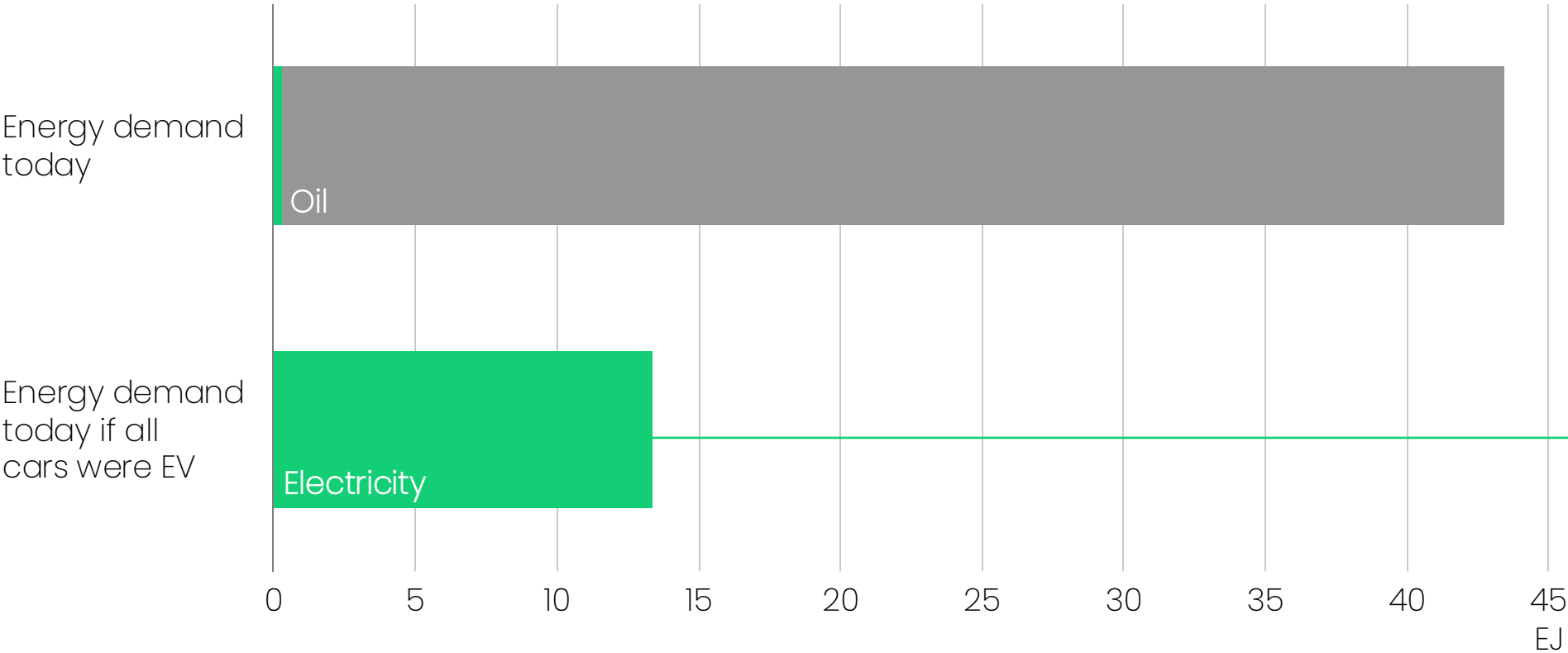


Electrotech enables us to get much more for much less

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**

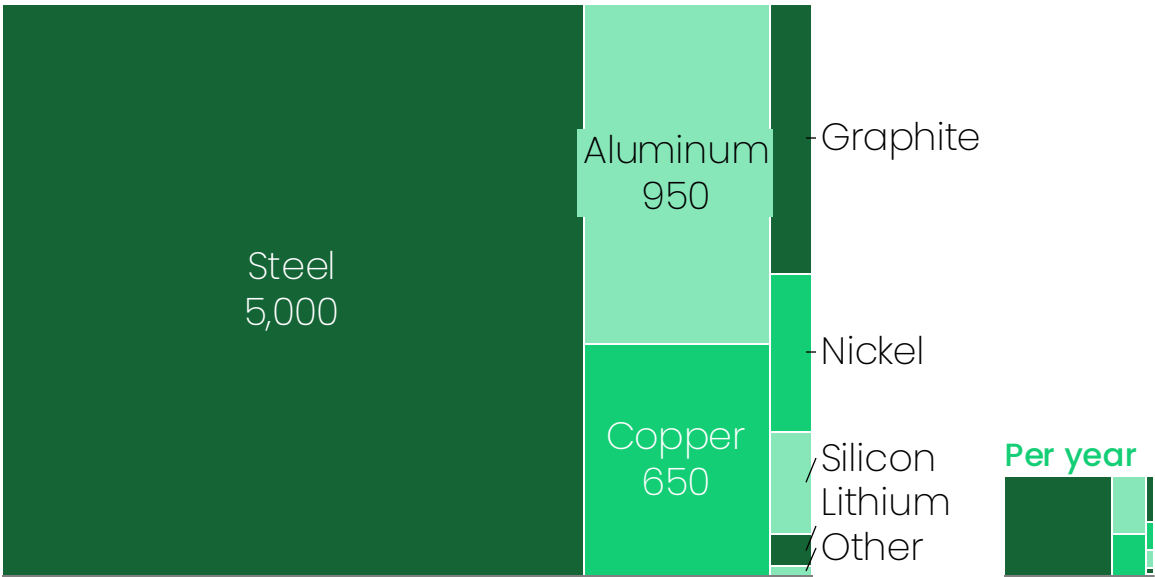


The unbearable heaviness of the fossil fuel system

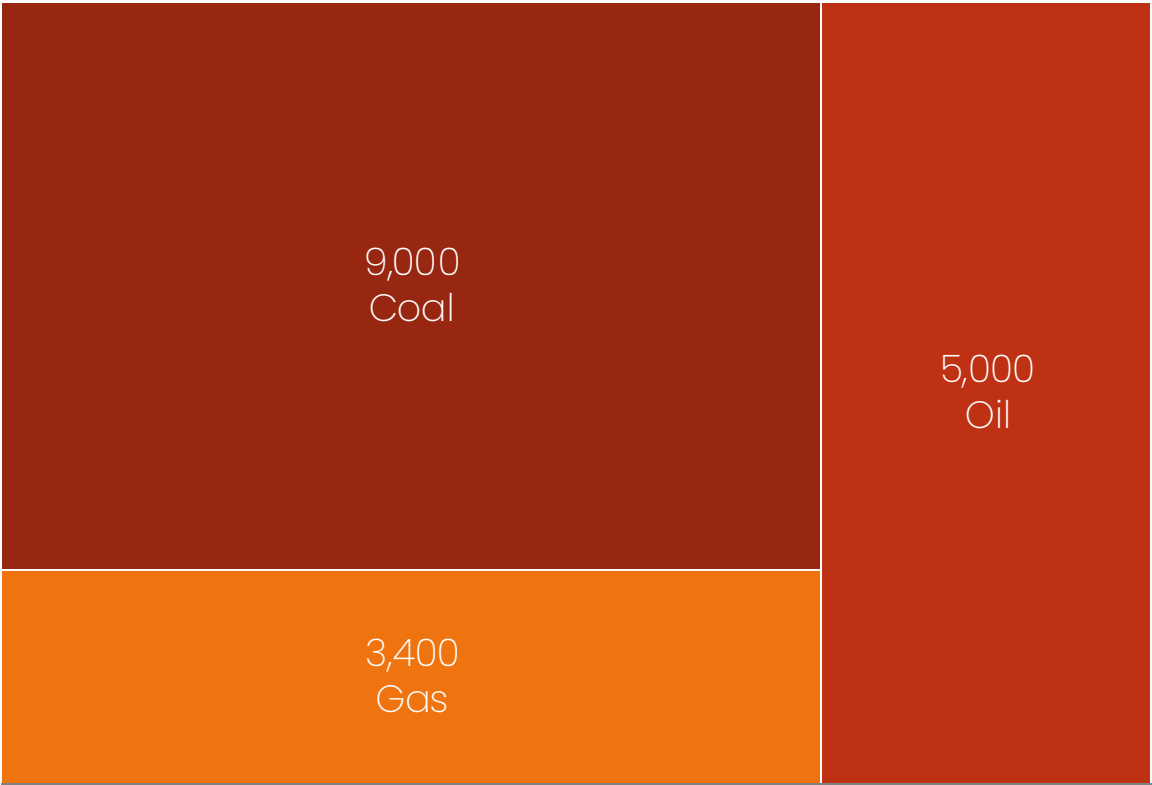
The fossil fuel system requires over 50x more materials than electrotech

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

Total over 25 years

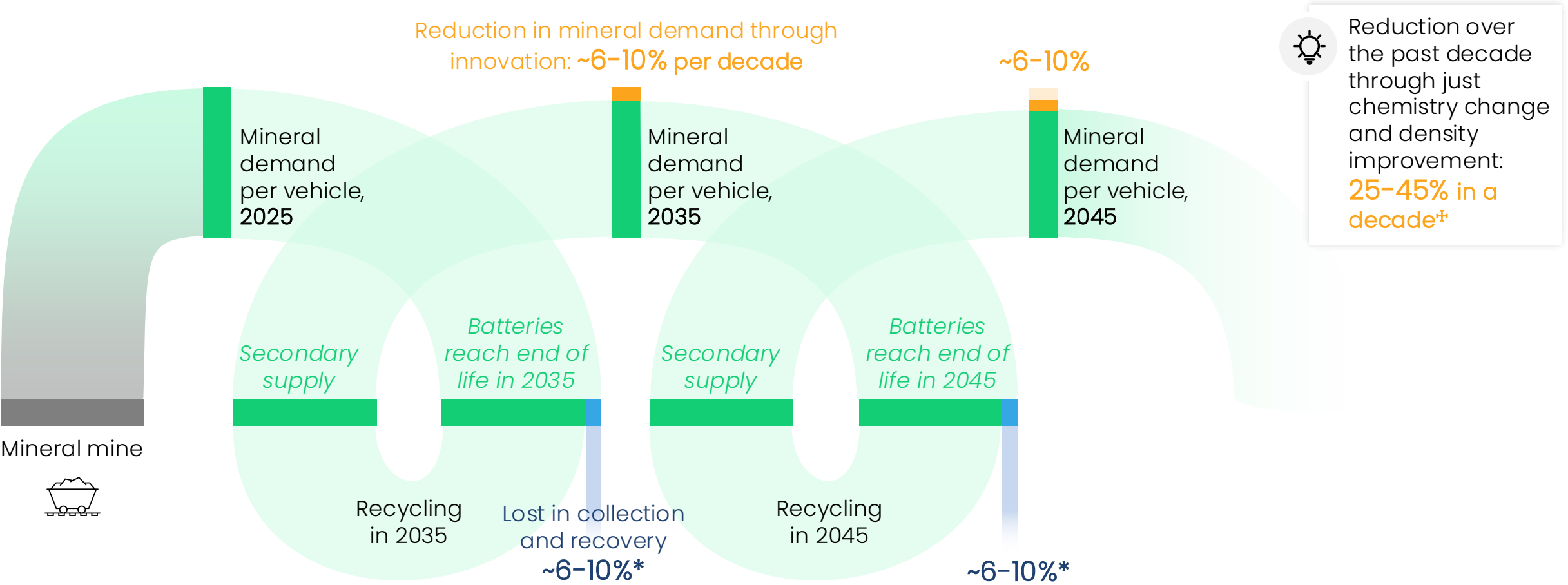


Fossil fuel extraction *per year today*, Million metric tons



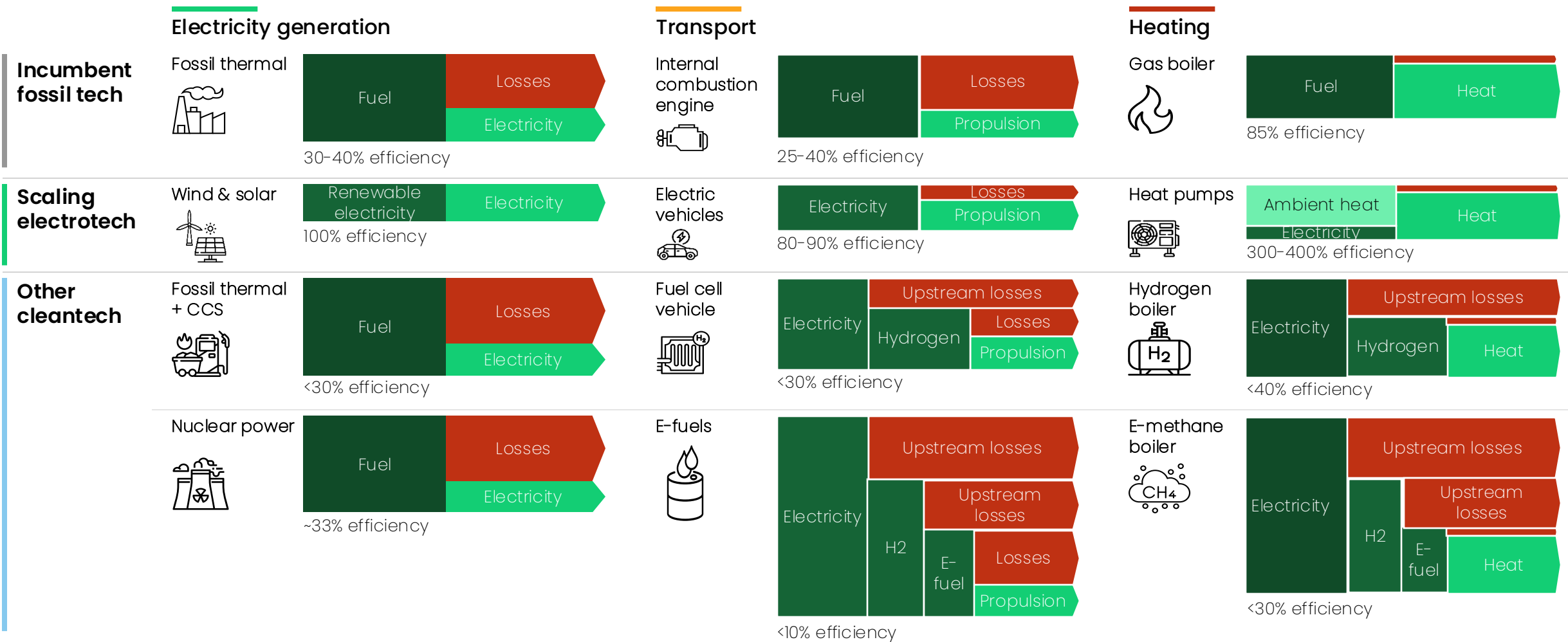
Borrowing, not burning

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



Efficiency differentiates electrotech from other cleantech

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



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

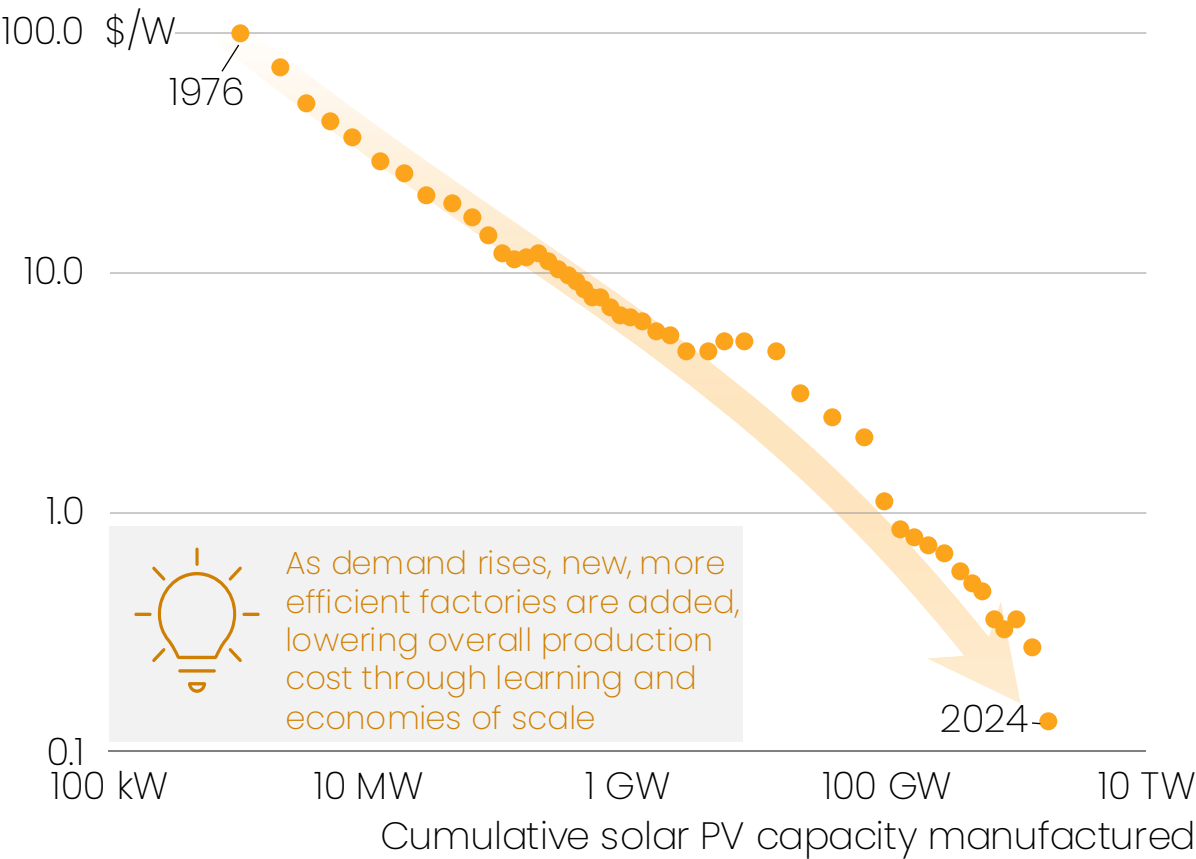
Electrotech drives GDP growth, powers the industries of the future and supplies all the expected growth in energy jobs.

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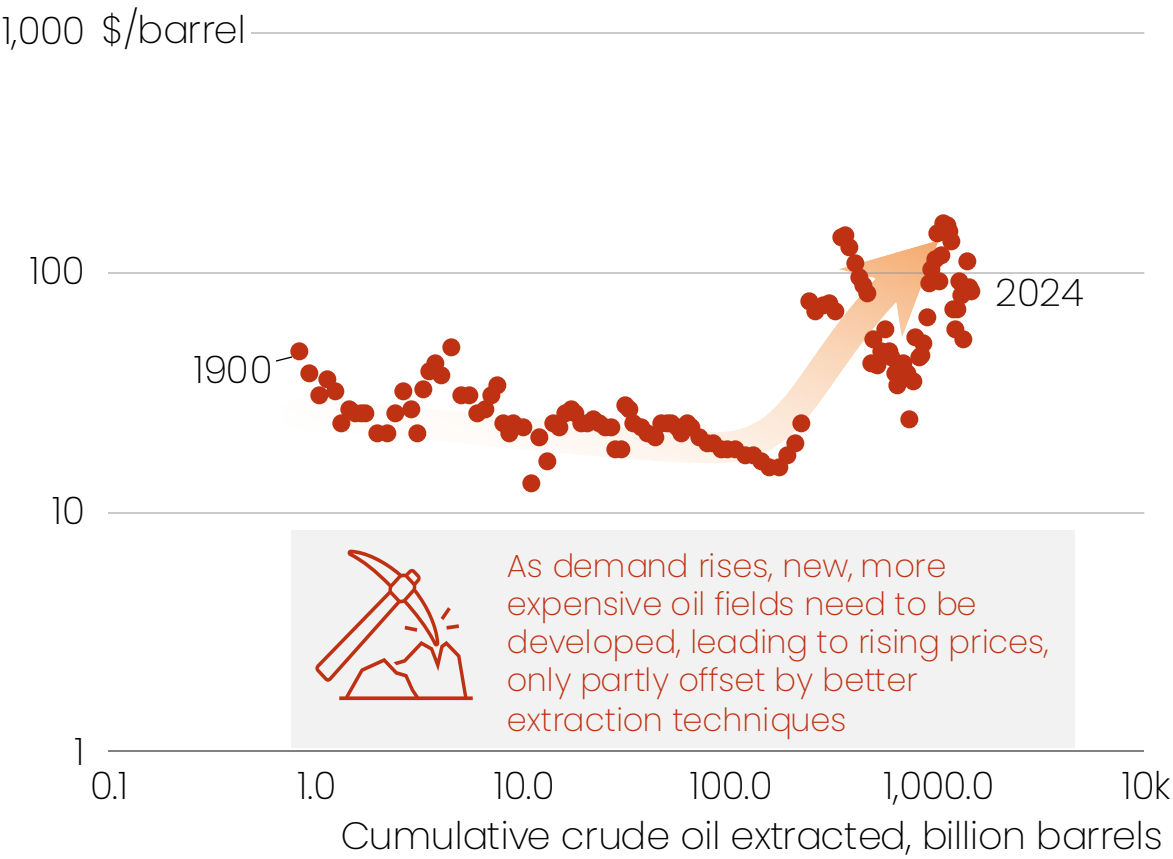
Learning beats digging

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

Solar panel price cost versus amount manufactured



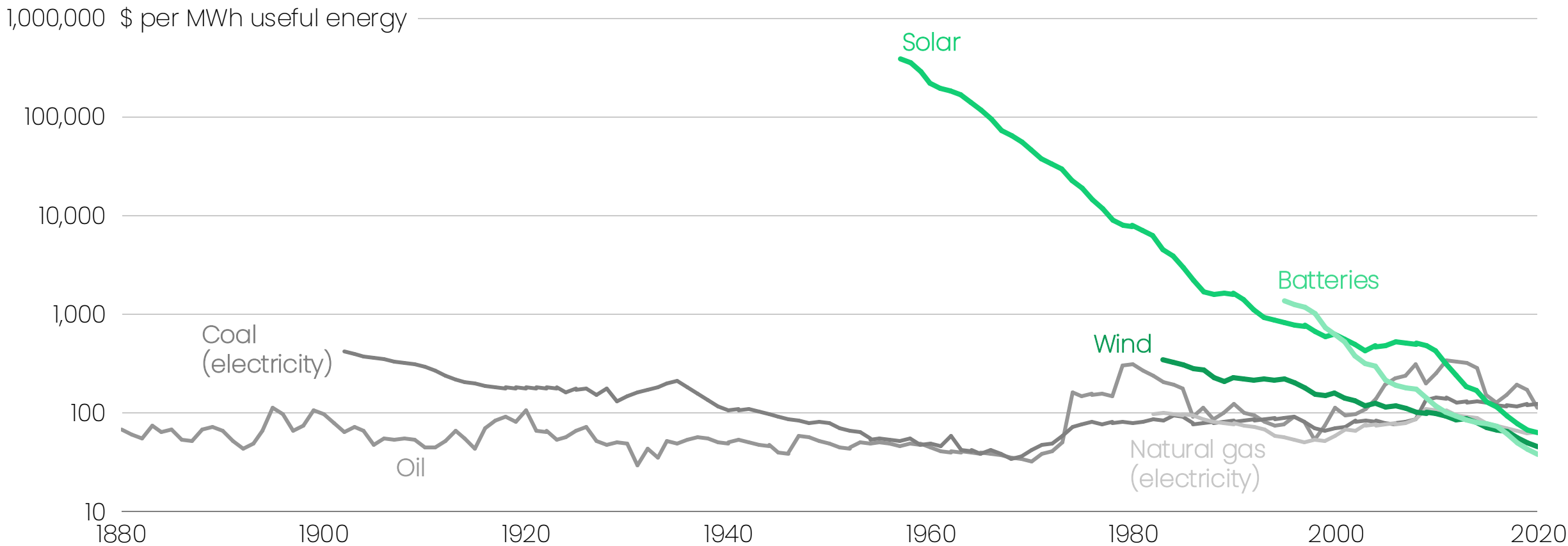
Oil price versus amount extracted



Technologies beat commodities on cost

Electrotech is the triumph of brain over brawn

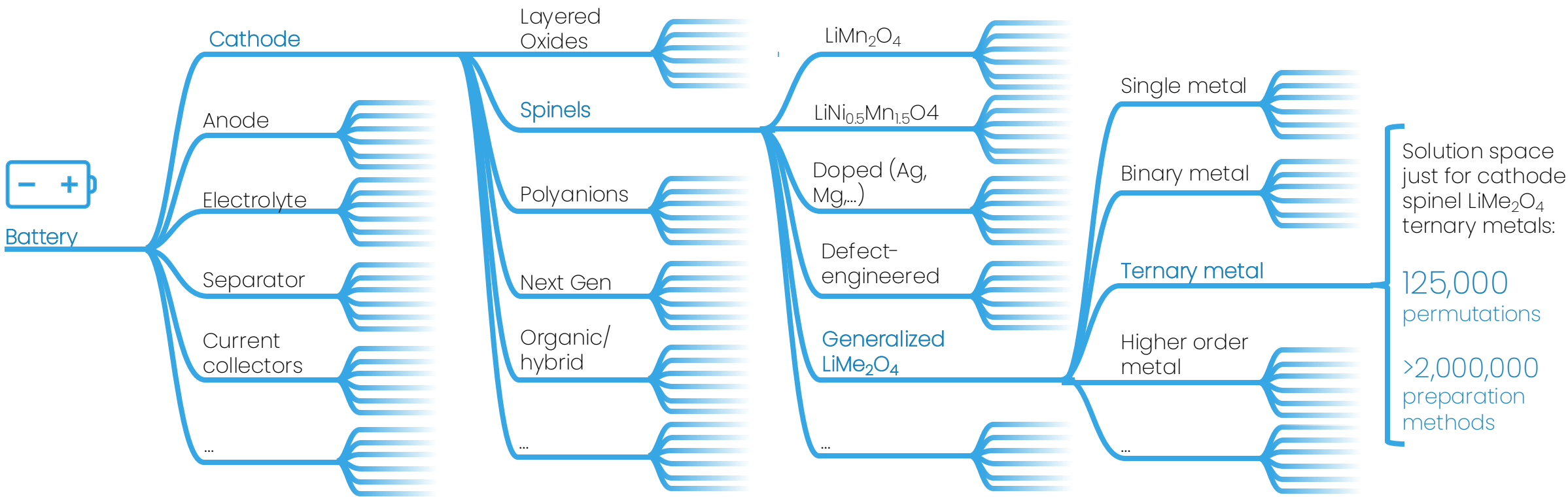
Historical costs of energy sources



There is a huge solution space to explore

The electrochemical solution space underlying electrotech is enormous

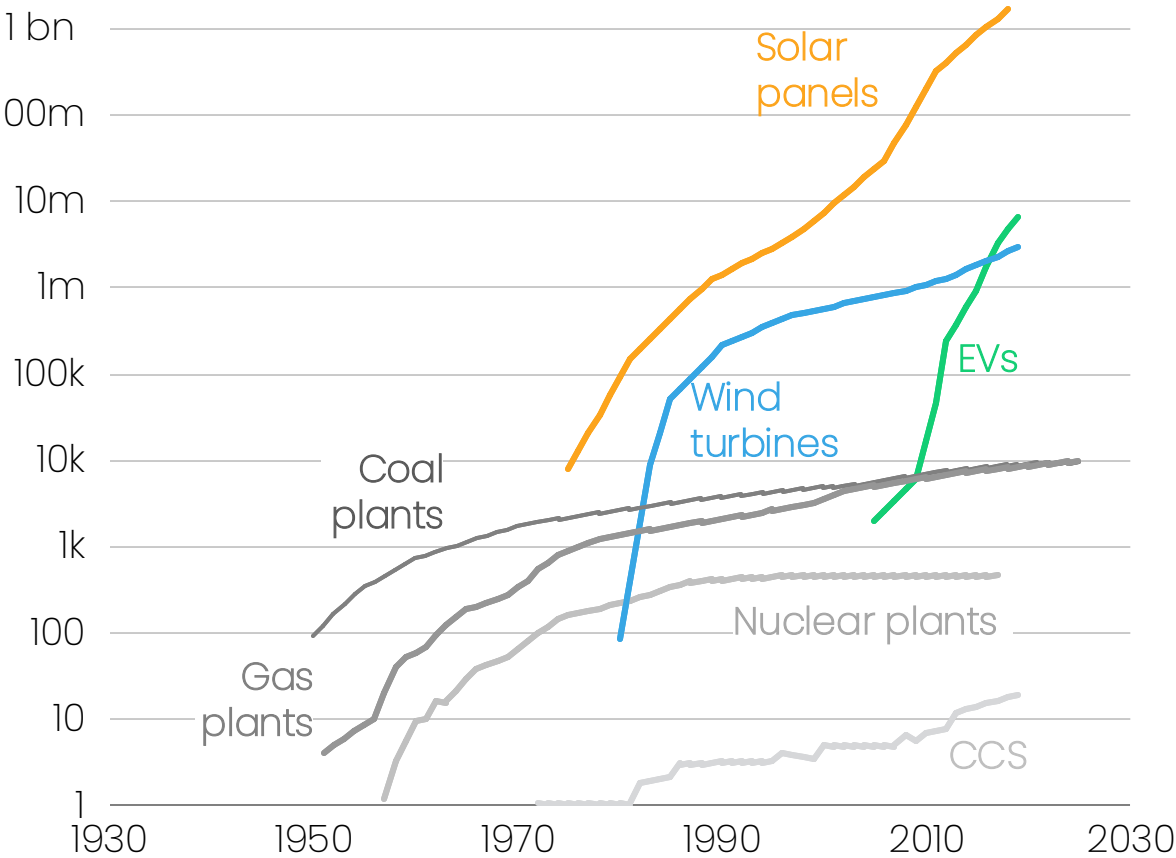
Example: battery cell solution space



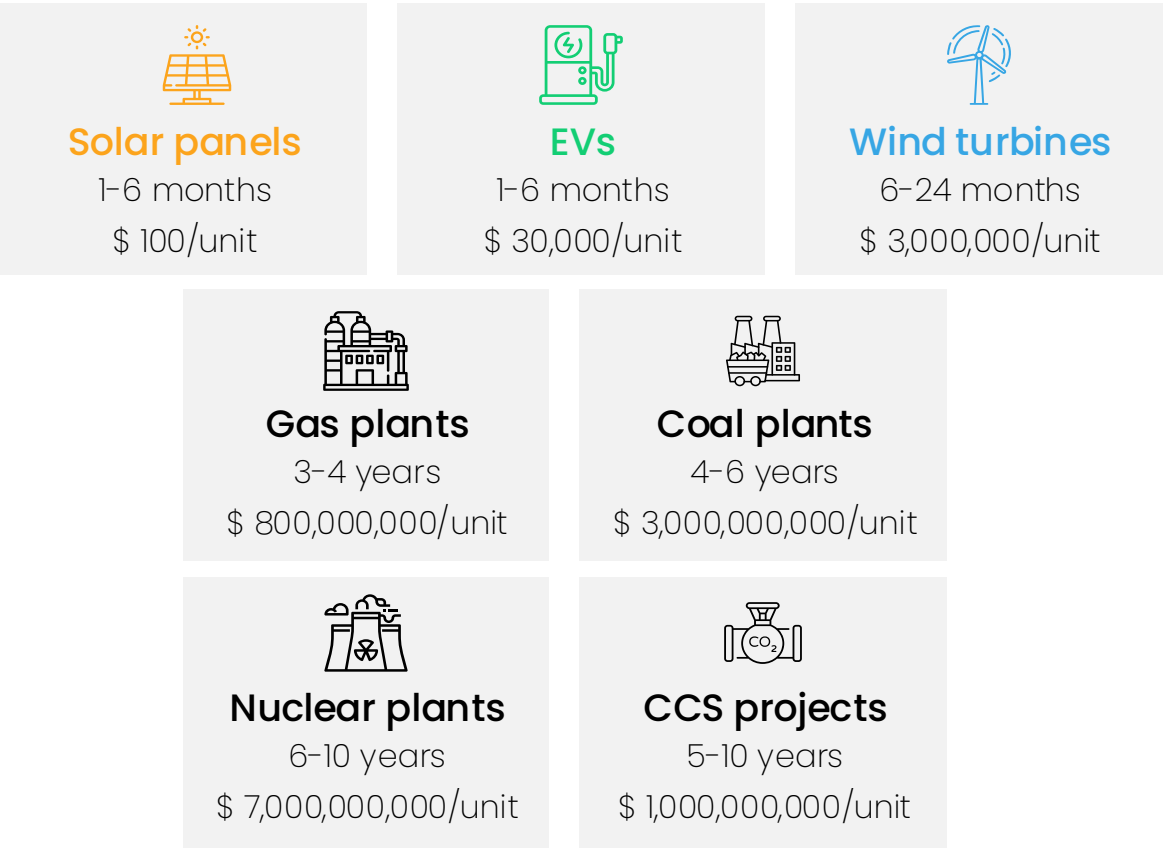
Learning by doing

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

Cumulative units produced



Typical deployment effort

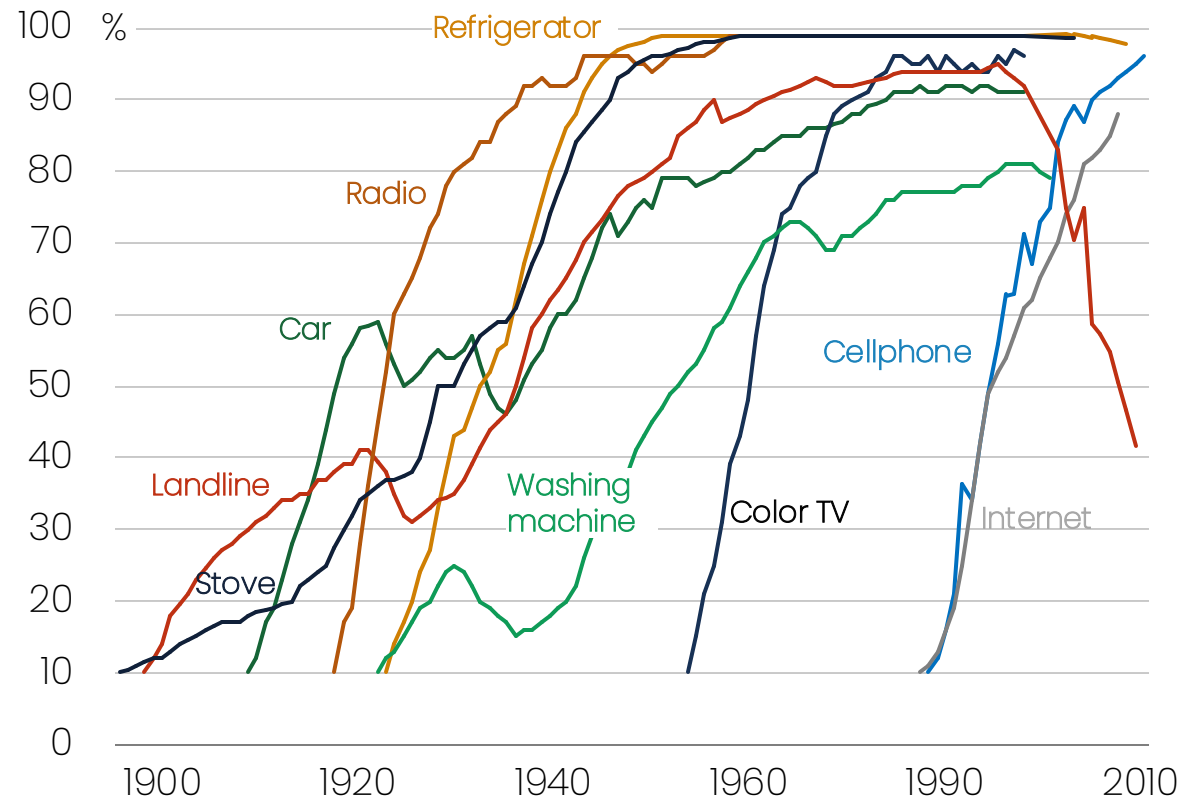


S-curve as usual, not business as usual

Successful technologies grow along S-curves

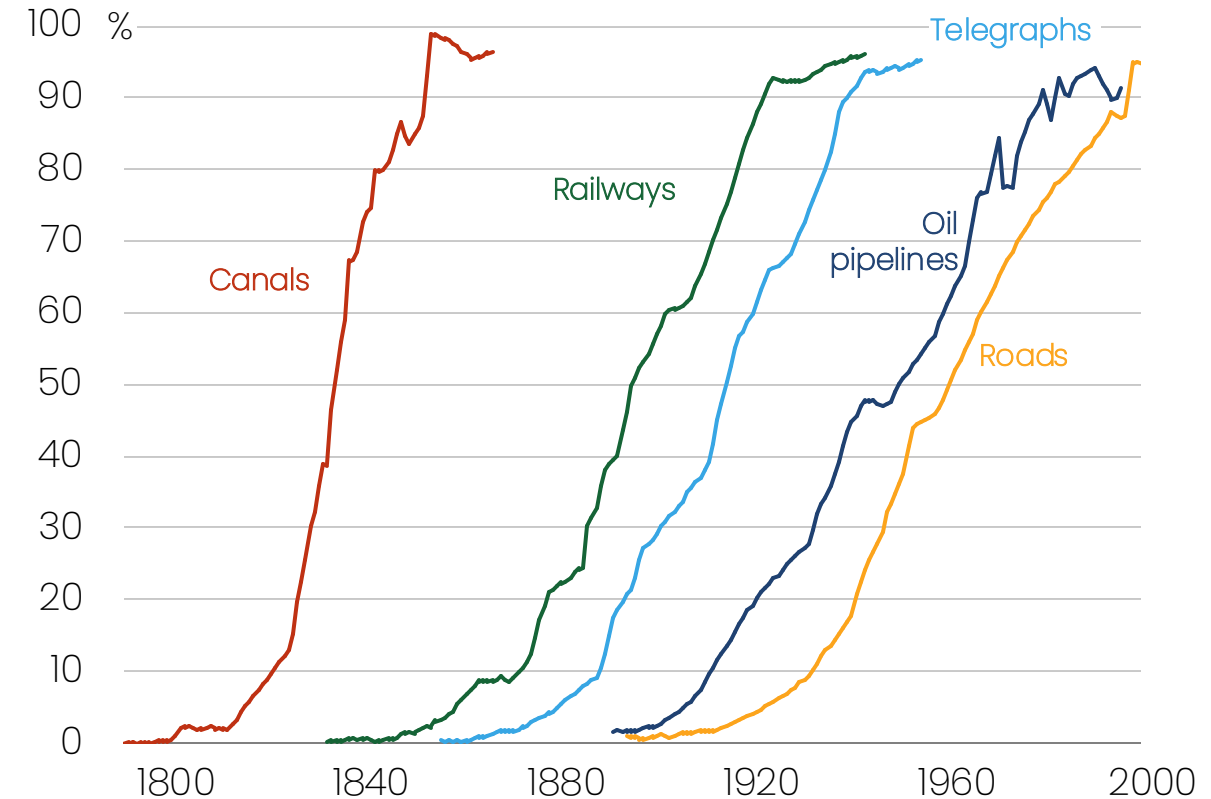
Individual products

Technological adoption by household in the United States



Infrastructure systems

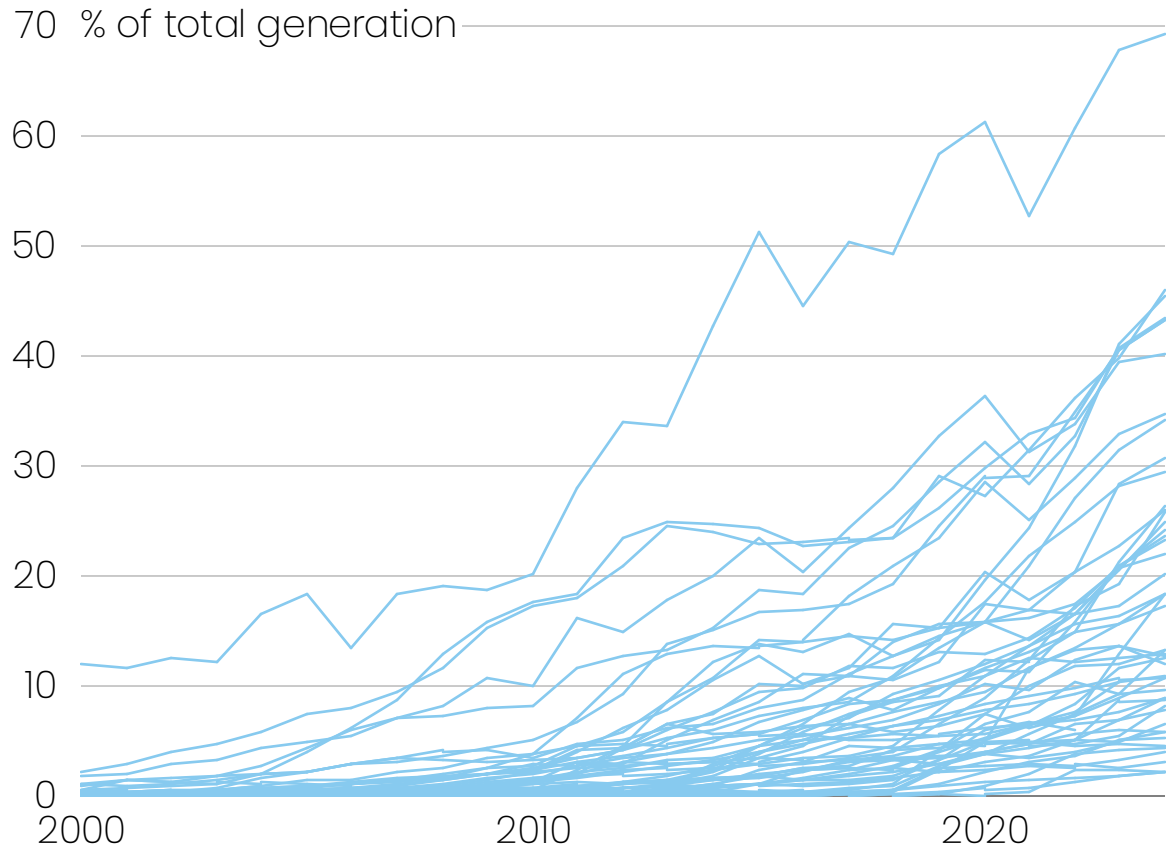
Share of maximum size in the United States



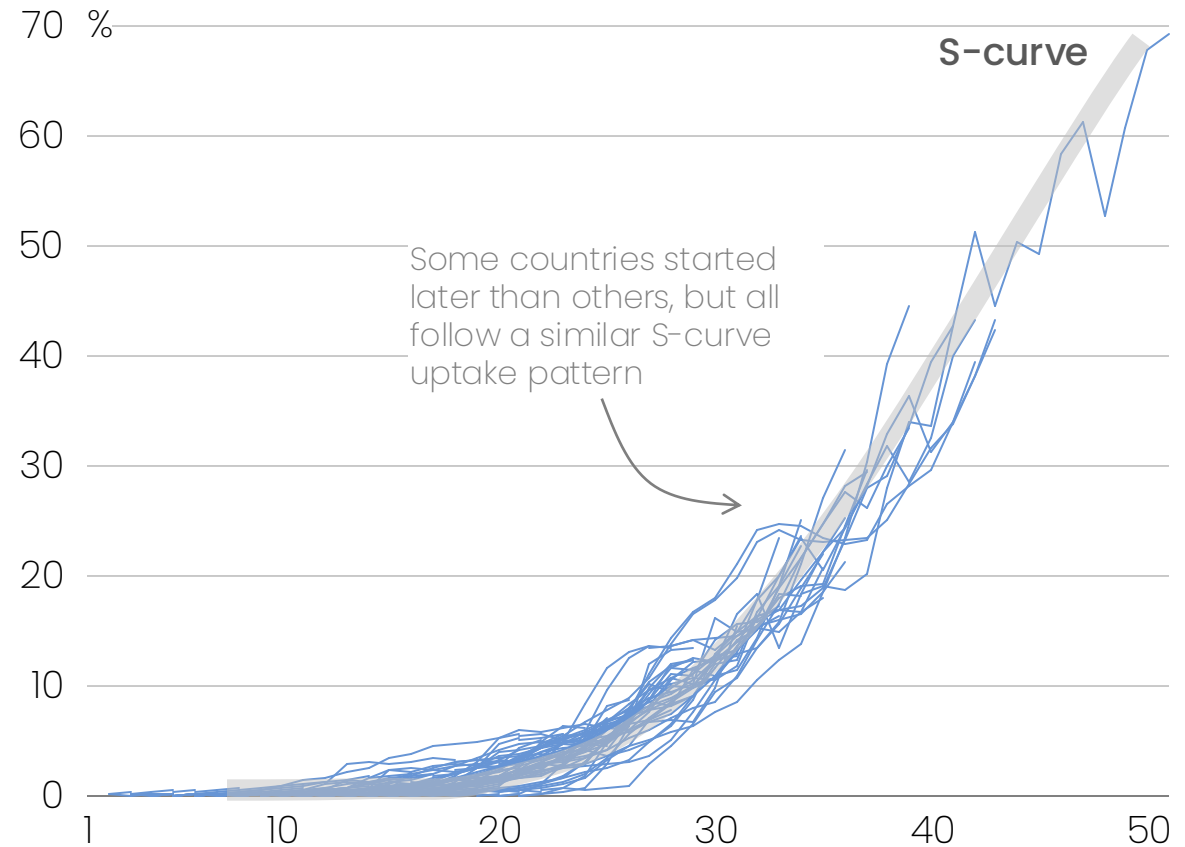
S-curves are the signal in the noise

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

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



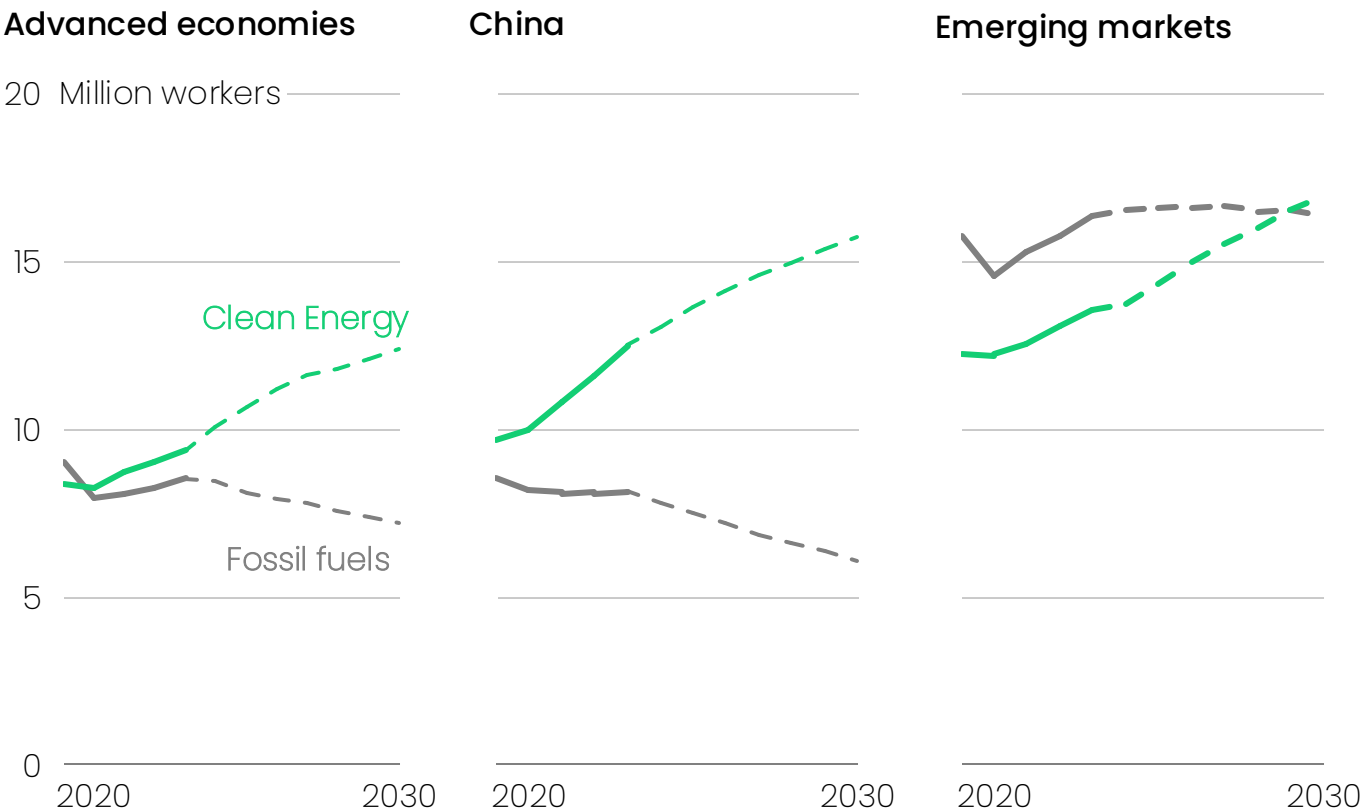
»»» Solar and wind uptake by country – **time-shifted**



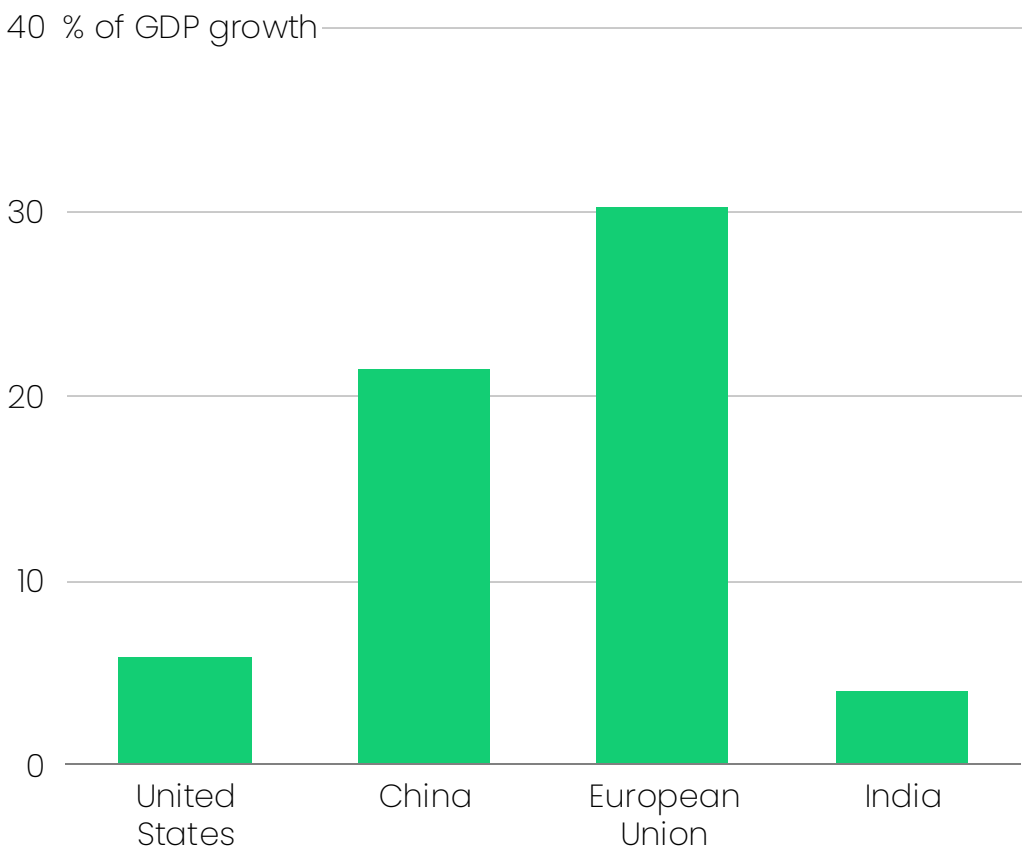
To the victor go the spoils

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



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 of 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

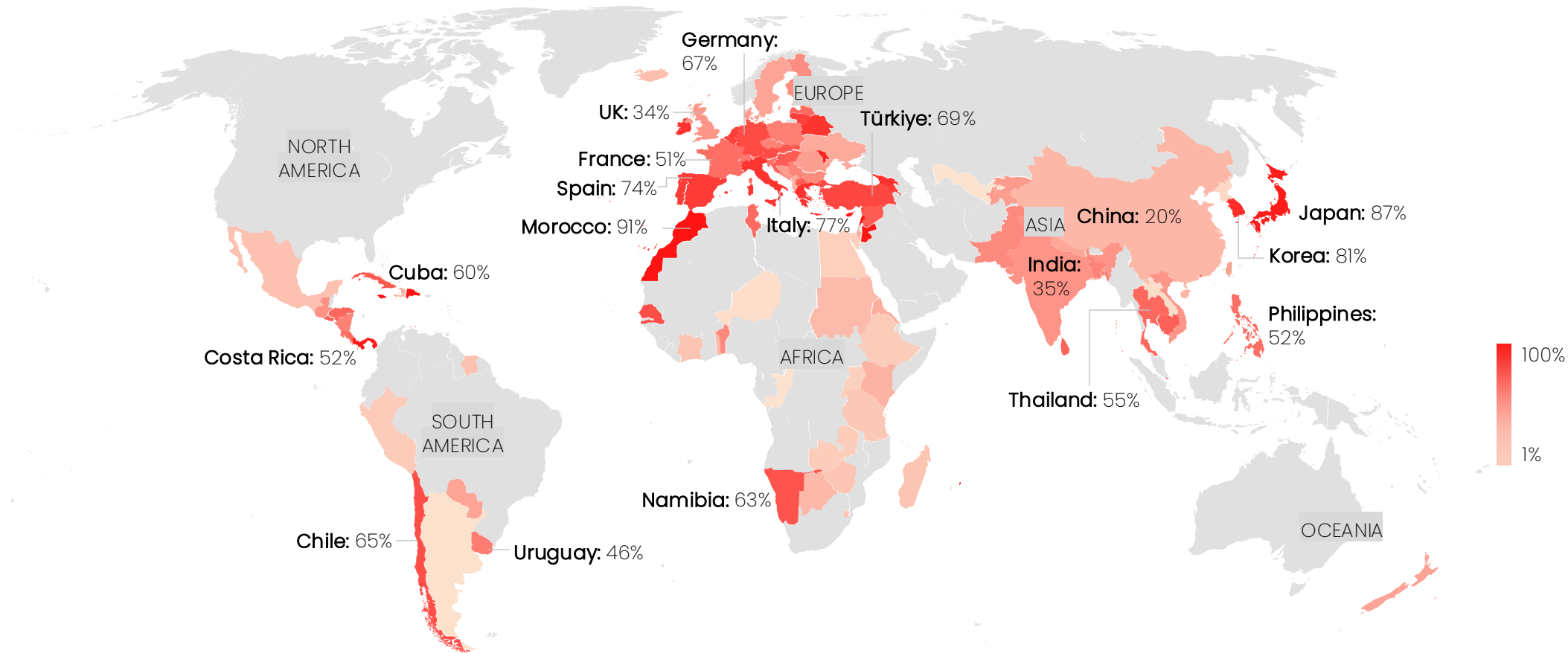
China is leading the electrotech revolution and deploying its technology at scale and speed into the emerging markets. Other countries seeking independence and influence will need to compete in this race to the top for the superior technologies of the future.

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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, %

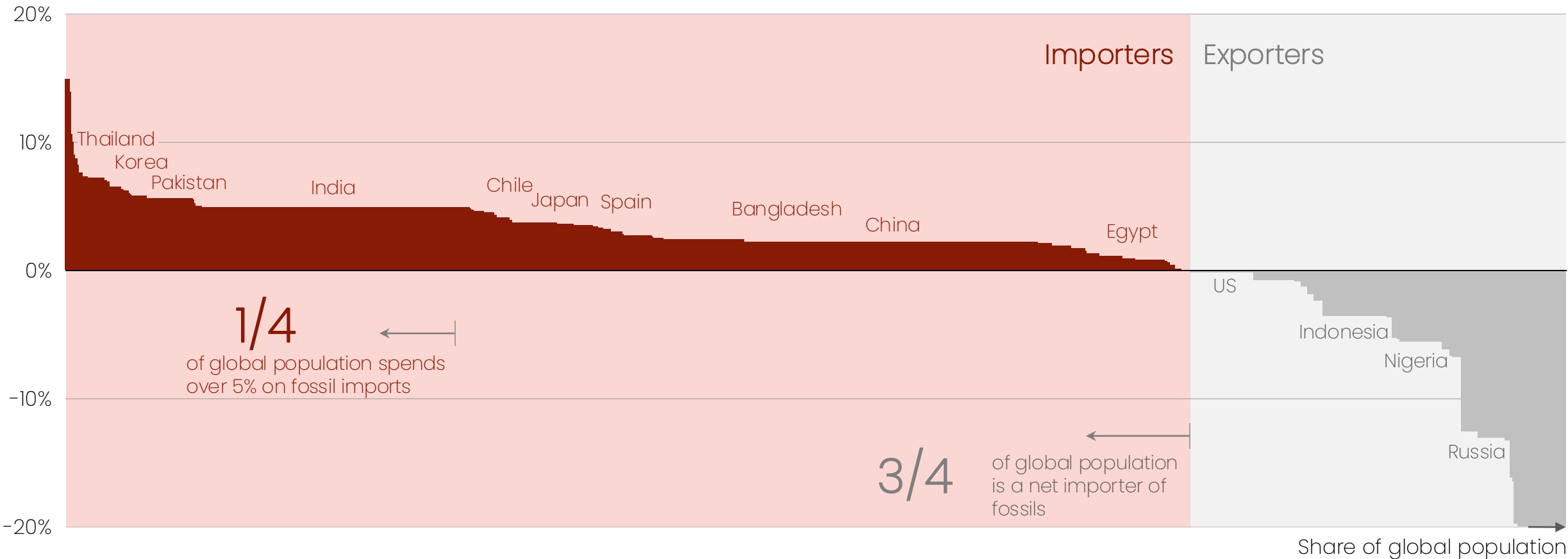




Fossil fuel imports are very expensive

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



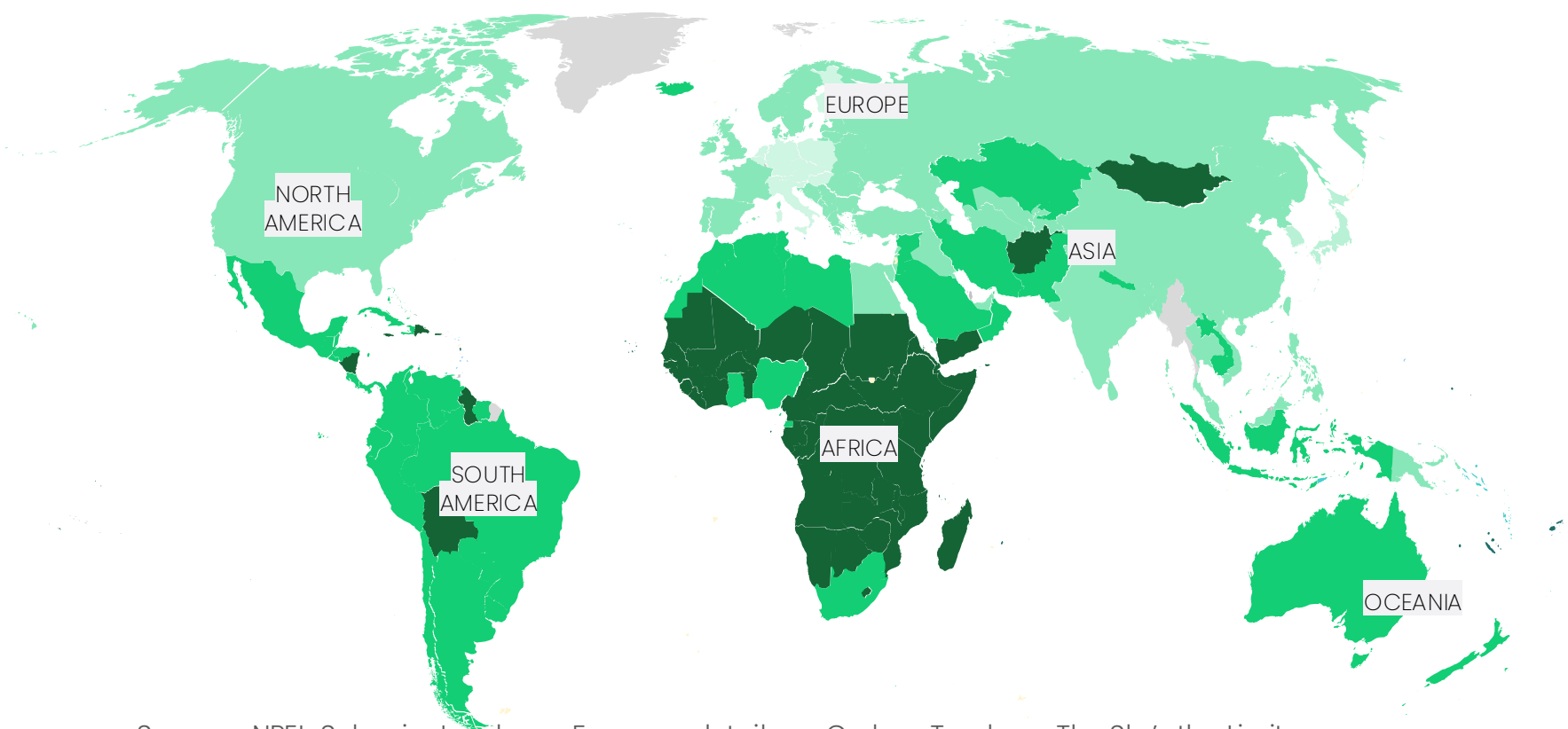
Note: GDP balance based on energy trade balances in EJ from 2022, multiplied by typical commodity prices from IEA.
Sources: IEA WEB, Ember analysis. • Note 1: the y-axis is capped at -20% for readability.

Renewables are available to all

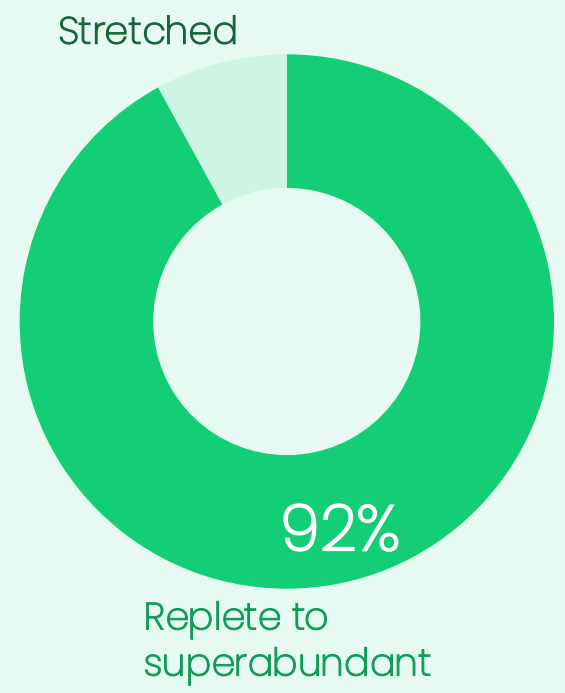
They are 100x bigger than fossil fuels and every country has enough to be self-sufficient

Renewable potential as a multiple of energy demand in 2022

■ Superabundant: >1,000x ■ Abundant: >100x ■ Replete: >10x ■ Stretched: <10x ■ No data



Share of population endowed with replete or better renewable resource

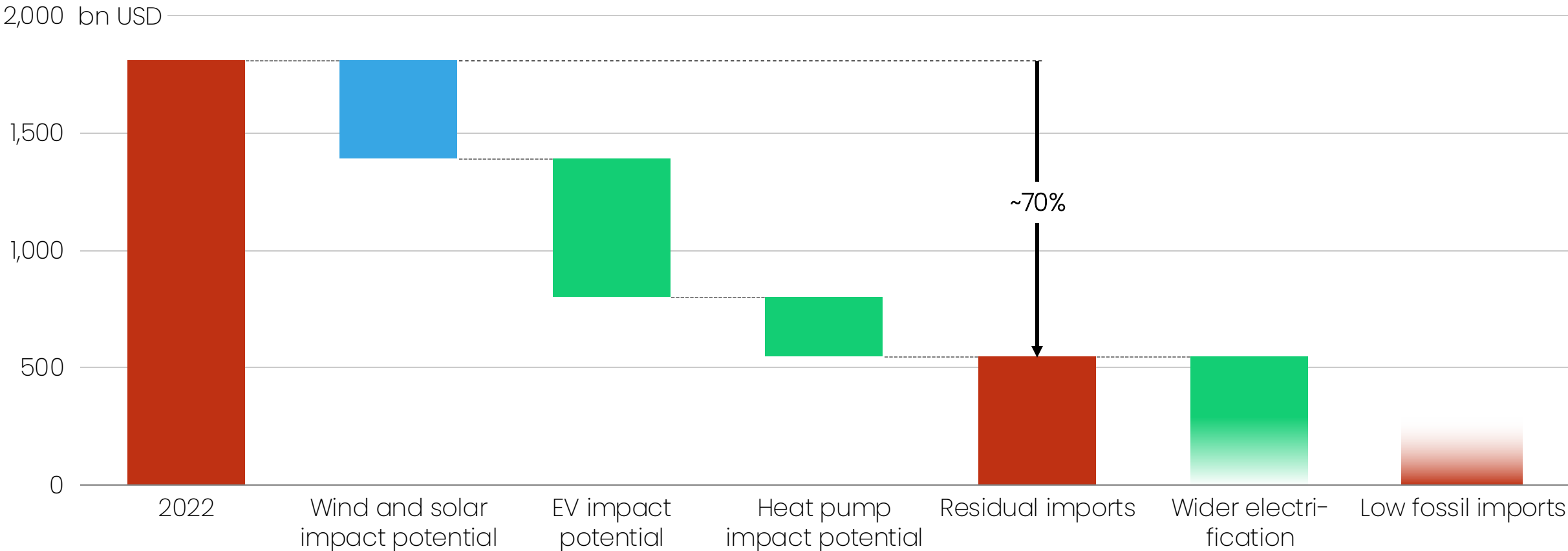




Renewables, EVs and heat pumps set you free

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

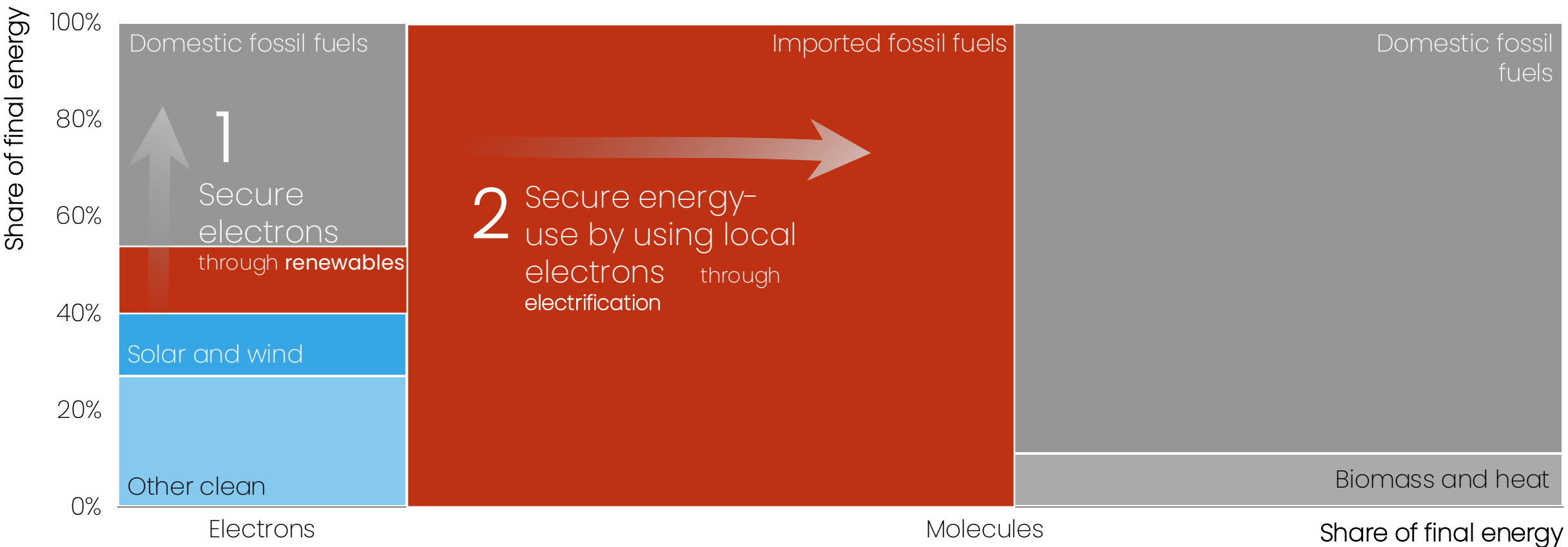
Global net spending on fossil fuels by importers



Electrotech brings energy security

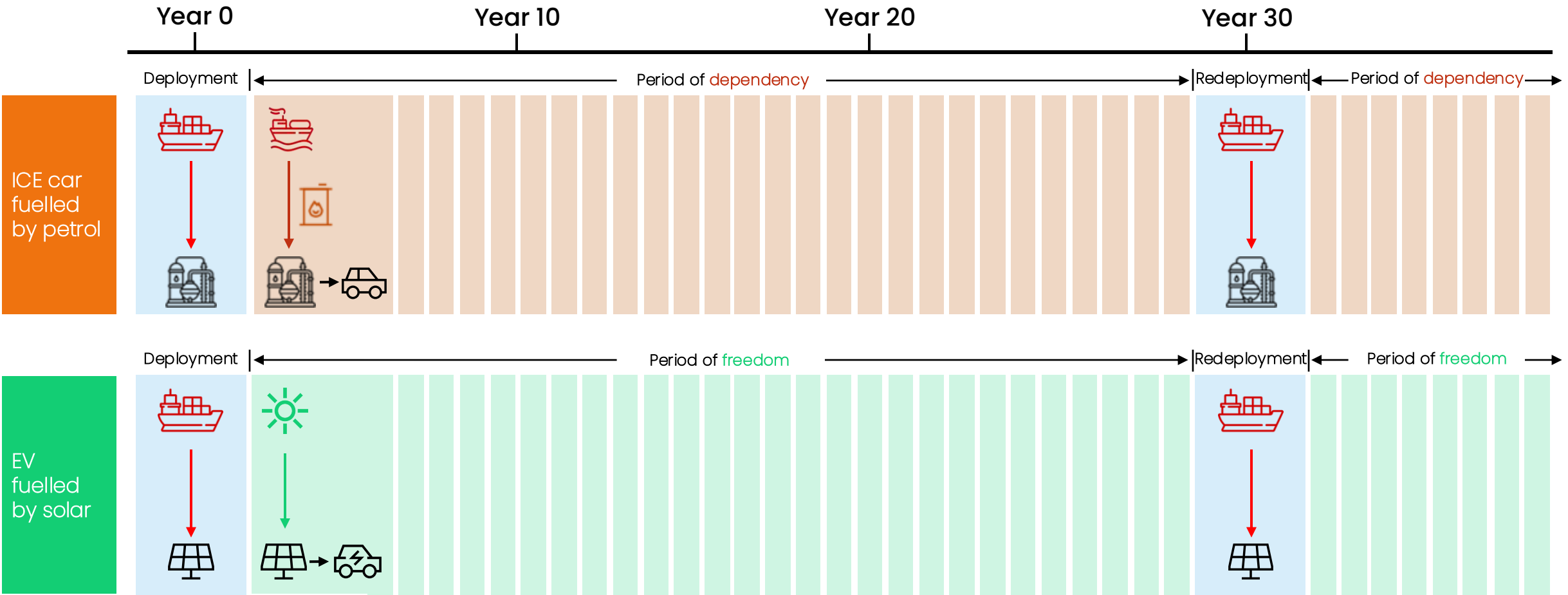
More domestic renewables and electrification can drastically curb energy dependence

Global energy demand in 2023



You can't turn off the sun

A solar panel provides 30 years of energy freedom

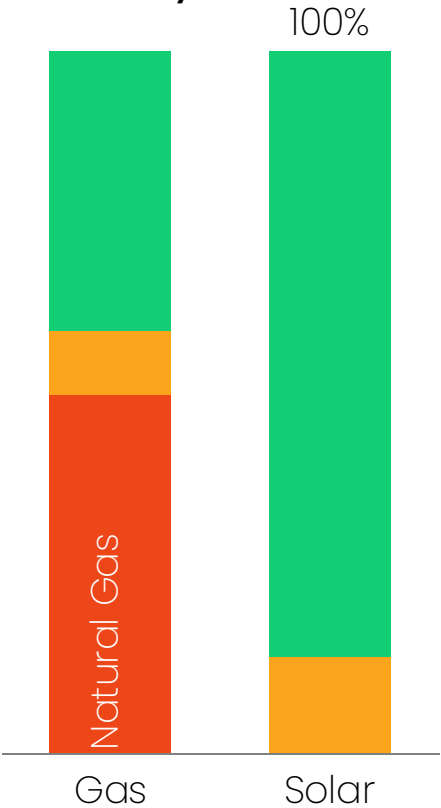


Electrotech saves you from fossil volatility

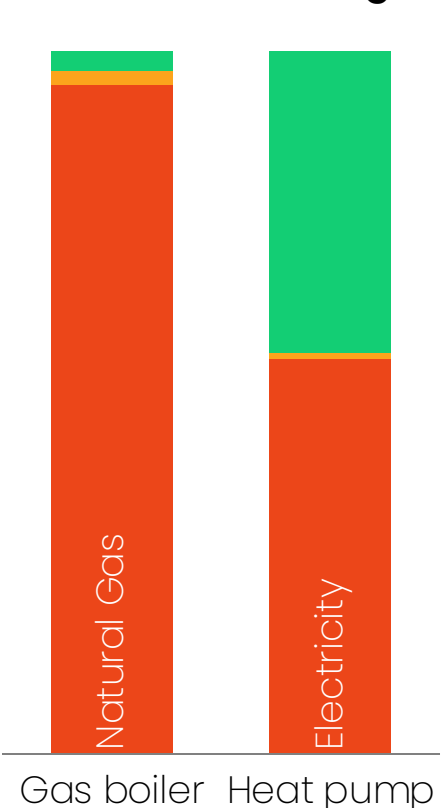
Once installed, electrotech costs remain stable — even if global supply chains falter or fuel costs rise

Total cost of ownership breakdown, %, US examples

Electricity



Residential heating



Passenger cars



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.

Electrotech offers a path to permanent energy security

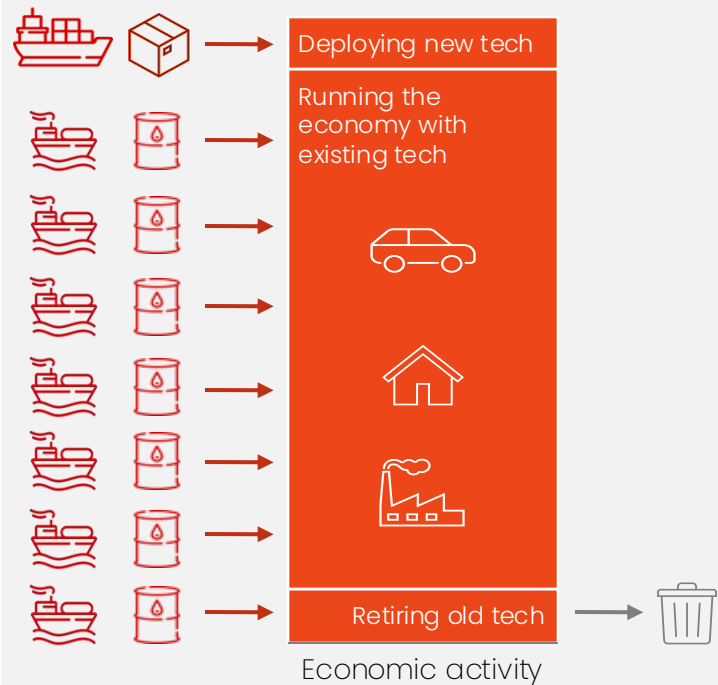
When fossil flows stop, the economy stops. When electrotech flows stop, only growth is at risk

From fossil import dependency...

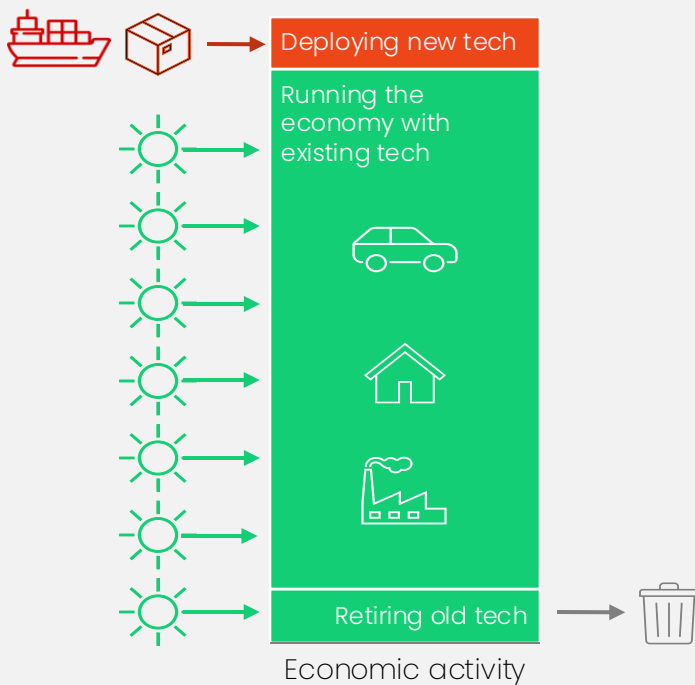
→ ...to electrotech import dependency...

→ ...to full circular energy independence.

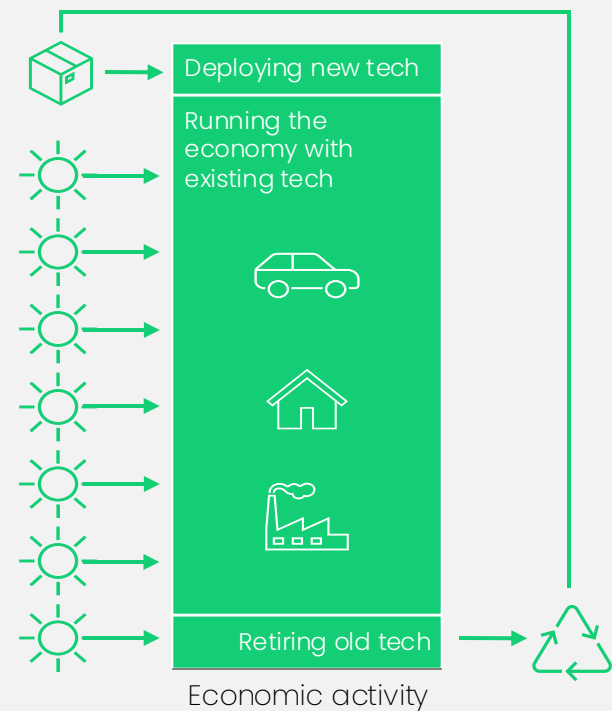
In an economy running on fossil imports, when imports stop, all activity stops



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

China is the first major electrostate

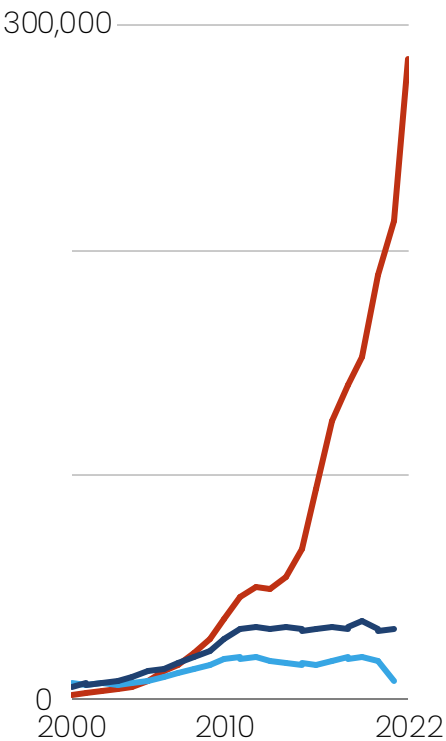
And that sparks a geopolitical race

China US Europe Other

Inventing

Patents

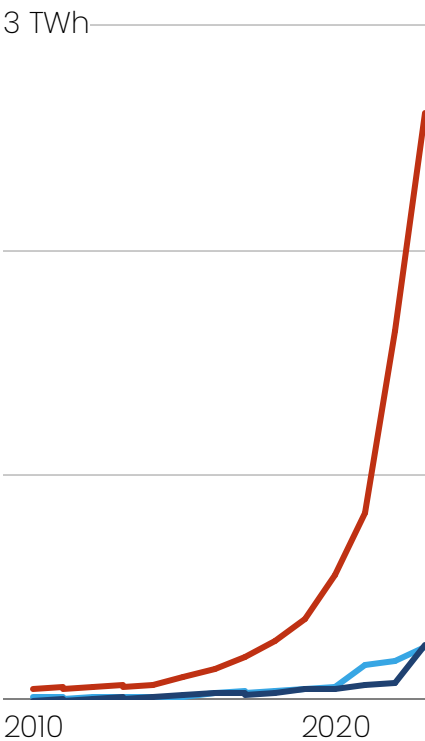
Annual cleantech patents



Producing

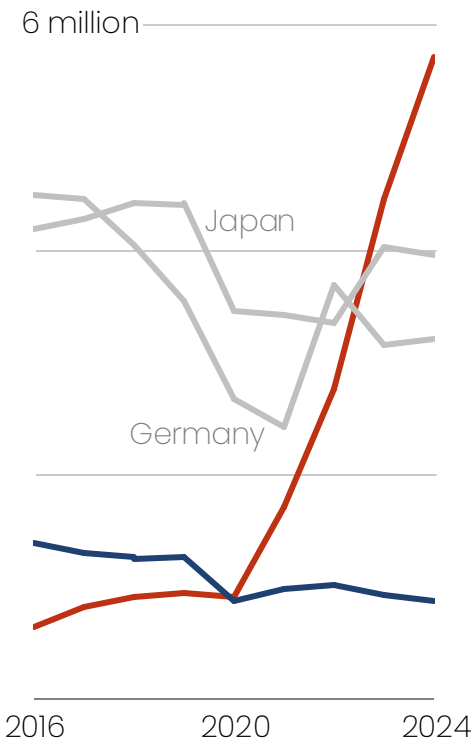
Manufacturing

Battery manufacturing



Exporting

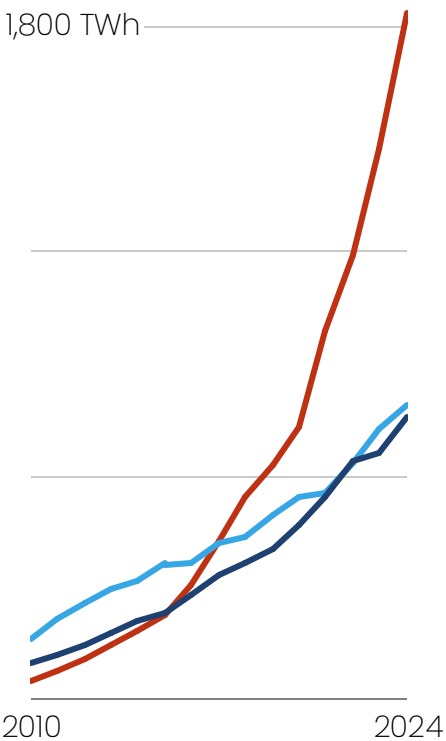
Cars



Deploying

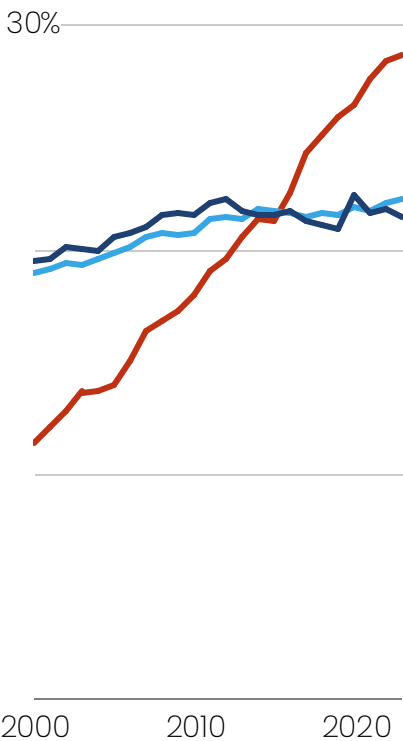
Renewables

Solar & wind generation



Electrification

% of final energy



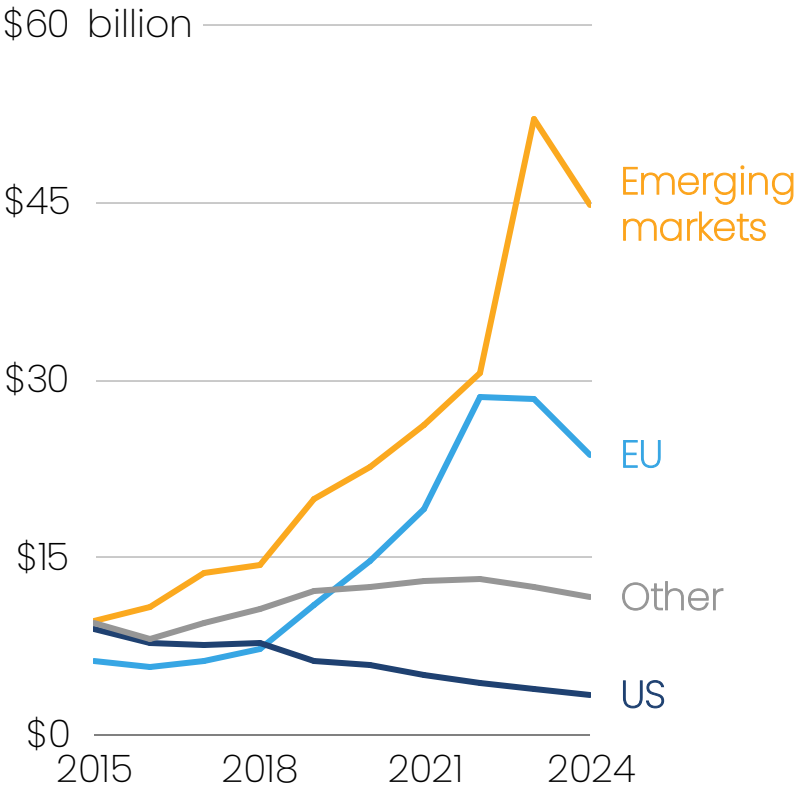


China is exporting the electrotech revolution to the world

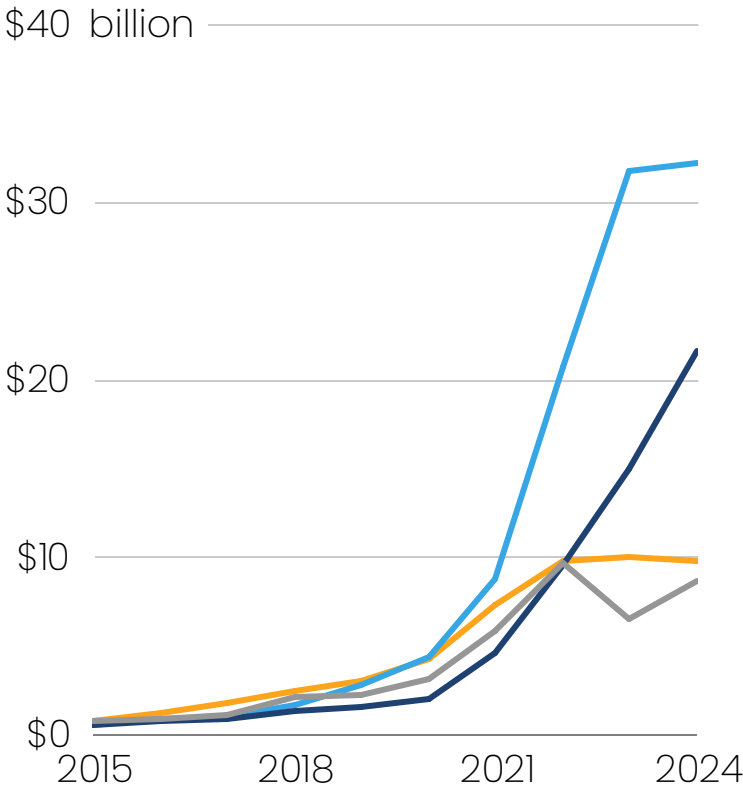
Gaining allies along the way — especially in the emerging markets

Chinese exports

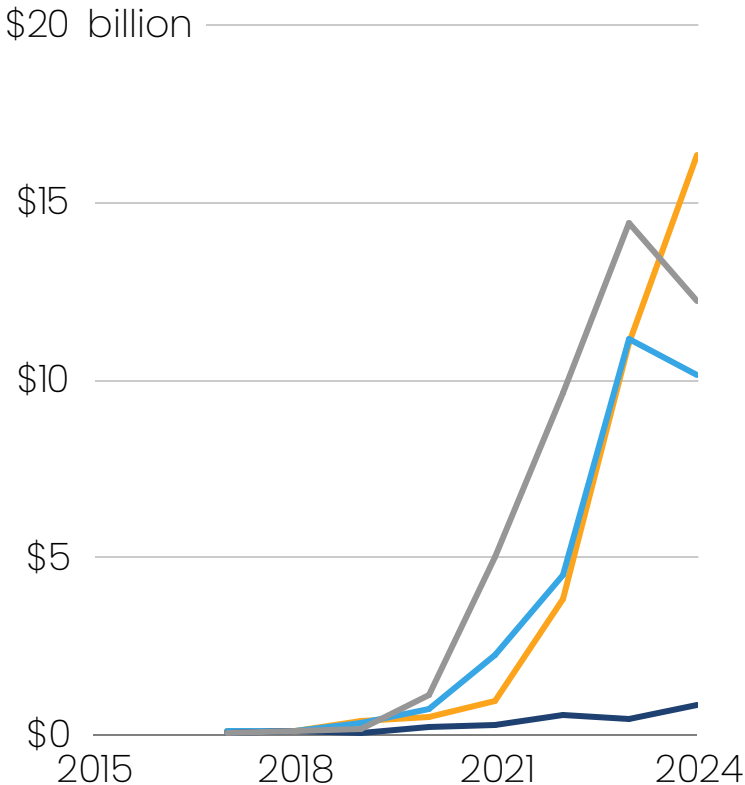
Solar PV



Batteries



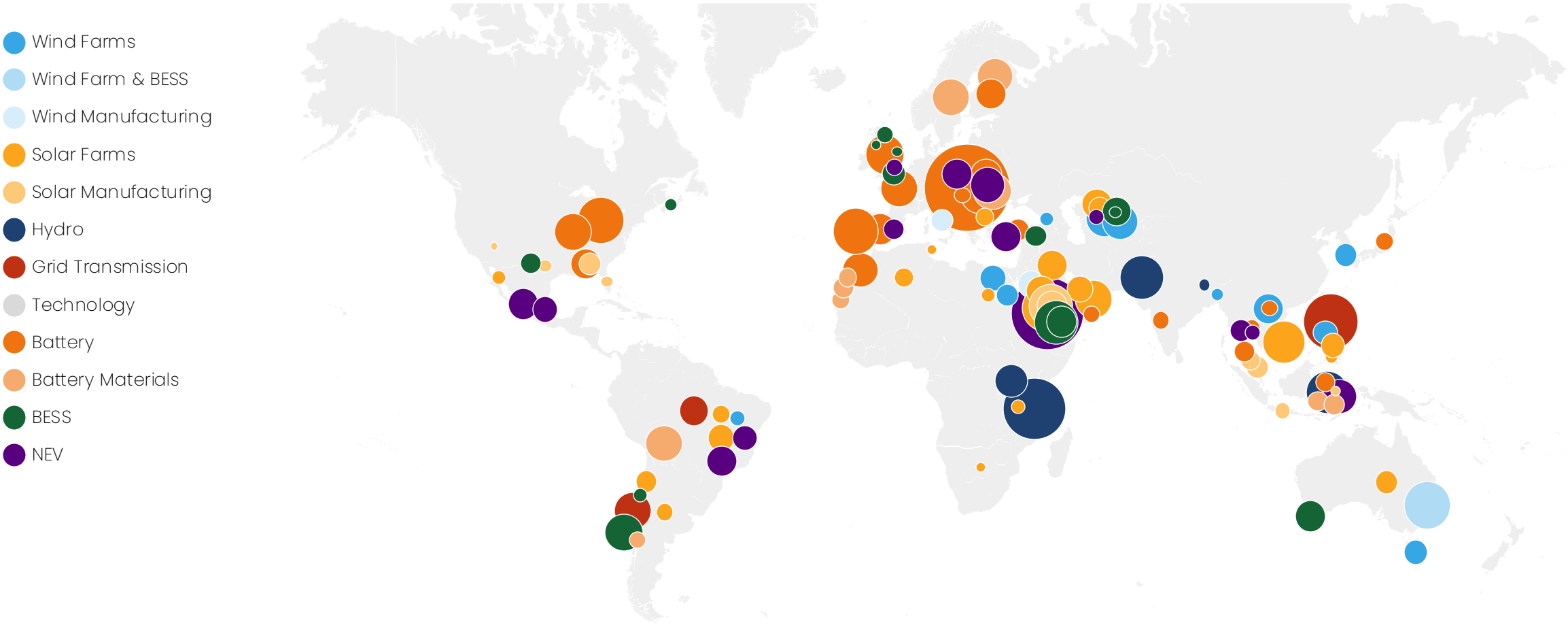
Electric vehicles



China is exporting the capacity to build electrotech

Over \$100bn of outbound FDI on electrotech since 2023

Chinese electrotech investment since 2023



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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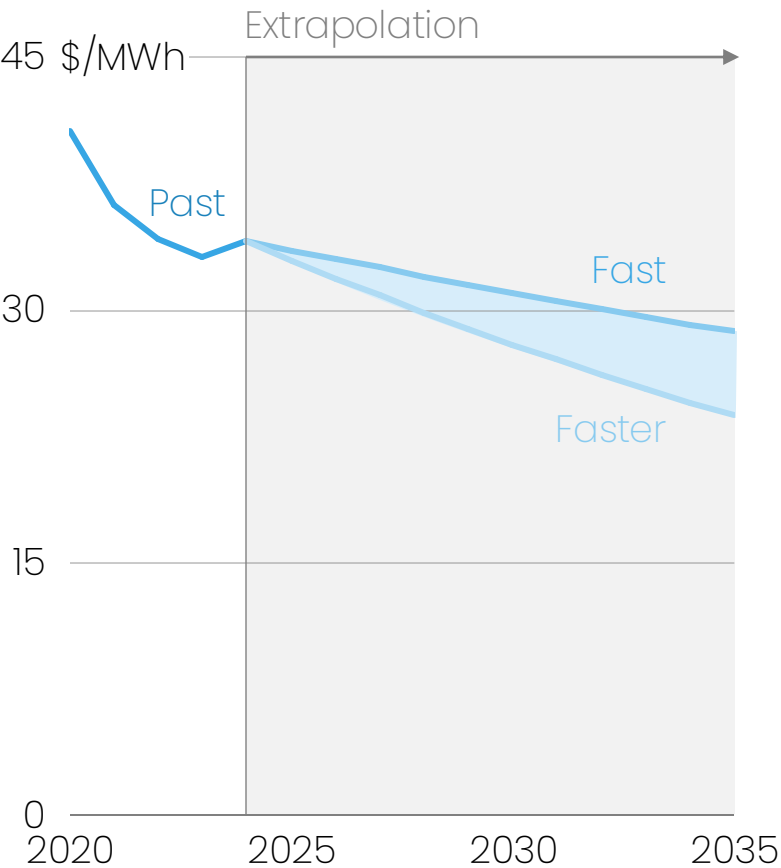


Electrotech will get cheaper driven by learning curves

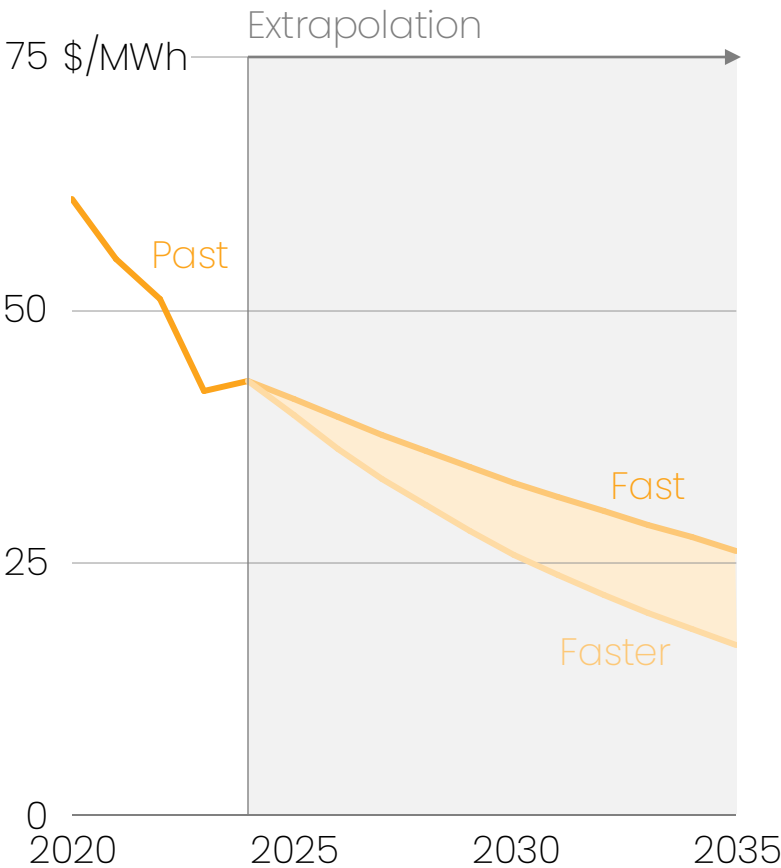
From competitive to irresistible



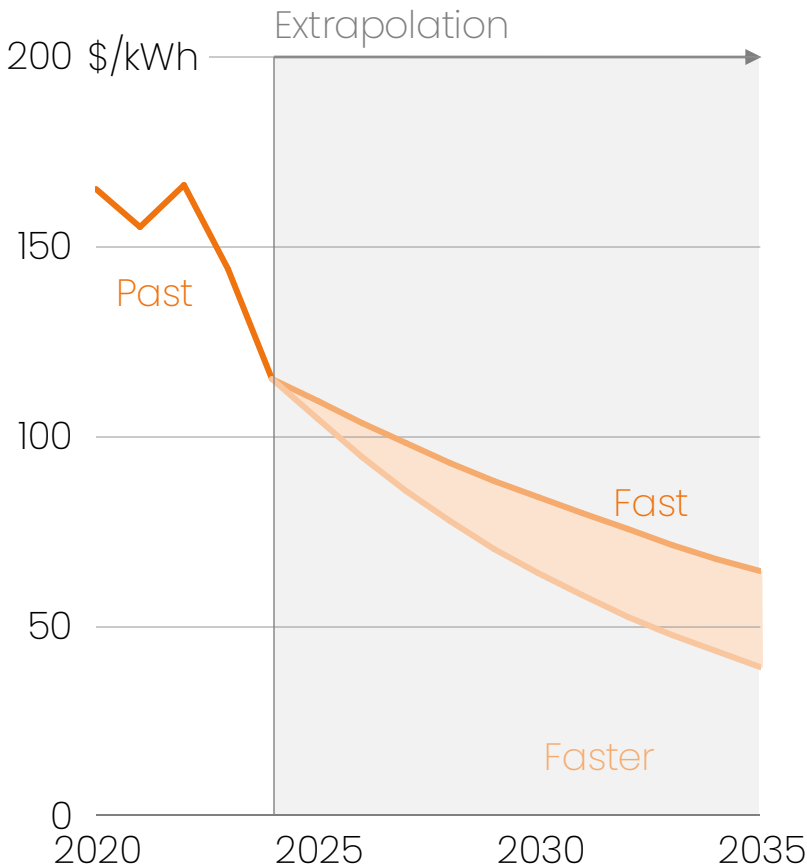
Wind costs



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.

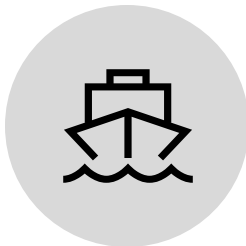
Electricity 2.0 is here

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

Electricity
1.0



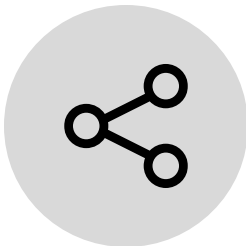
Driven by inefficient
burning



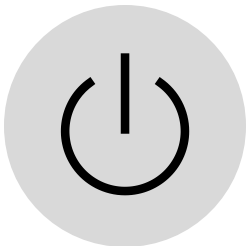
Reliant on
imported fuels



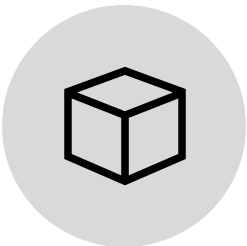
Volatile costs set
by commodities



Centralised
generation

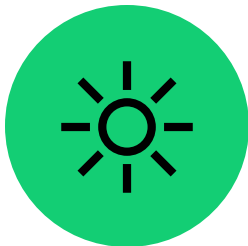


Analogue, static
demand



Non-fungible

Electricity
2.0



Directly from the sun,
without combustion



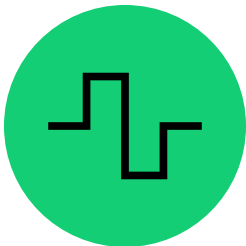
Local



Falling costs set
by technologies



Decentralised
generation



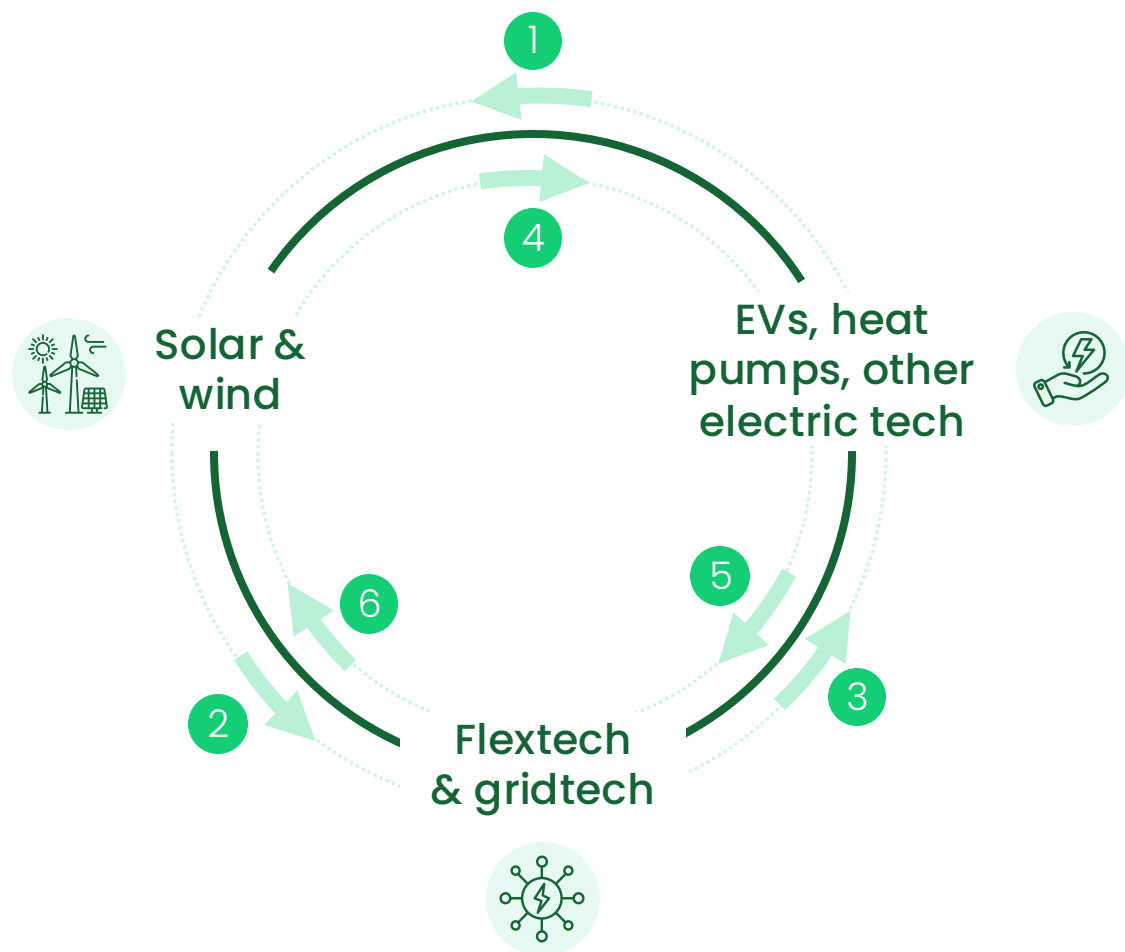
Digital, adaptive
demand



Fungibility from
batteries

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

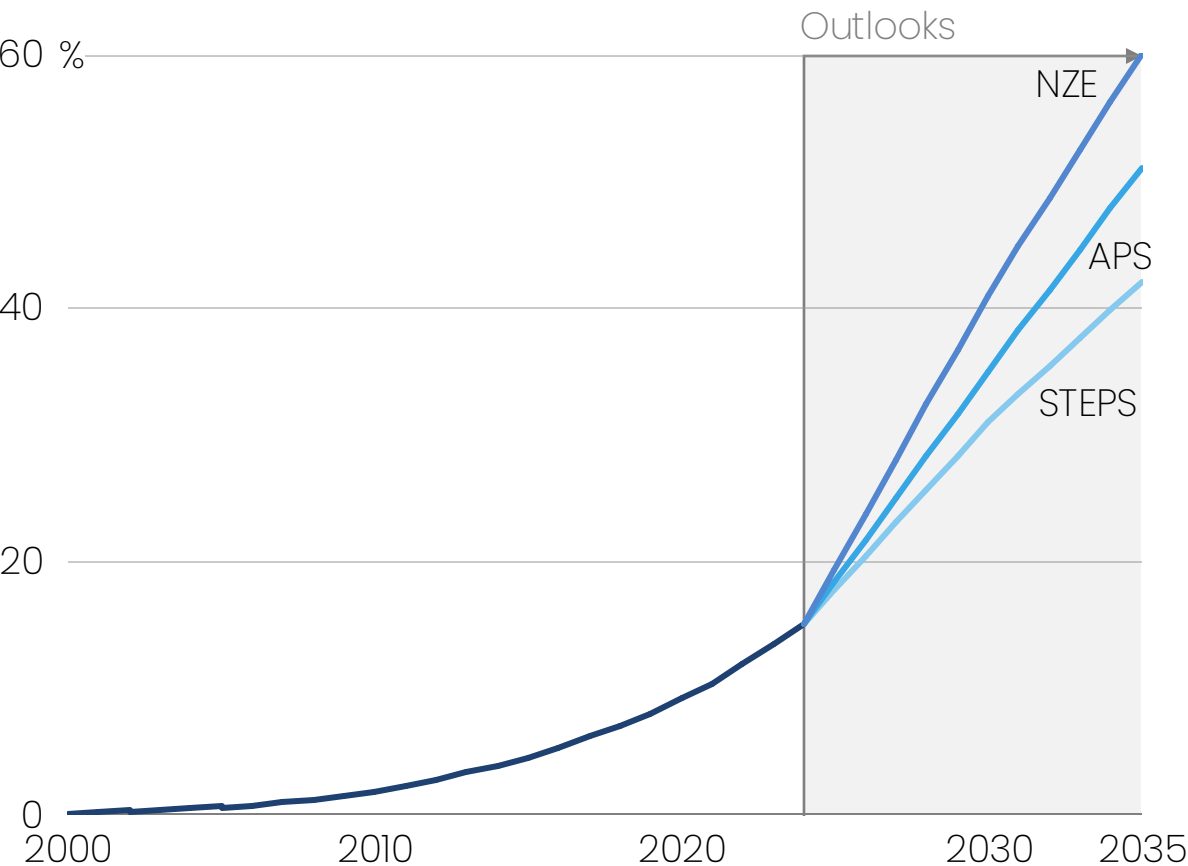


Renewables and electrification will keep growing

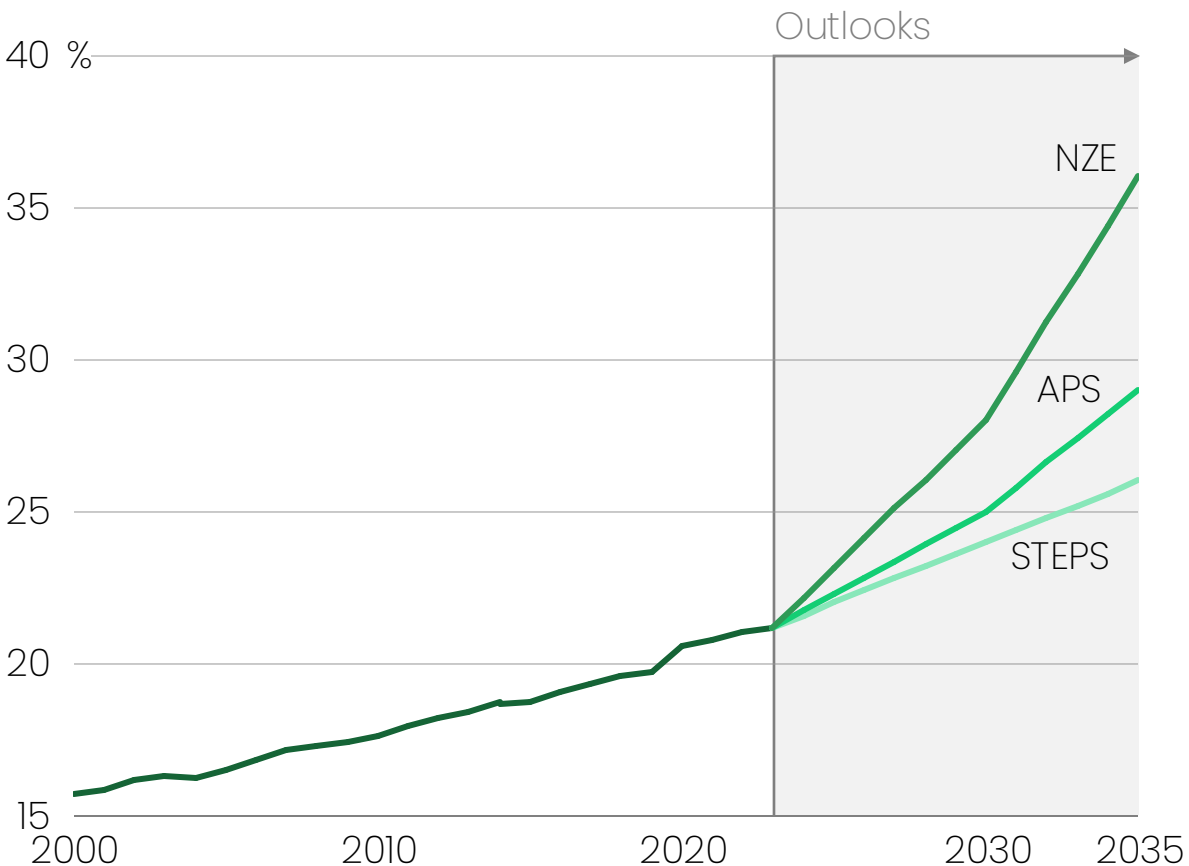
The momentum will continue



Solar & wind share of global generation



Electricity share of final energy



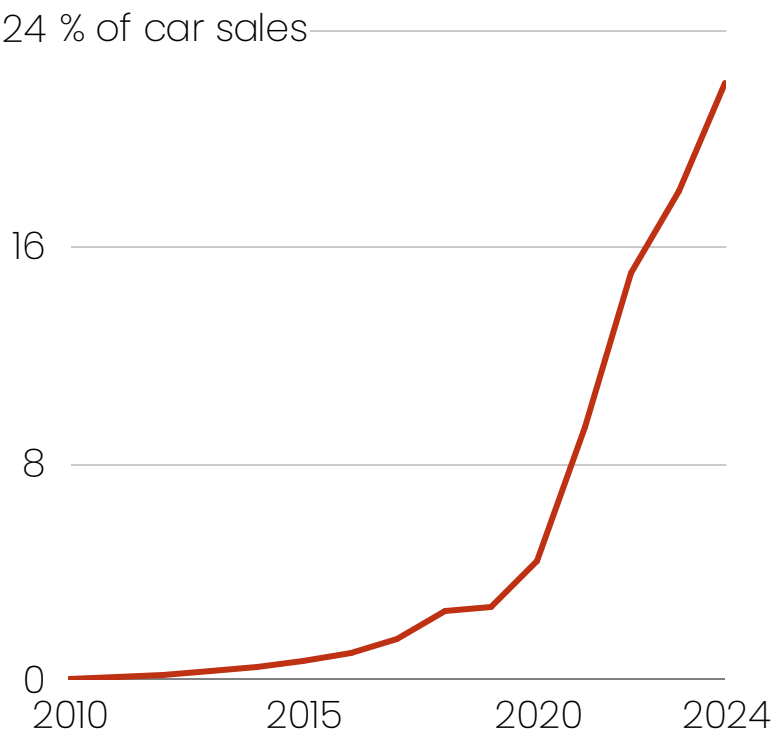


Don't expect the road to be smooth

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

Smooth global curve

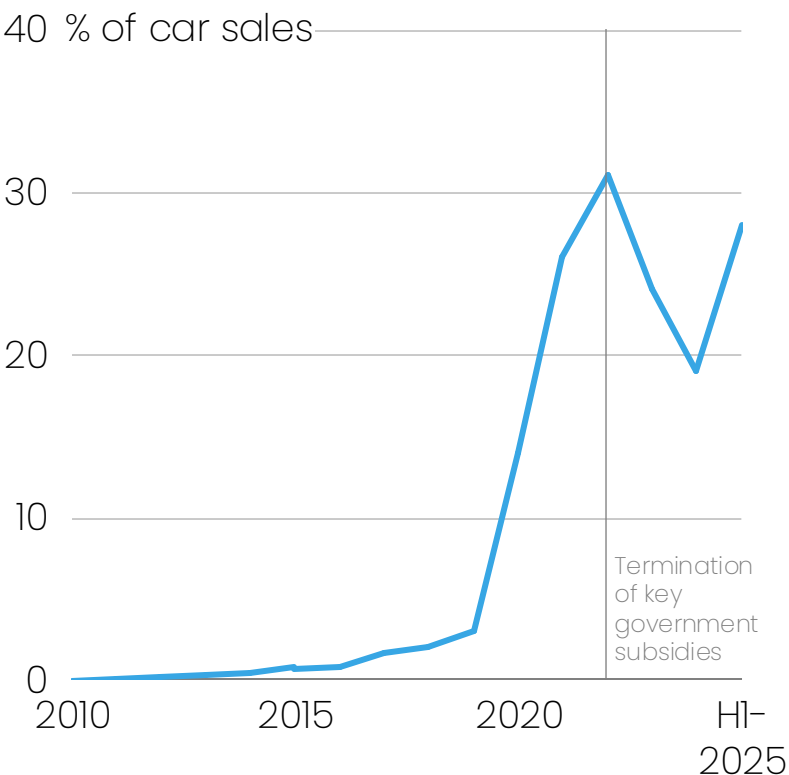
Global EV car sales



Bumpy local curves

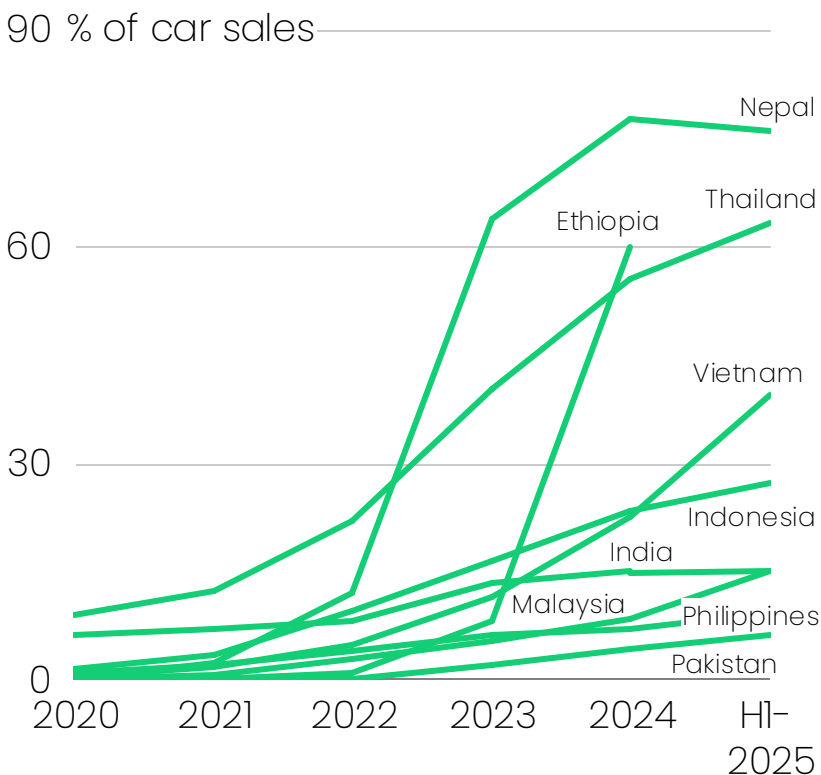
Larger-than-expected slowdown

Germany EV sales



Faster-than-expected acceleration

Emerging market EV sales

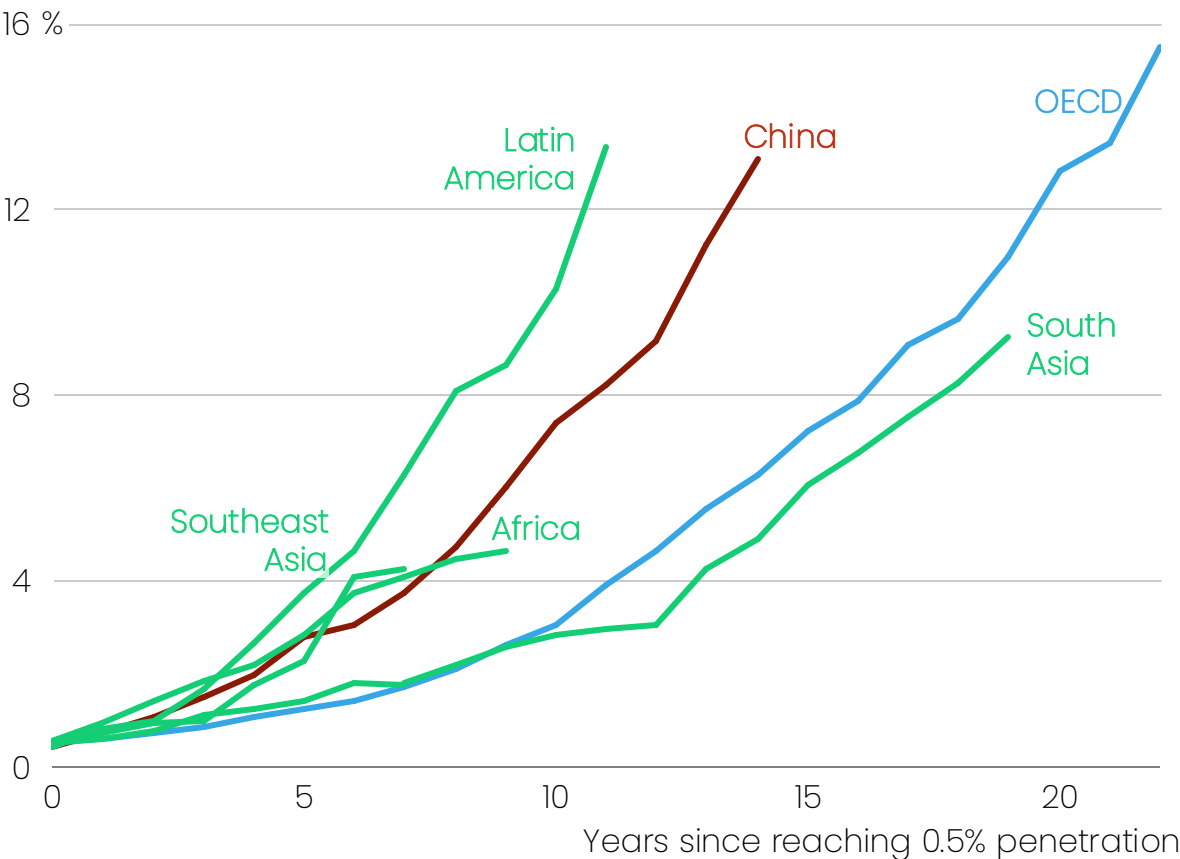




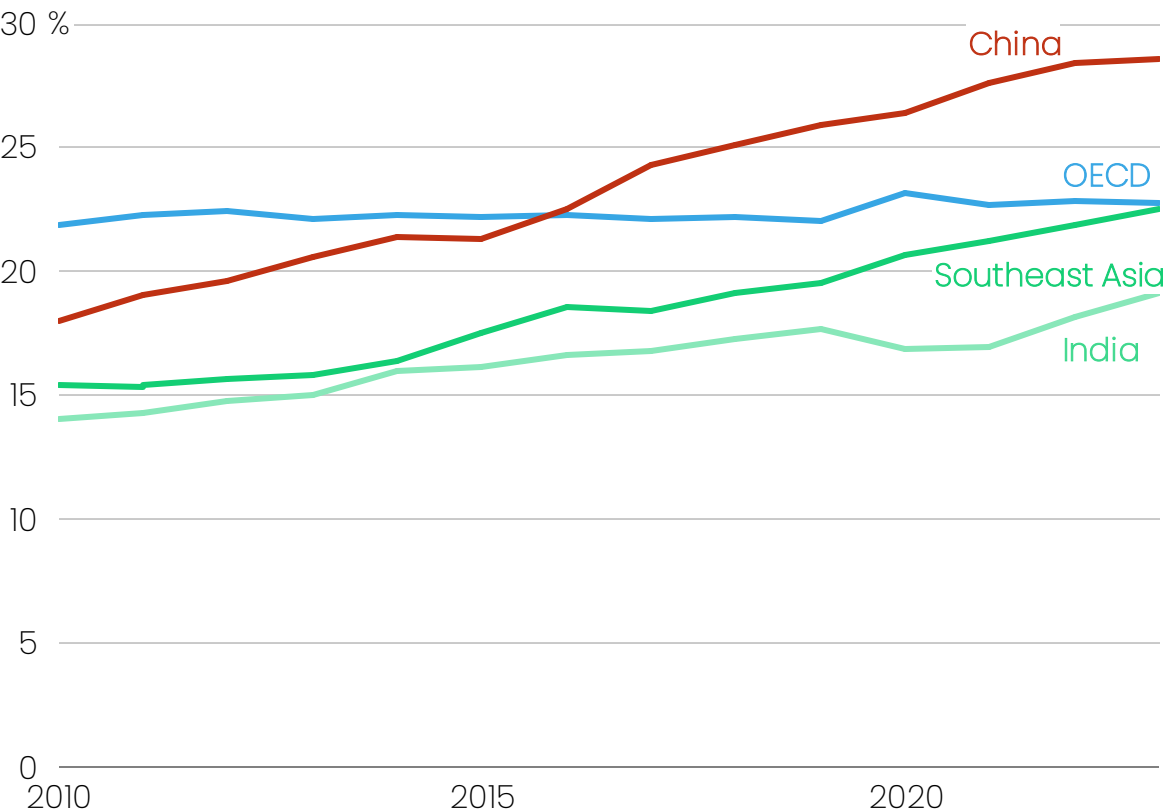
The emerging market leapfrog has strong momentum

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



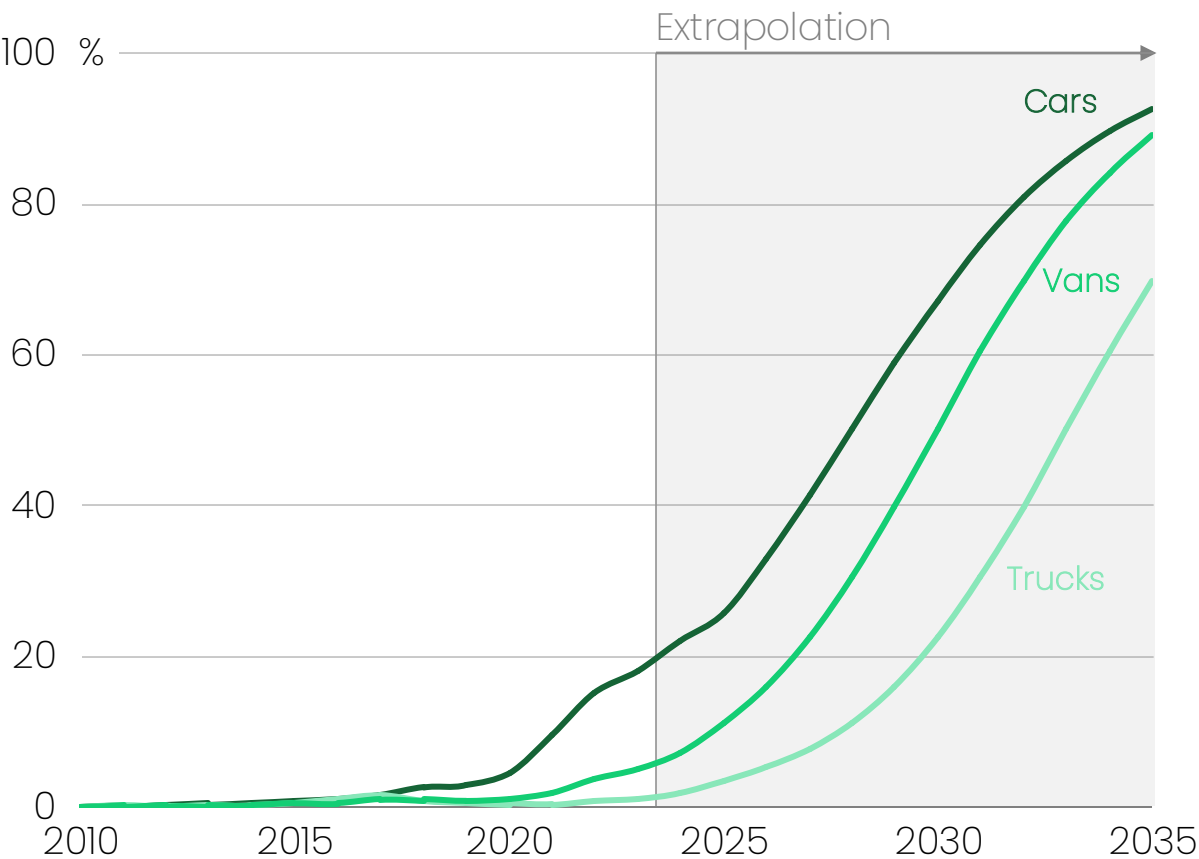


Road transport is the soft underbelly of the oil system

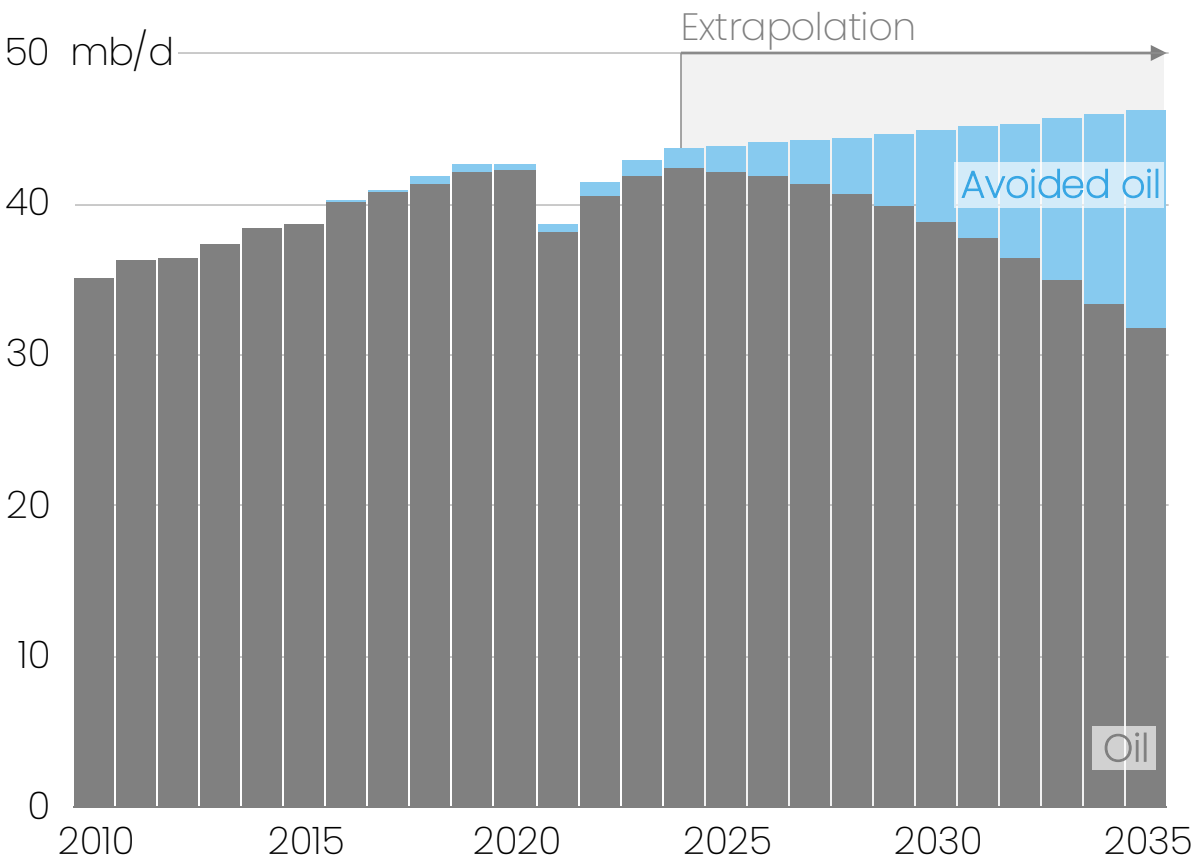
Sales translate into stocks within 15 years or less



Electric vehicle sales



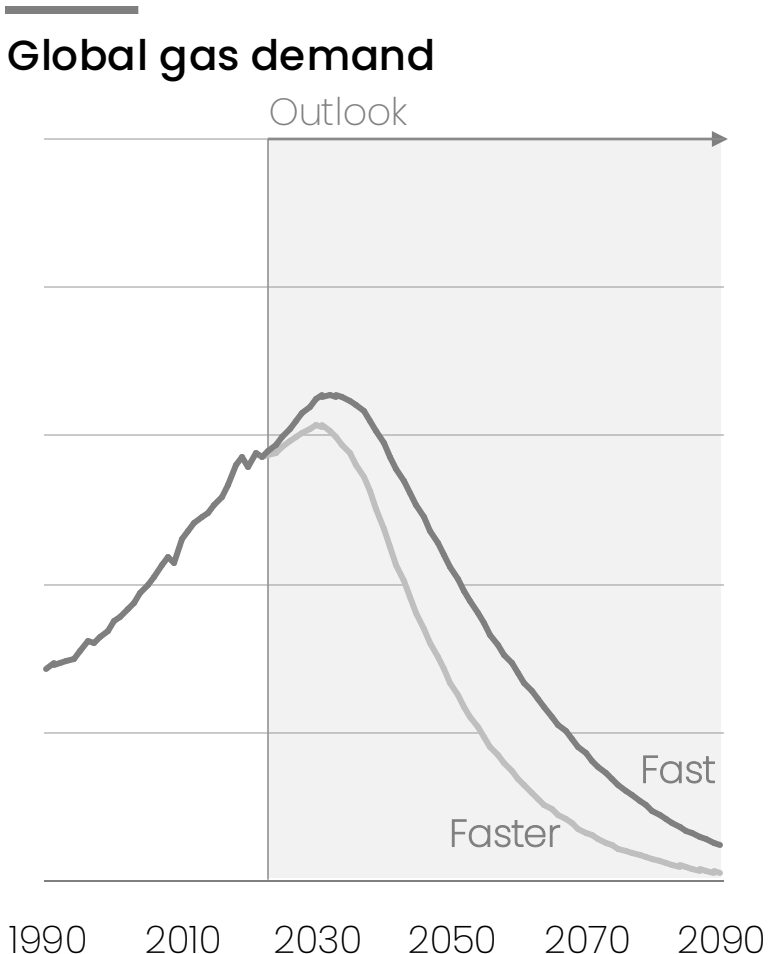
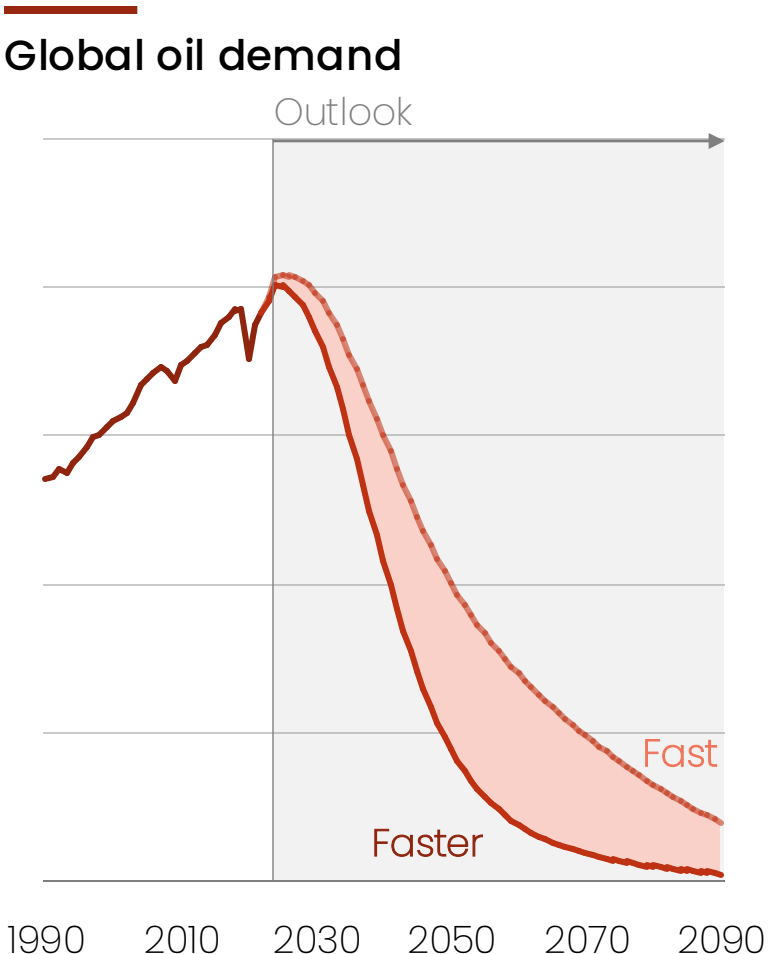
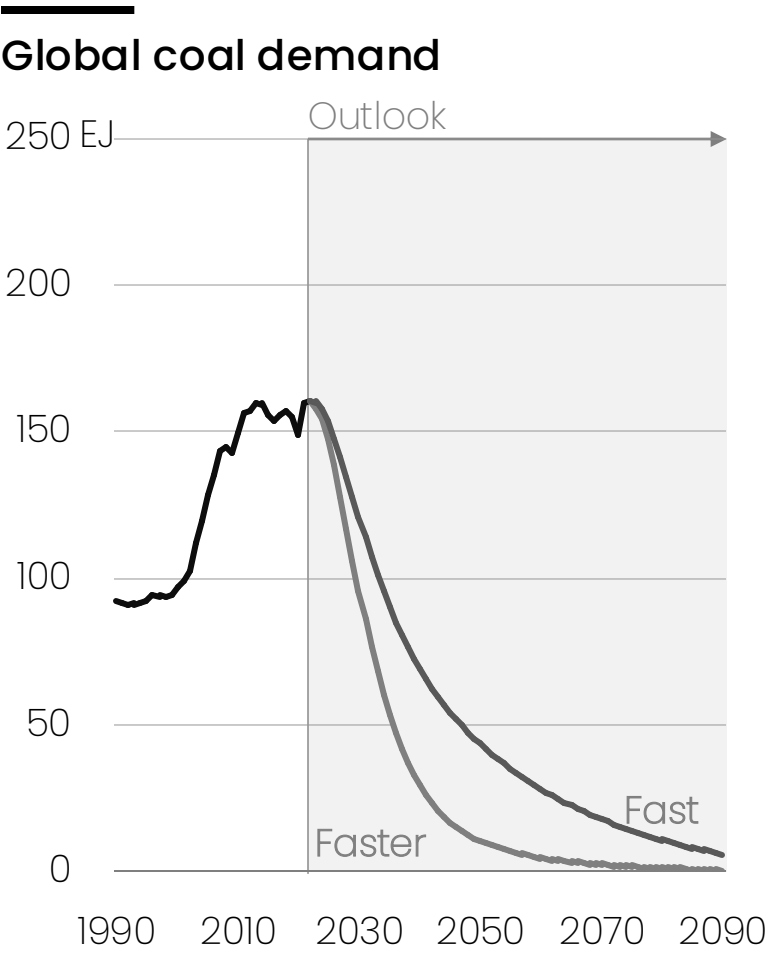
Oil demand for road transport





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

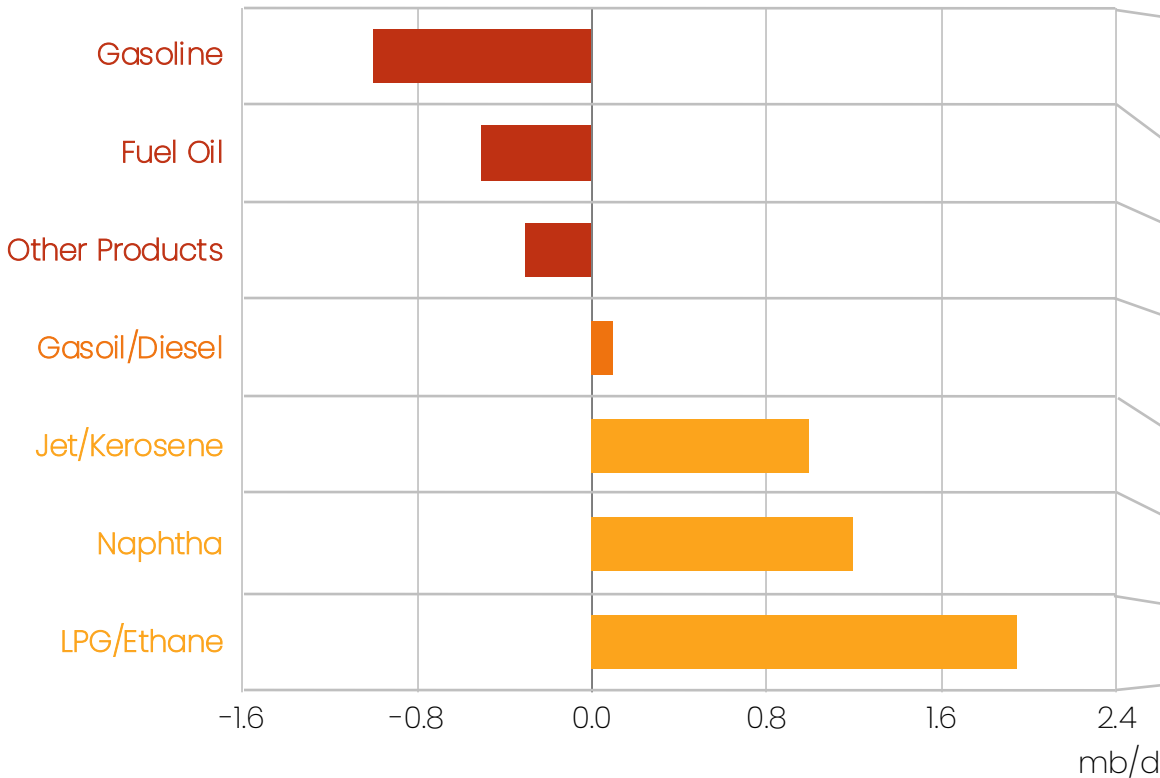


Skewed oil demand will disrupt refining

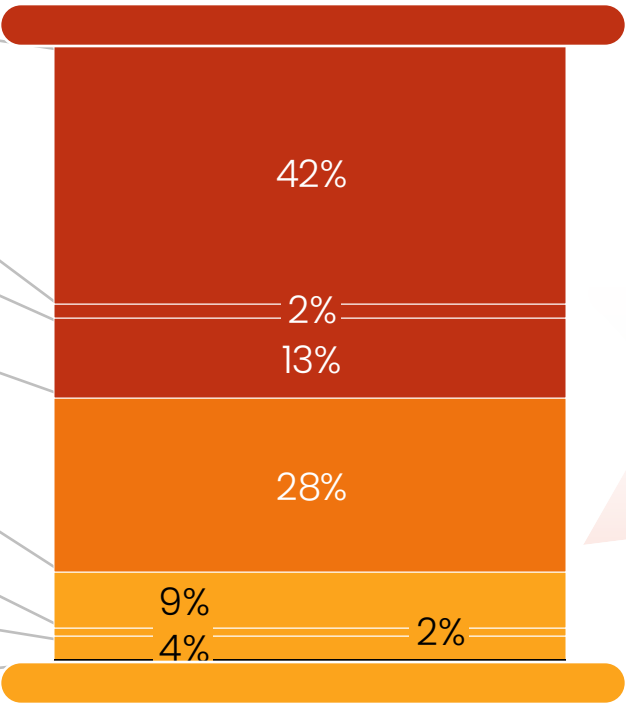
For the first time in history, the demand for a certain part of the barrel will start to structurally decline...

...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

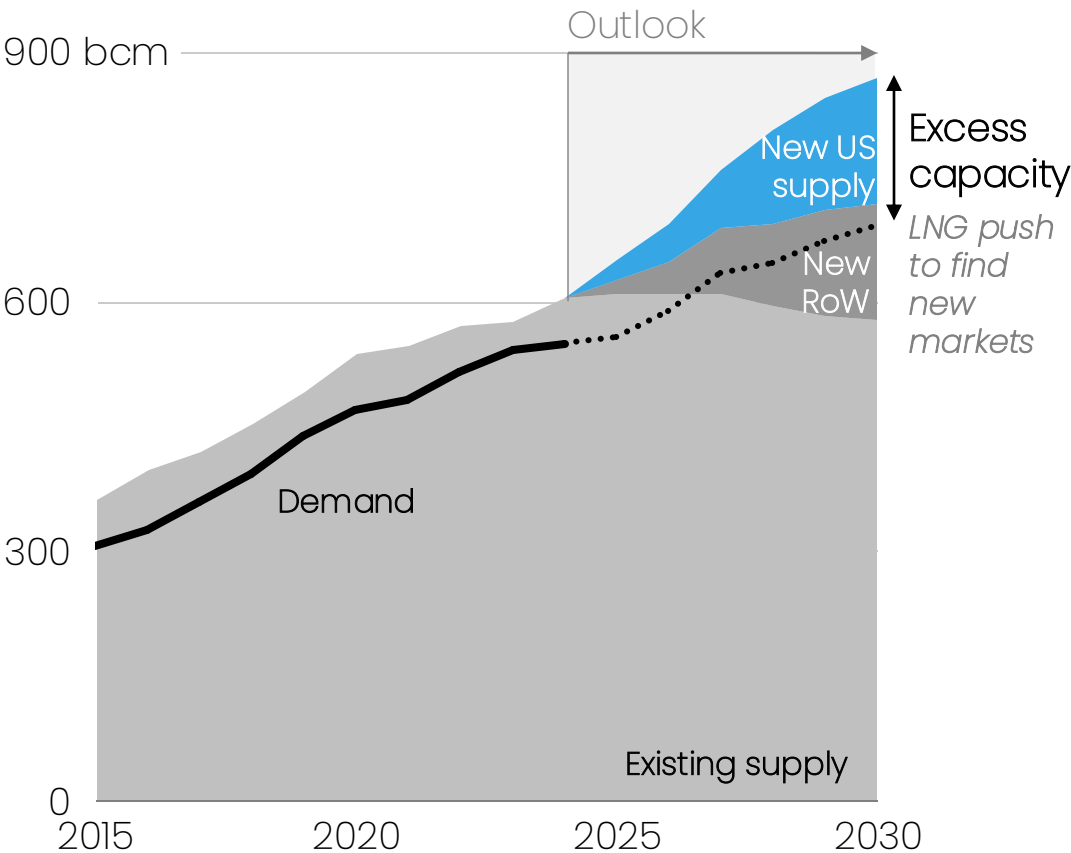


A battle between overcapacities

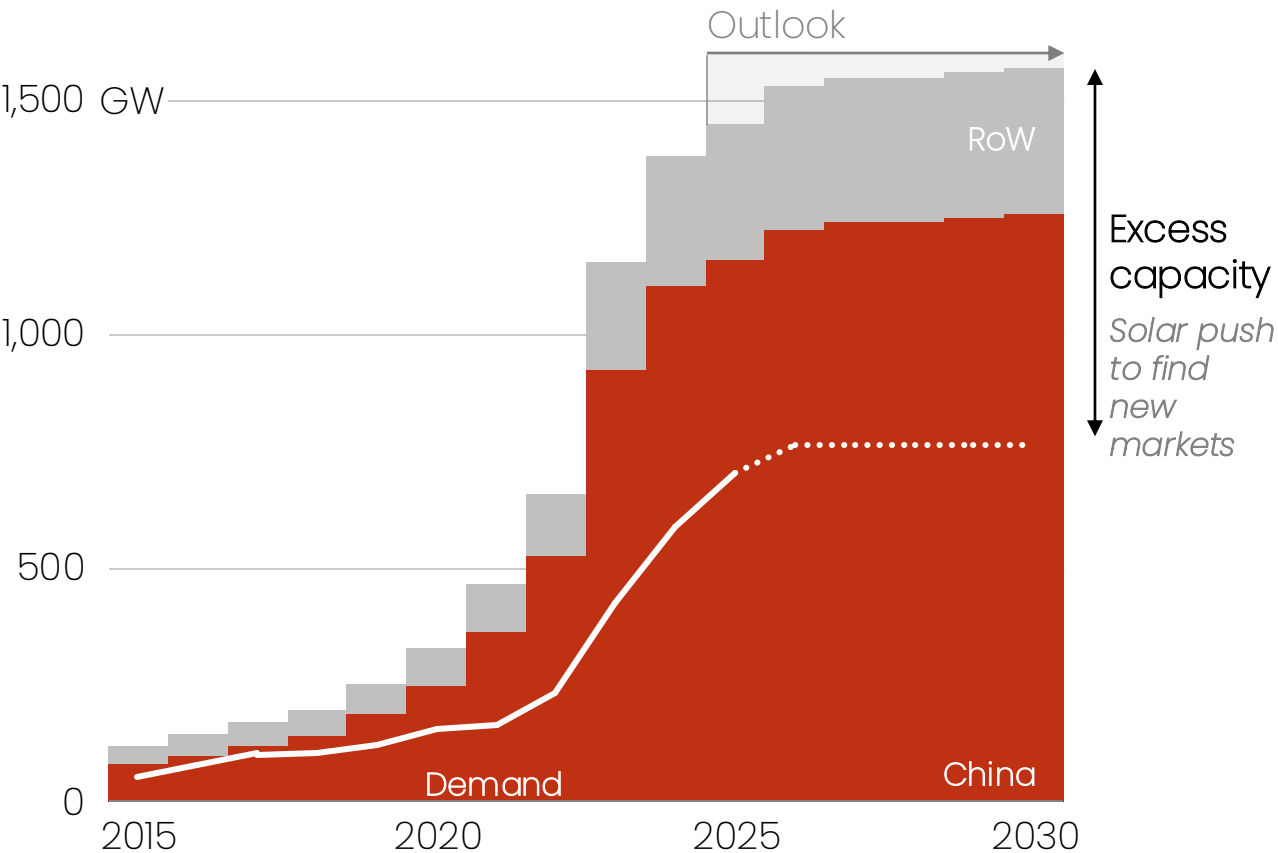
LNG versus solar is the great battle for the future of energy



LNG overcapacity – supply and demand

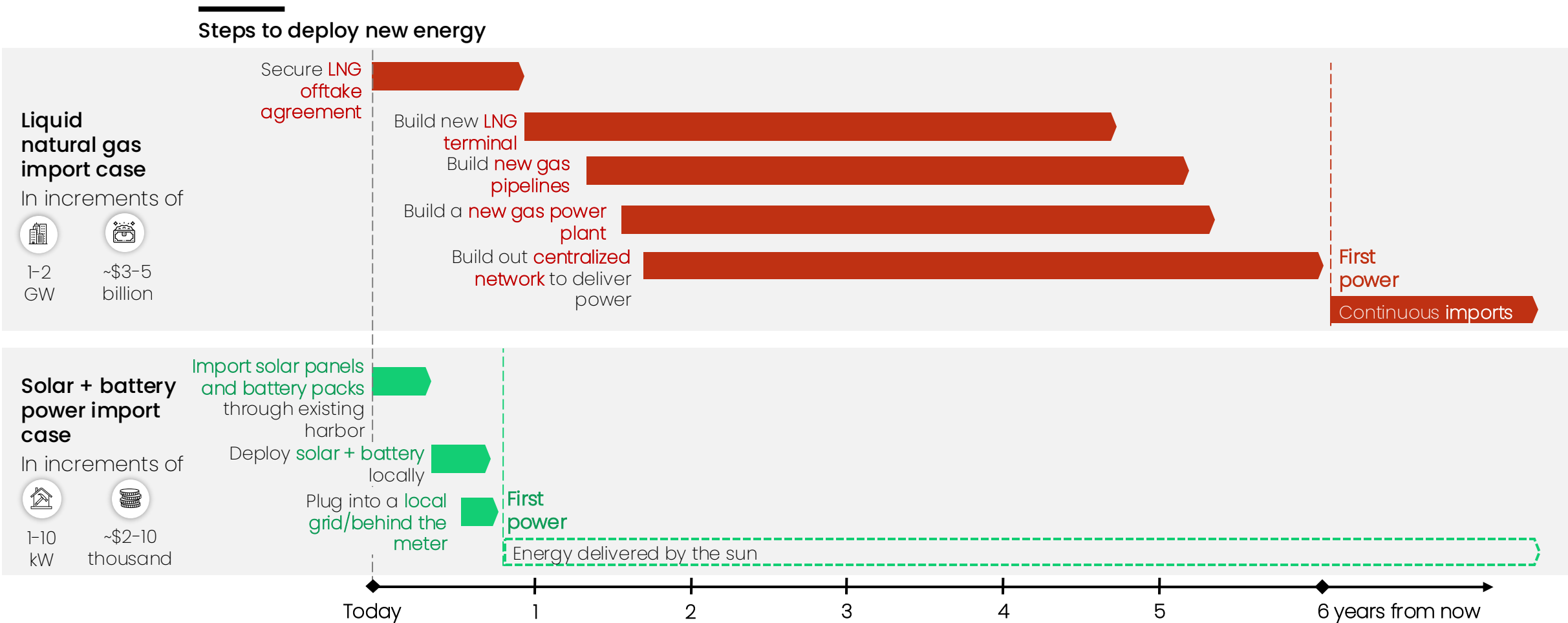


Solar PV module overcapacity – supply and demand



Solar will win the battle for the energy future

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



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

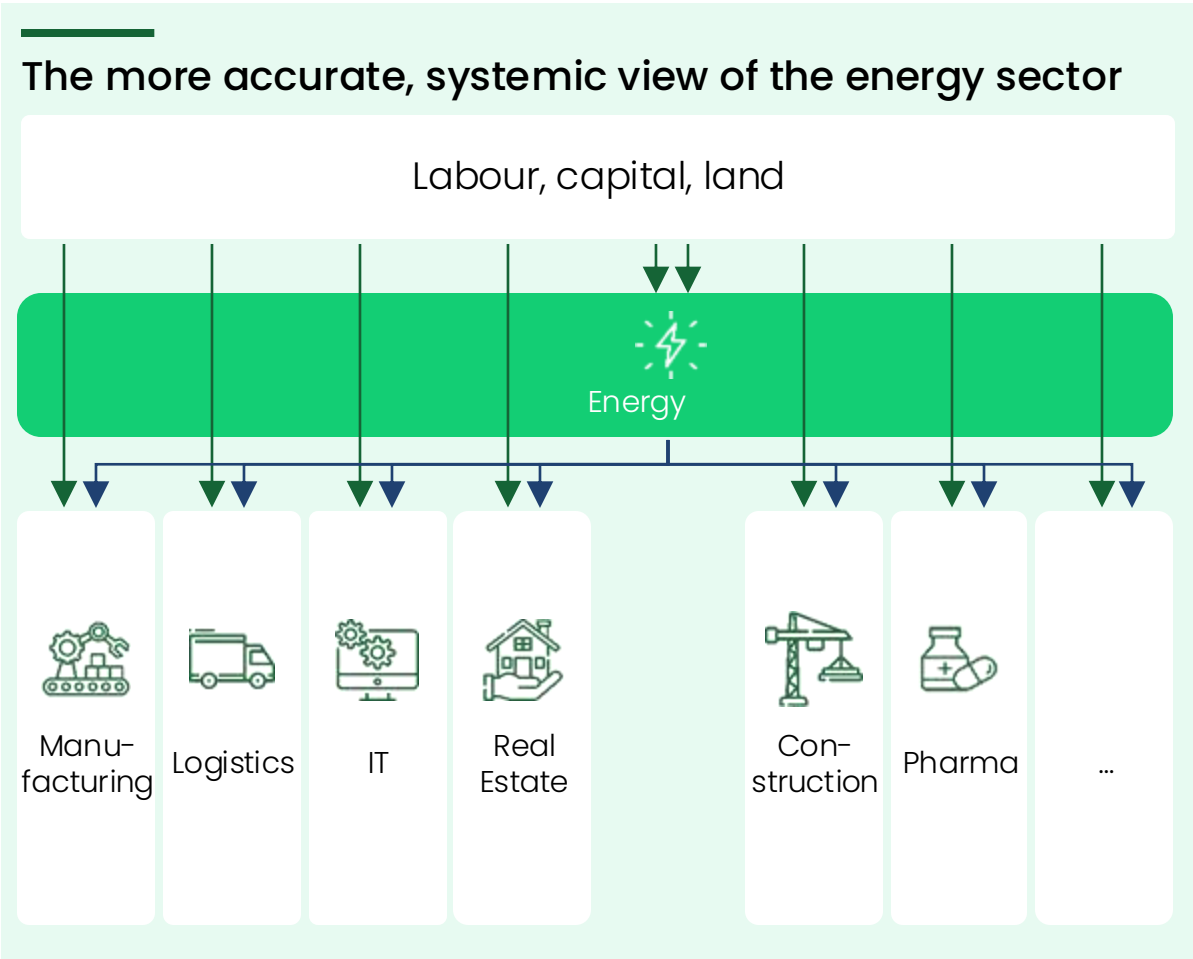
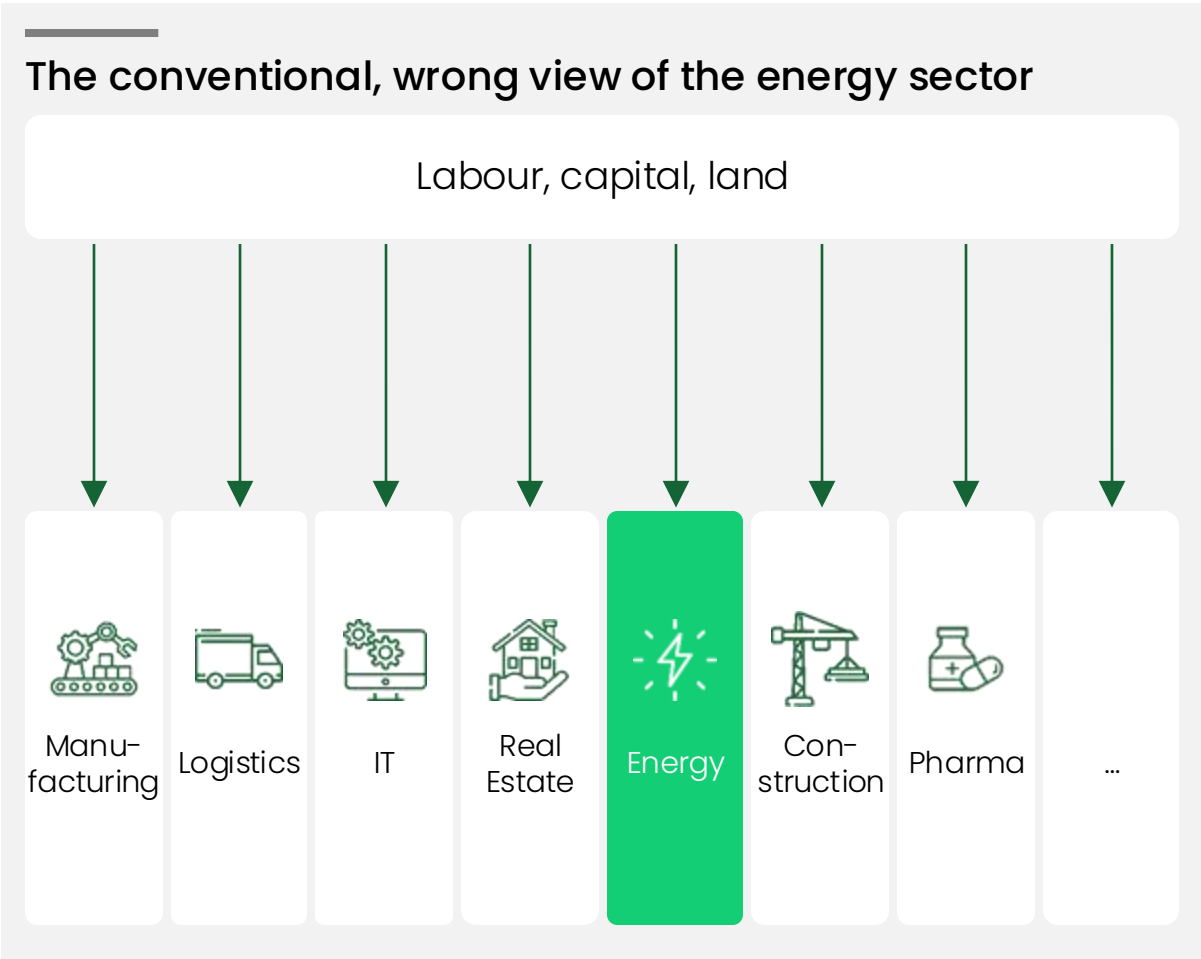
Losers will be those who cling to the old

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

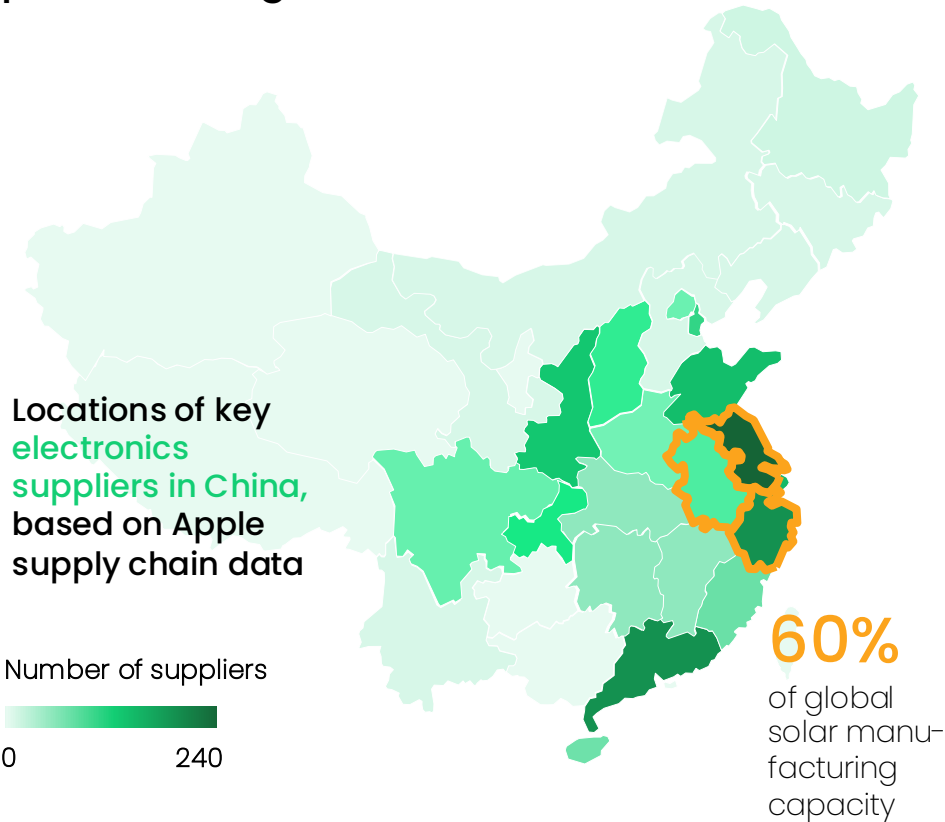
So energy transition means economic transition



Tech is coming for the energy sector

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

Electrotech is manufactured in the same places as digital tech



ILLUSTRATIVE AND NON-EXHAUSTIVE

Many electrotech leaders started in digital tech

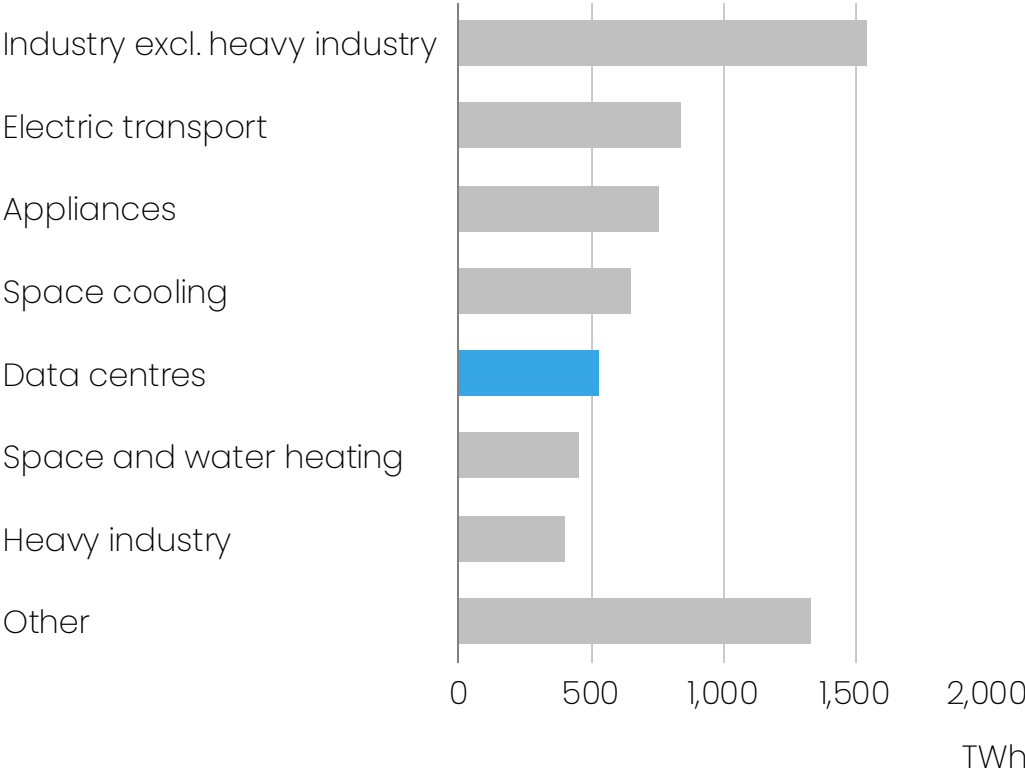
 CATL Robin Zeng Yuqun Founder & Chairman Spent a decade at ATL developing Li-polymer batteries for iPhones and other smartphones	 BYD Wang Chuanfu Founder, Chairman & CEO As GM at BAK Battery Co., scaled Li-ion cells for Nokia & Motorola phones	 SUNTECH Shi Zhengrong Founder & Chairman (until 2013) Led 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.

AI accelerates change

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

AI energy demand growth in context

Increase in electricity demand by sector, 2024-2030



Impact of scaling AI on electrotech, examples

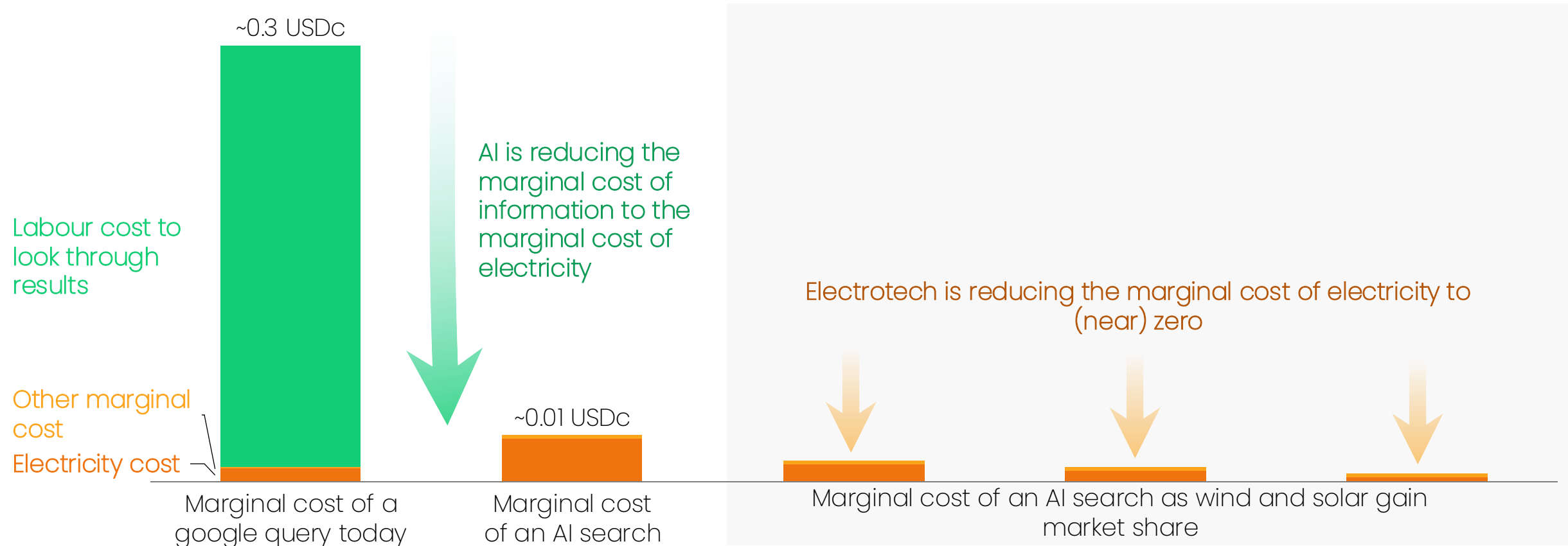
 Predictive maintenance	 Autonomous operations	 Smart charging
 Adaptive heating	 Grid optimisation	 Battery longevity
 Materials discovery	 Power-electronics tuning	 Automated permitting

The zero marginal cost economy is coming

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

Cost of information

ILLUSTRATIVE

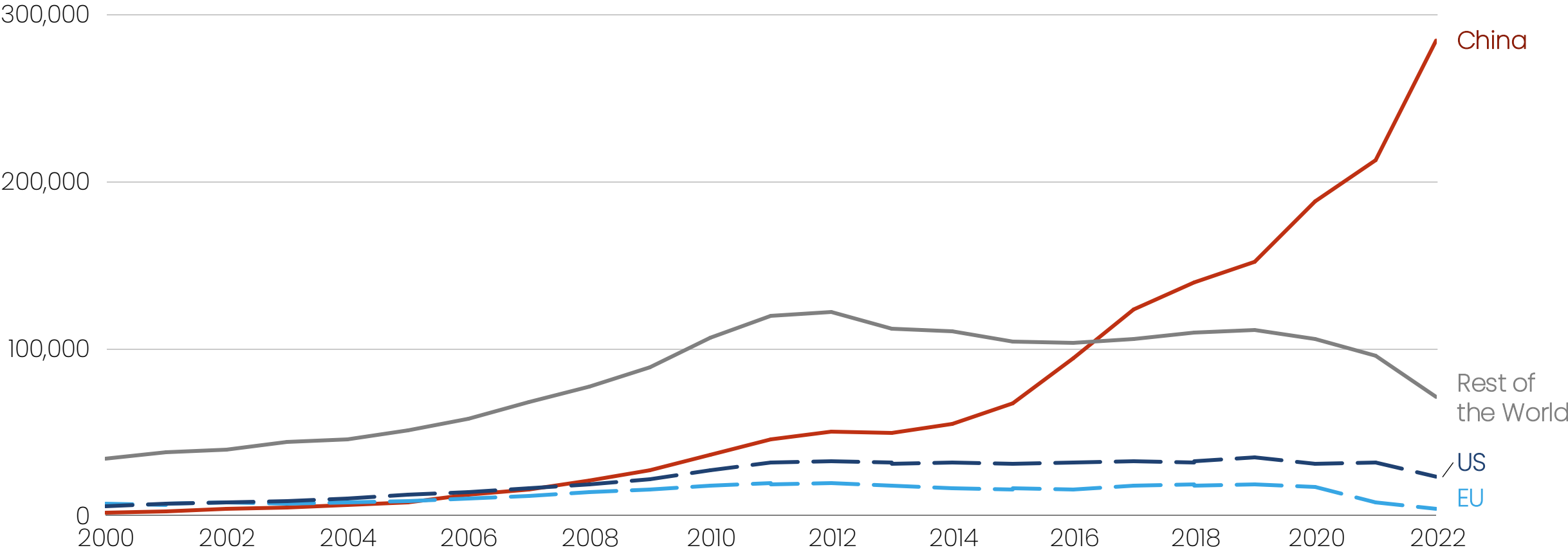




The energy technology frontier has moved East

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

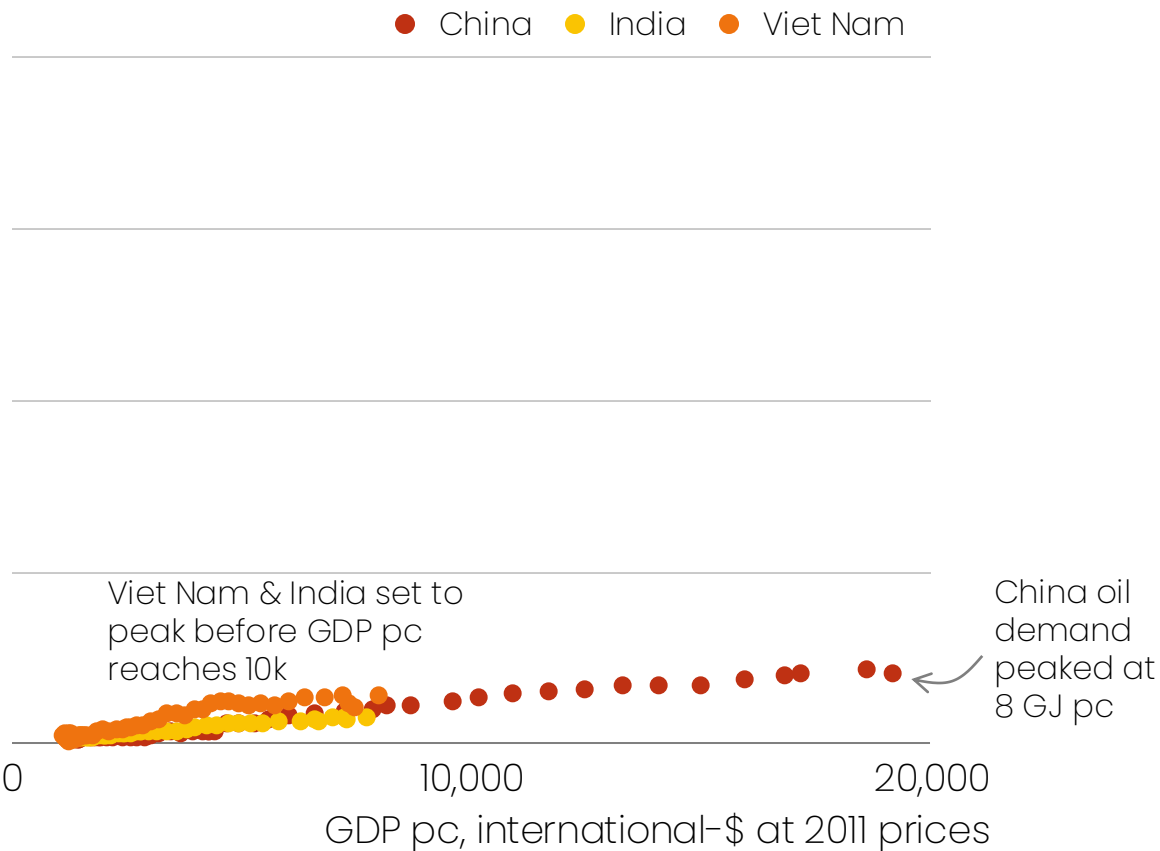
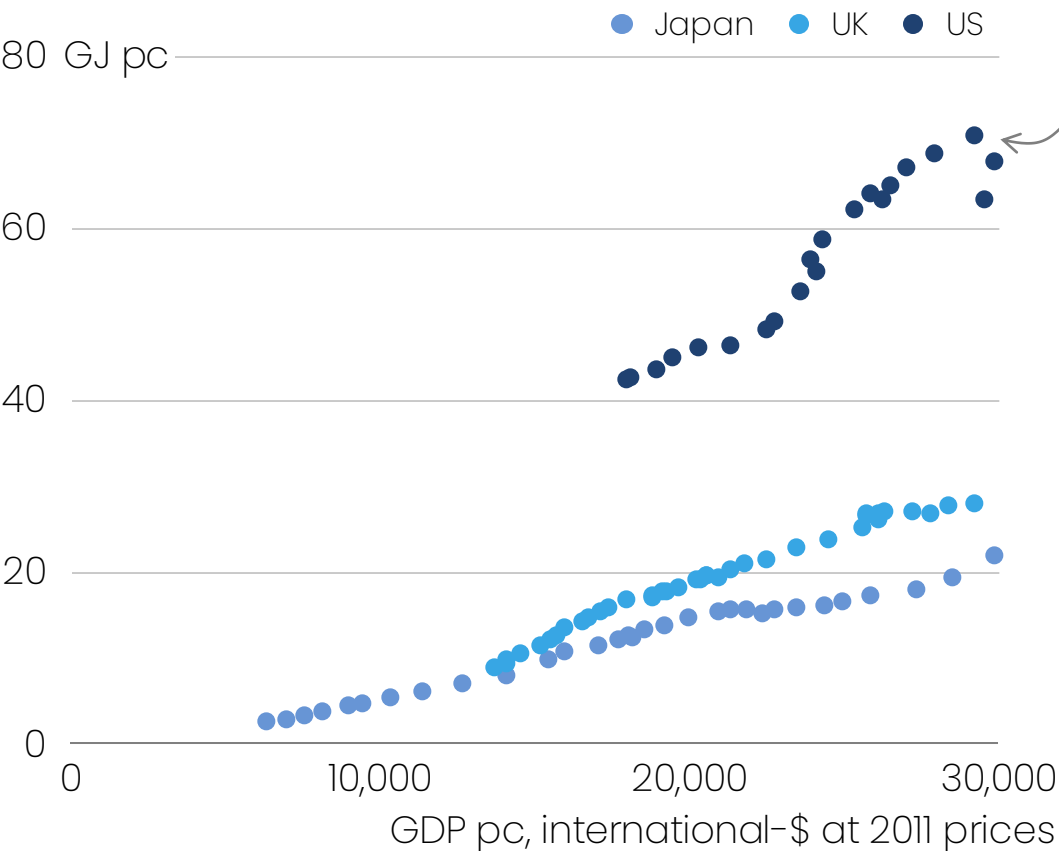
Annual applications for patents in clean energy technologies



The end of oil-intensive development

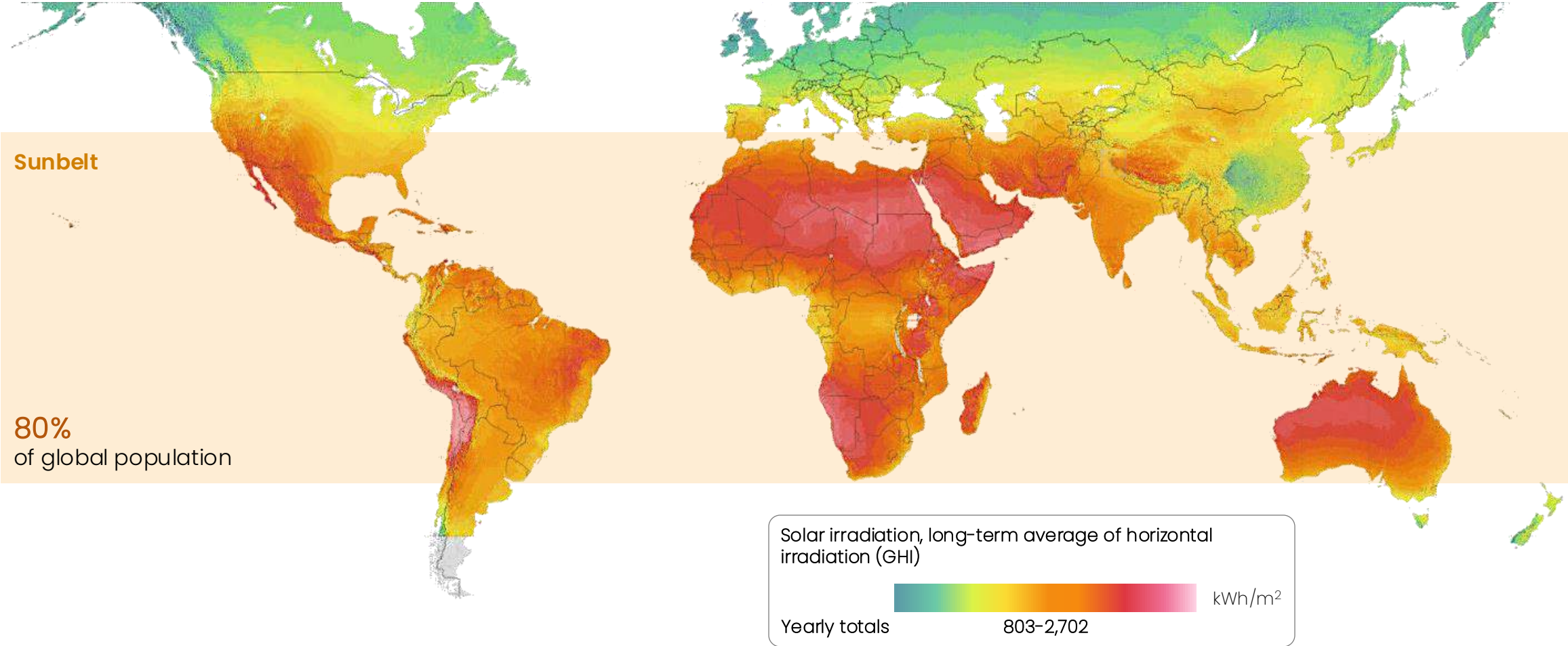
China's per capita road oil demand peaked at a tenth of US levels – other emerging markets are set to follow

Per capita road oil demand and GDP



Electrotech liberates the power of the Sunbelt

The emerging markets will have the lowest electricity cost

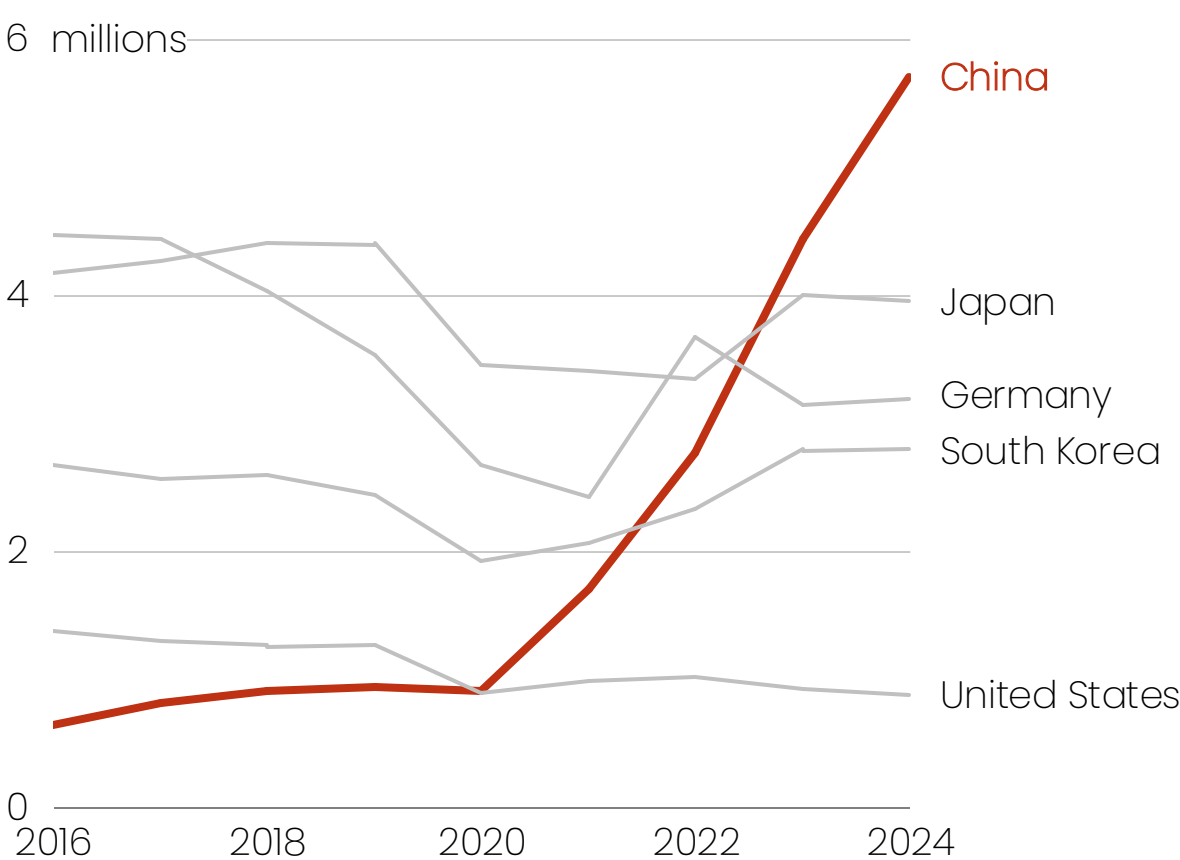




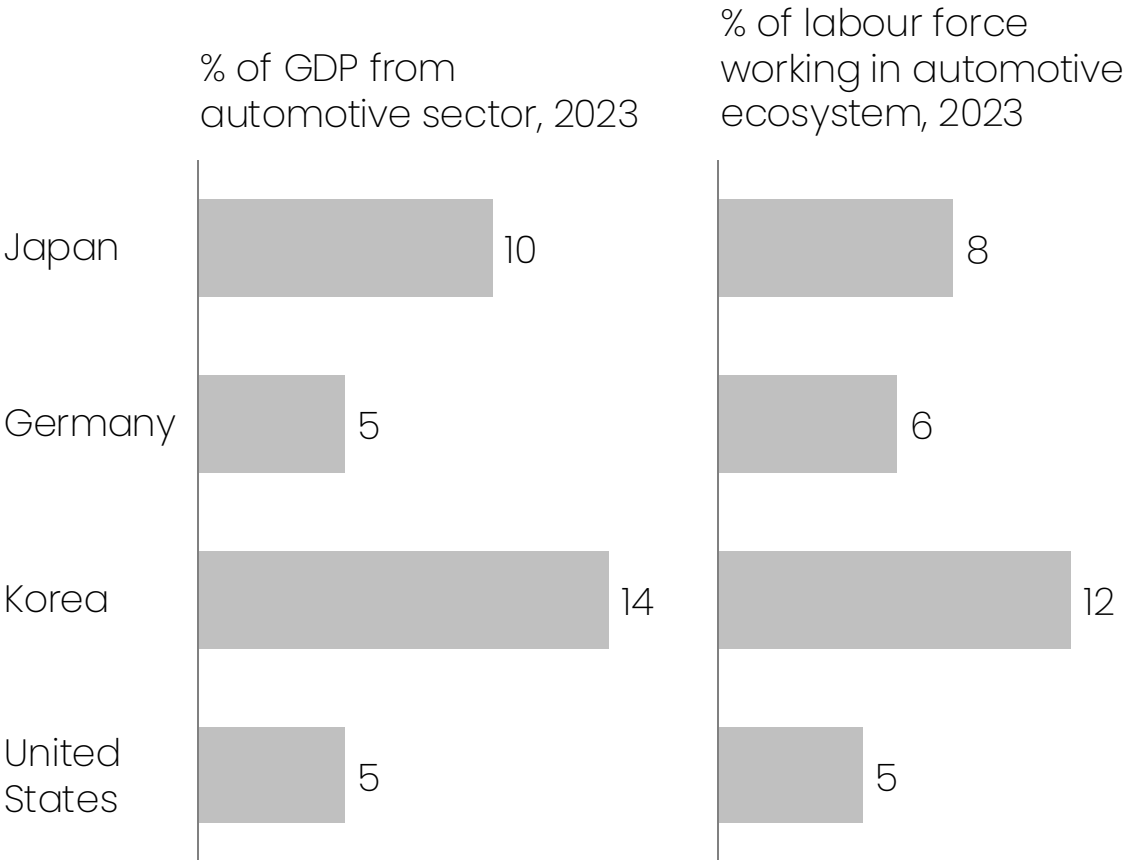
The automotive sector is a warning sign for other industries

In four years, China went from small to dominant

Car exports: China is taking over, enabled by EVs



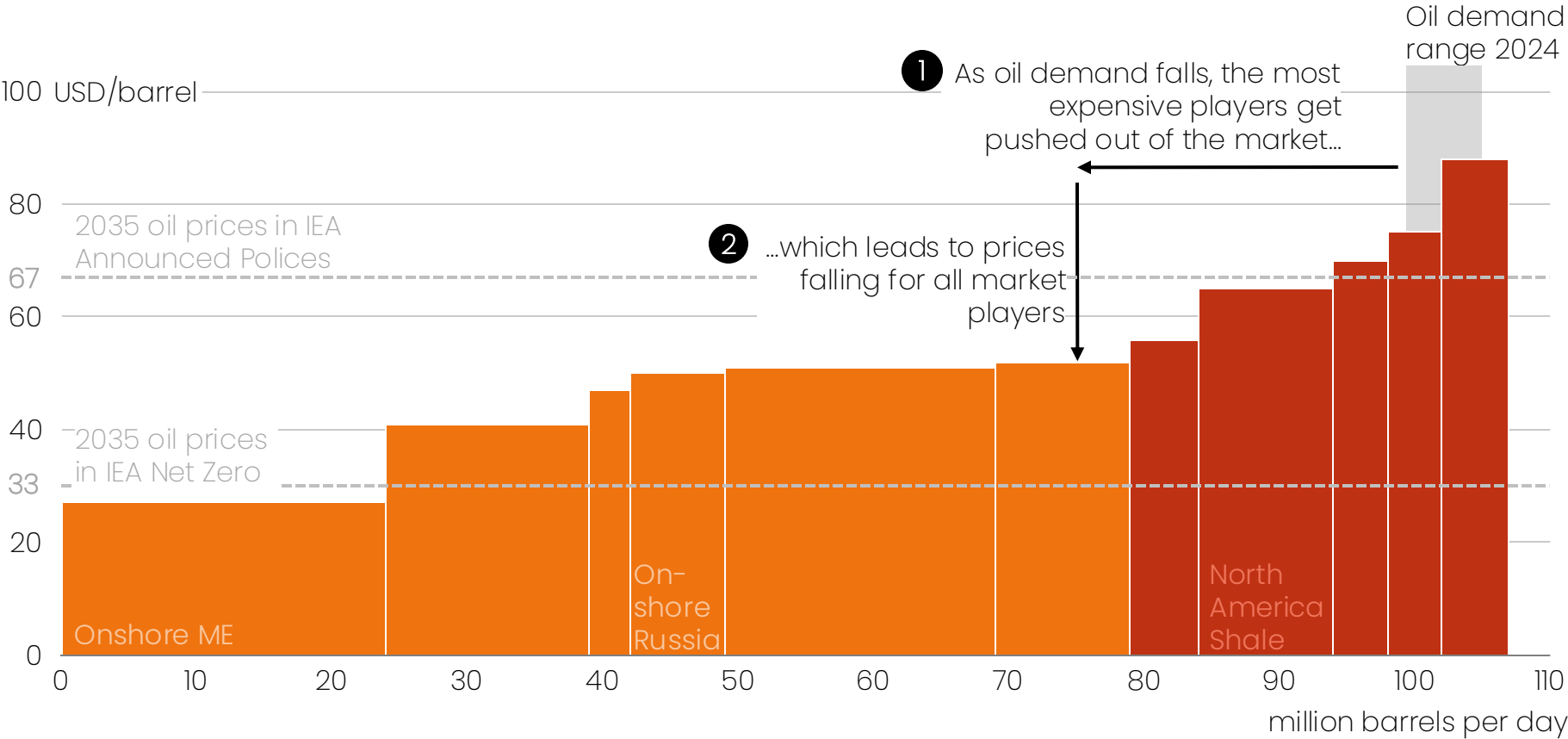
Role of automotive in selected economies



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:

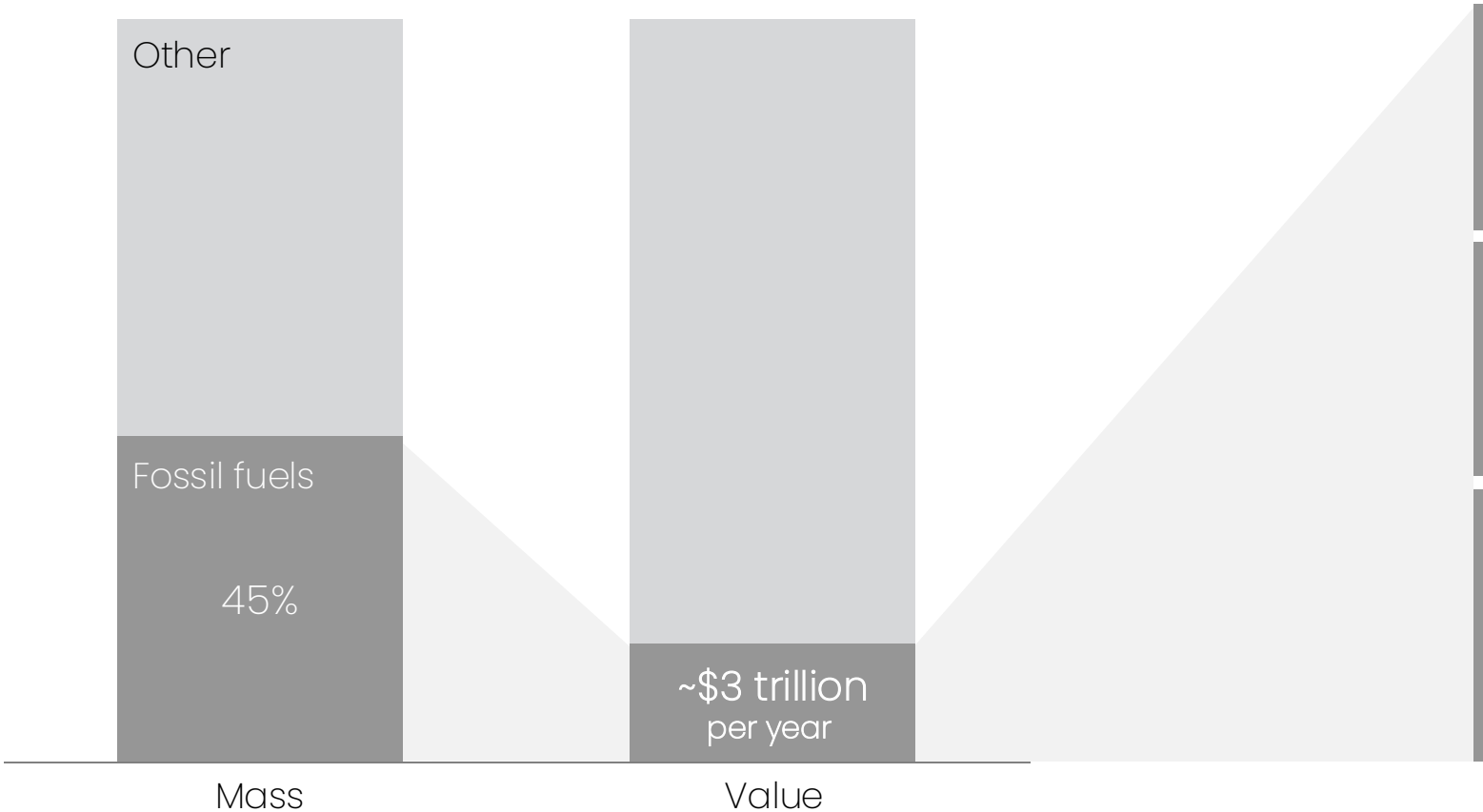
Fiscal breakeven oil price

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

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

Coal terminals



LNG terminals



Oil terminals



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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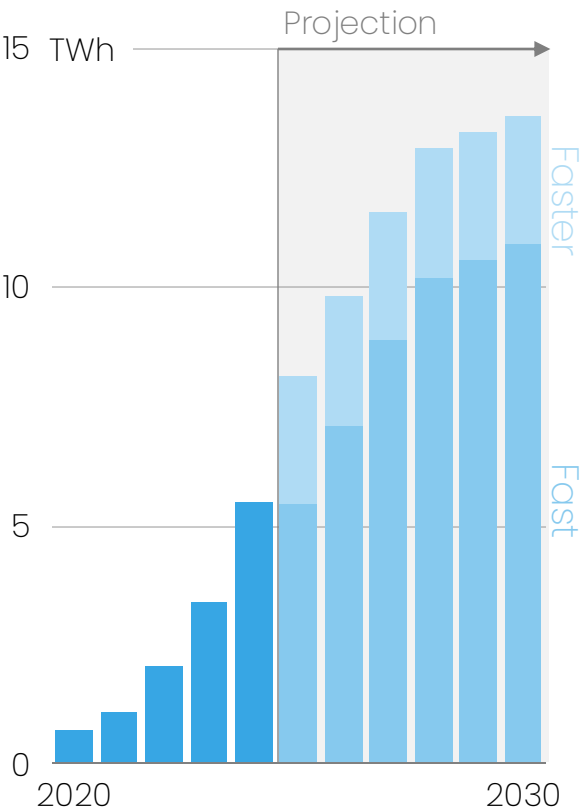


This is the decisive decade

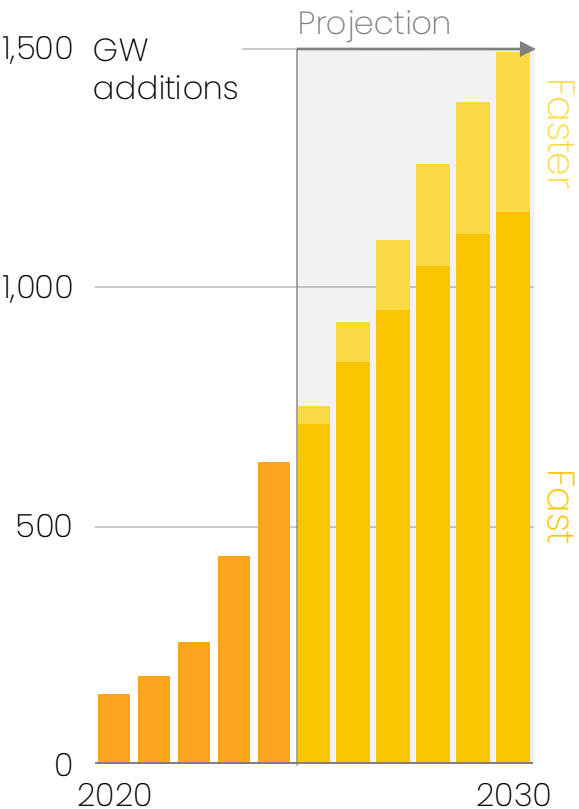
A century in the making, electrotech will define this decade



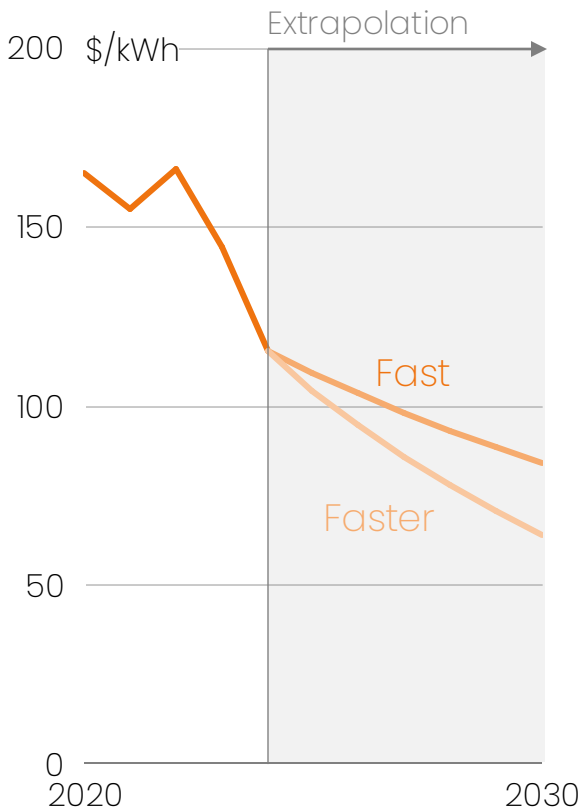
Manufacturing capacity is built: Batteries



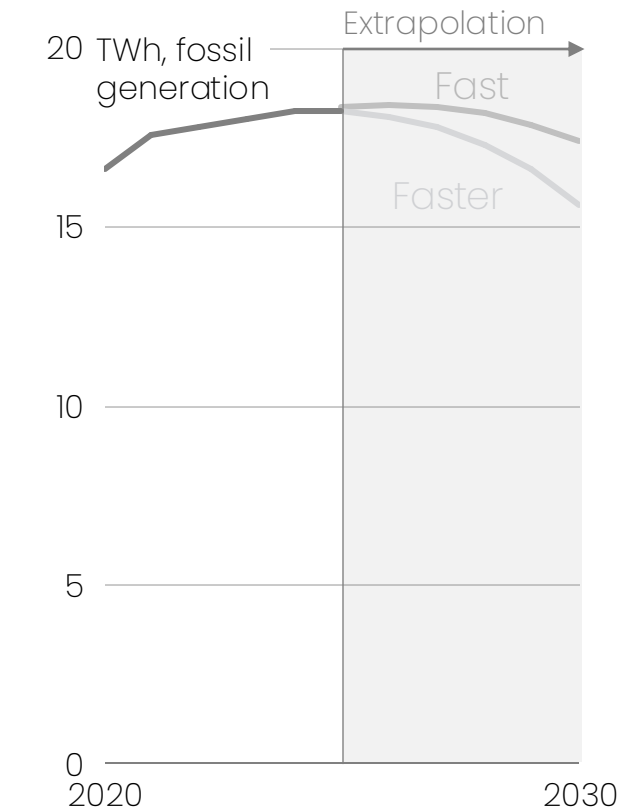
S-curves hit their steepest parts: Solar



Electrotech get too cheap to resist: Batteries



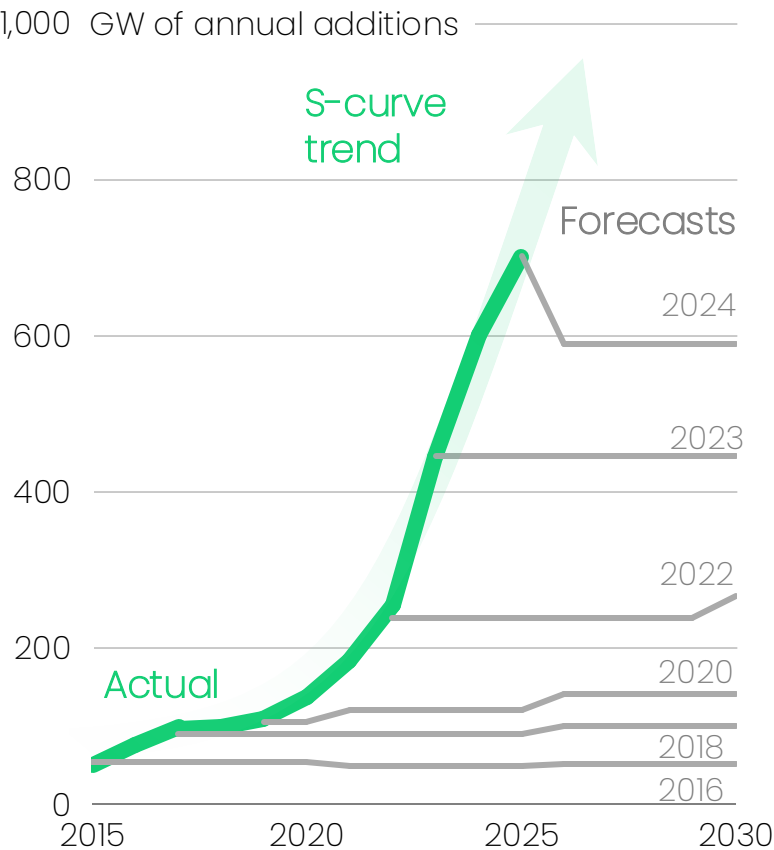
Fossil fuel demand enters terminal decline



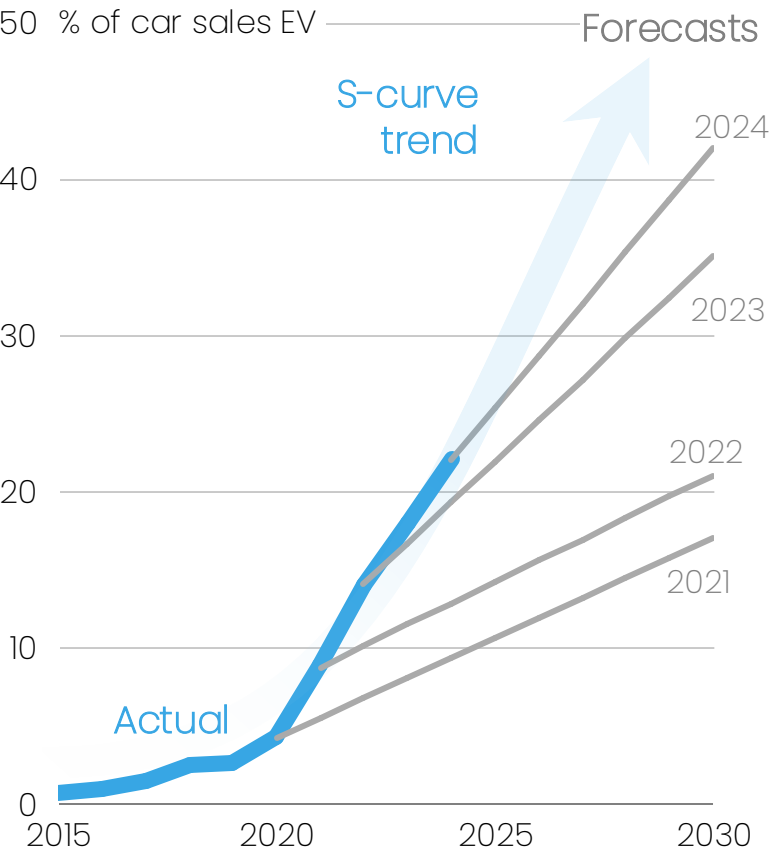
Beware of the limits of old energy models

Complex models are missing the reality of exponential change

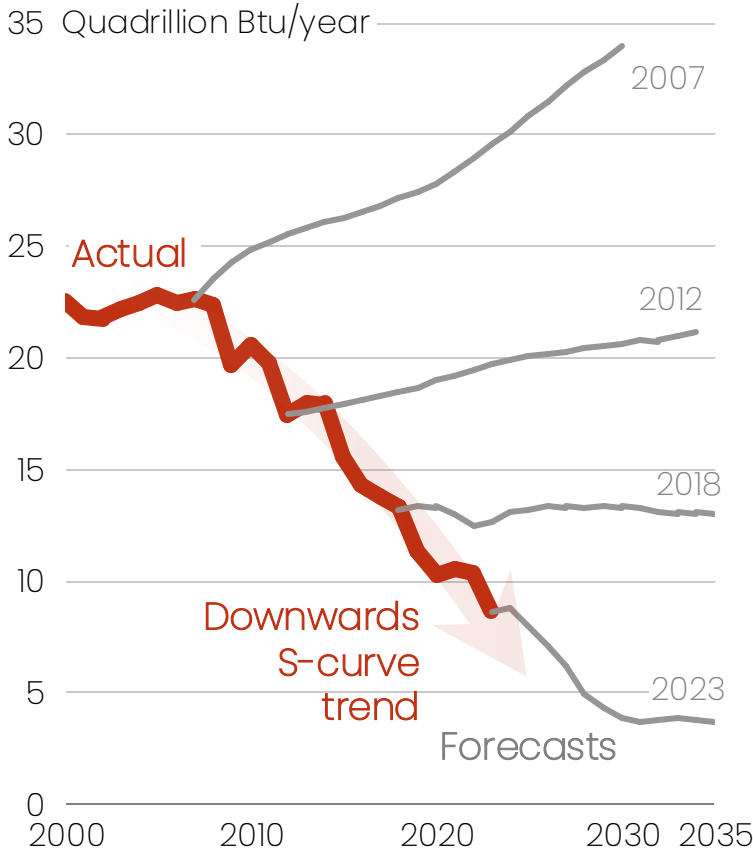
New solar additions



EV share of sales



US coal demand

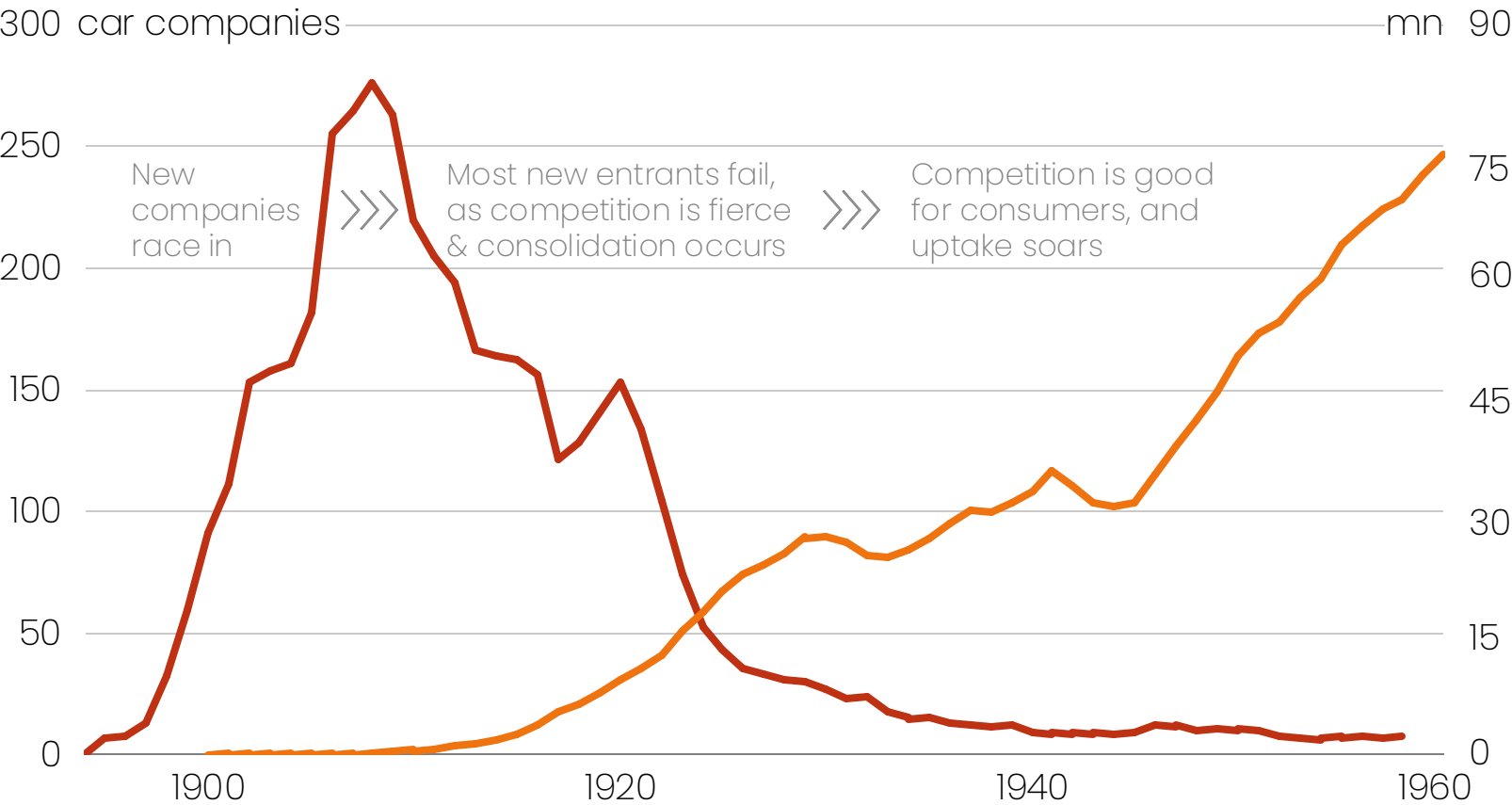


Nobody said it was easy

Investing in technology revolutions is always risky

Car companies in the US

Registered cars in the US



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 advancement at an economy level

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

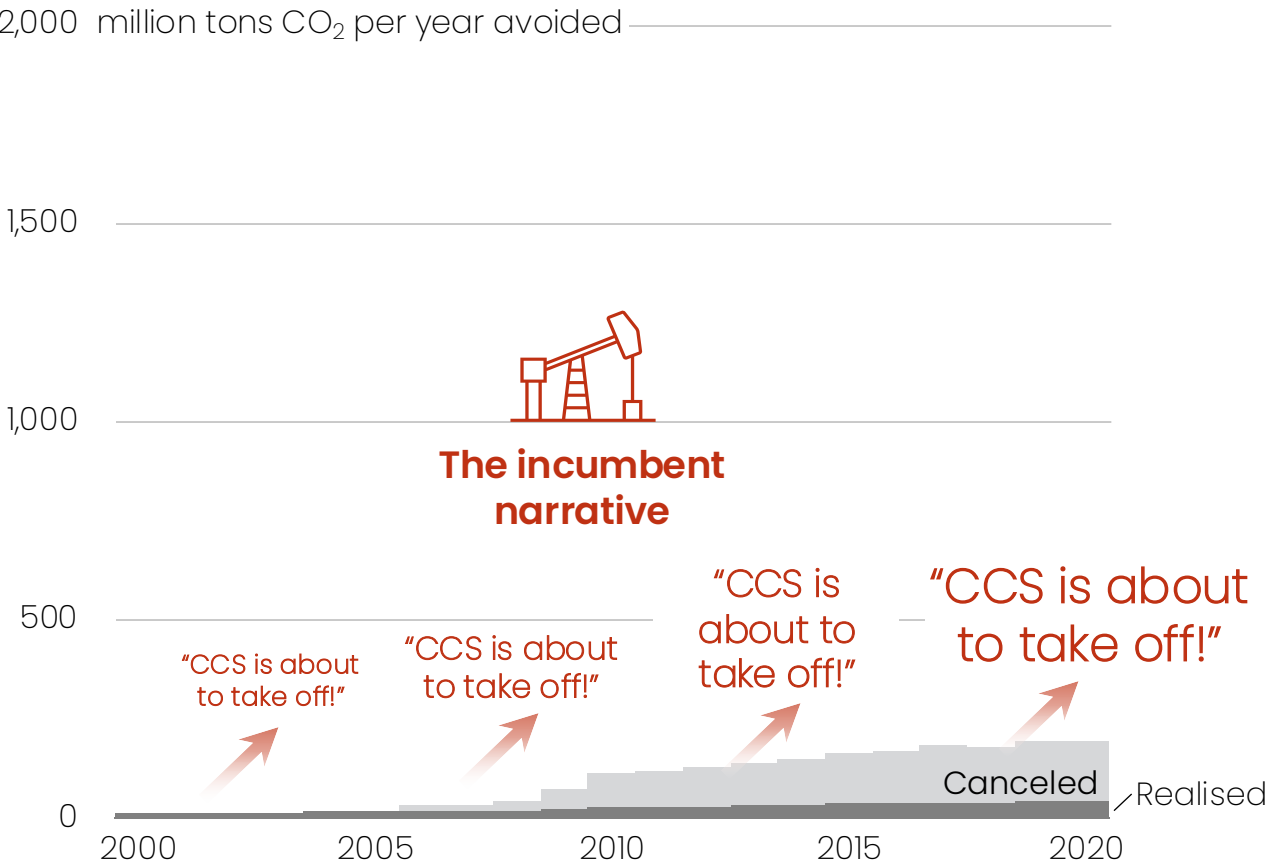
Many popular solutions will struggle in the face of reality

	Physics 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?
CCS	✗ No	✗ No	✗ No
Biofuels	✗ No	✗ No	✗ No unless you are Brazil
Green hydrogen	✗ No	✗ Not really except for the electrolyser	✓ Yes unless imported
Electrotech	✓ Yes	✓ Yes	✓ Yes

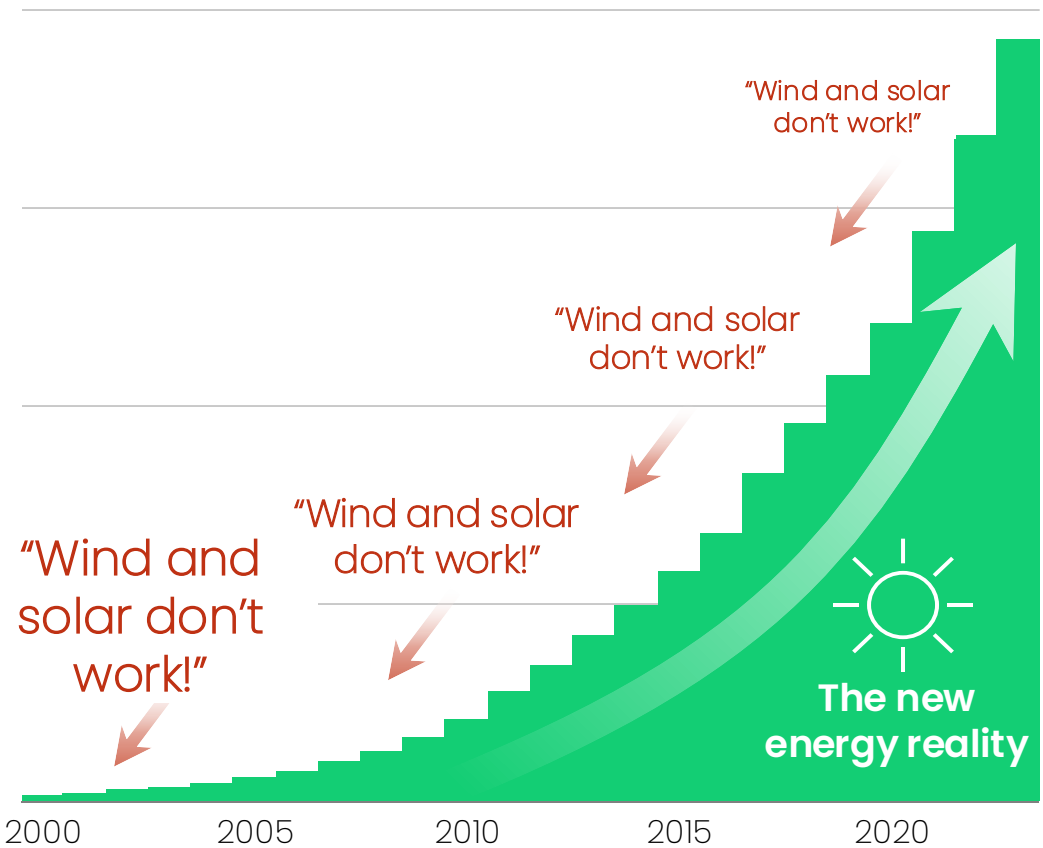
Avoid the distractions

Some cleantech only gets louder; electrotech actually delivers

Global installed CCS capacity



Wind and solar avoided emissions



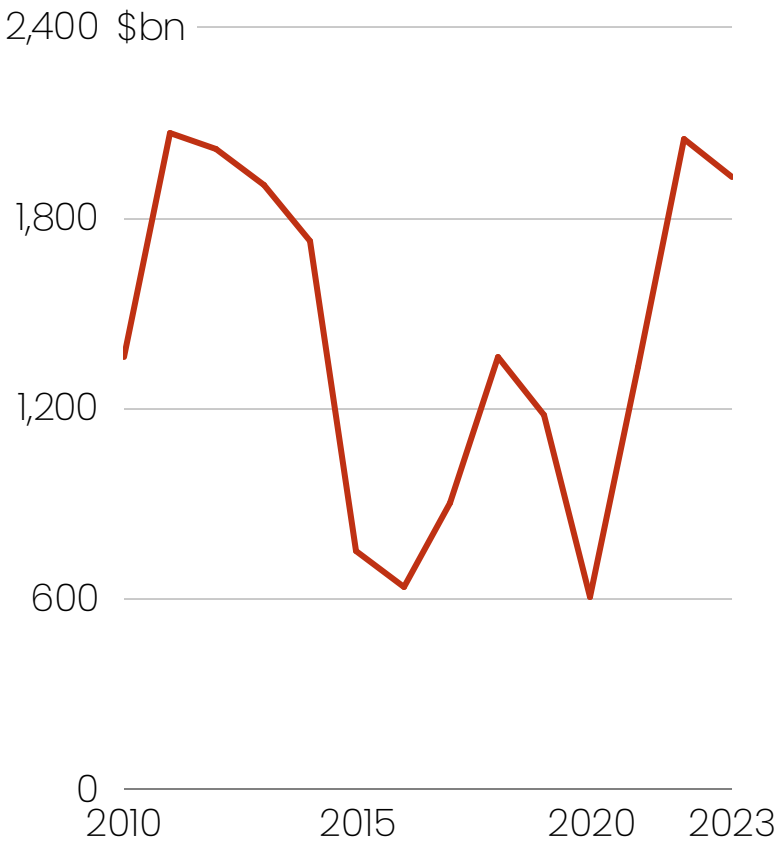


Incumbents resist change because the status quo is so profitable

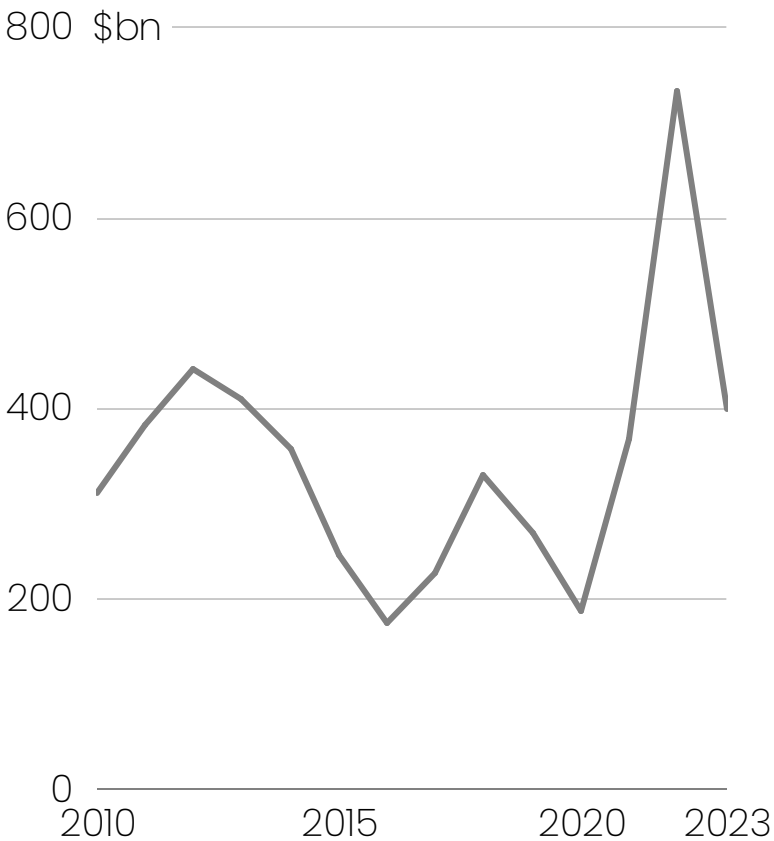
Governments need to decide what is in their country's best long-term interest



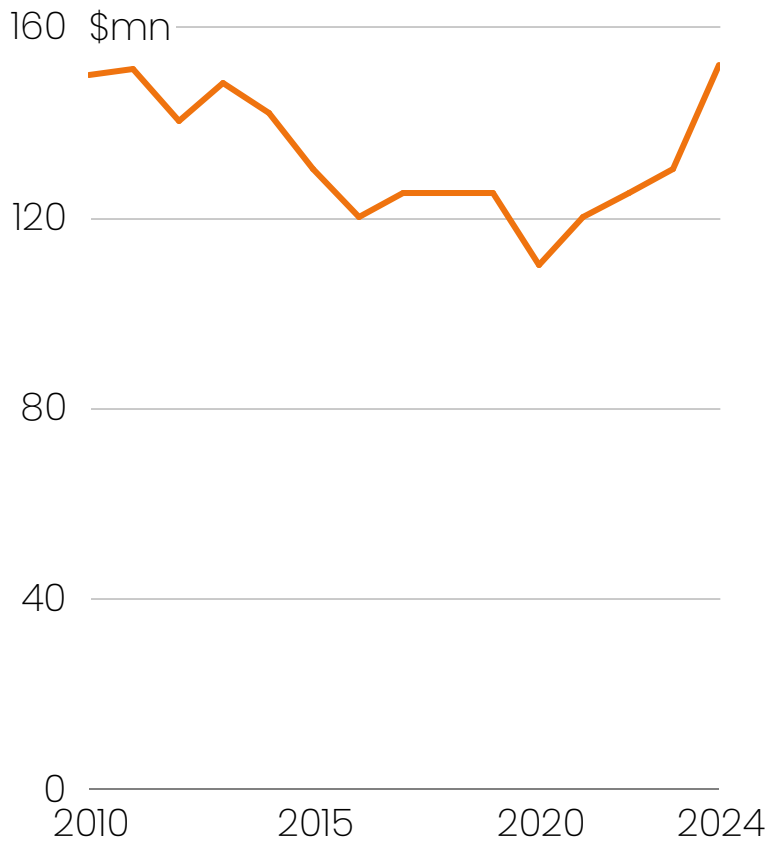
Oil rents



Fossil fuel subsidies



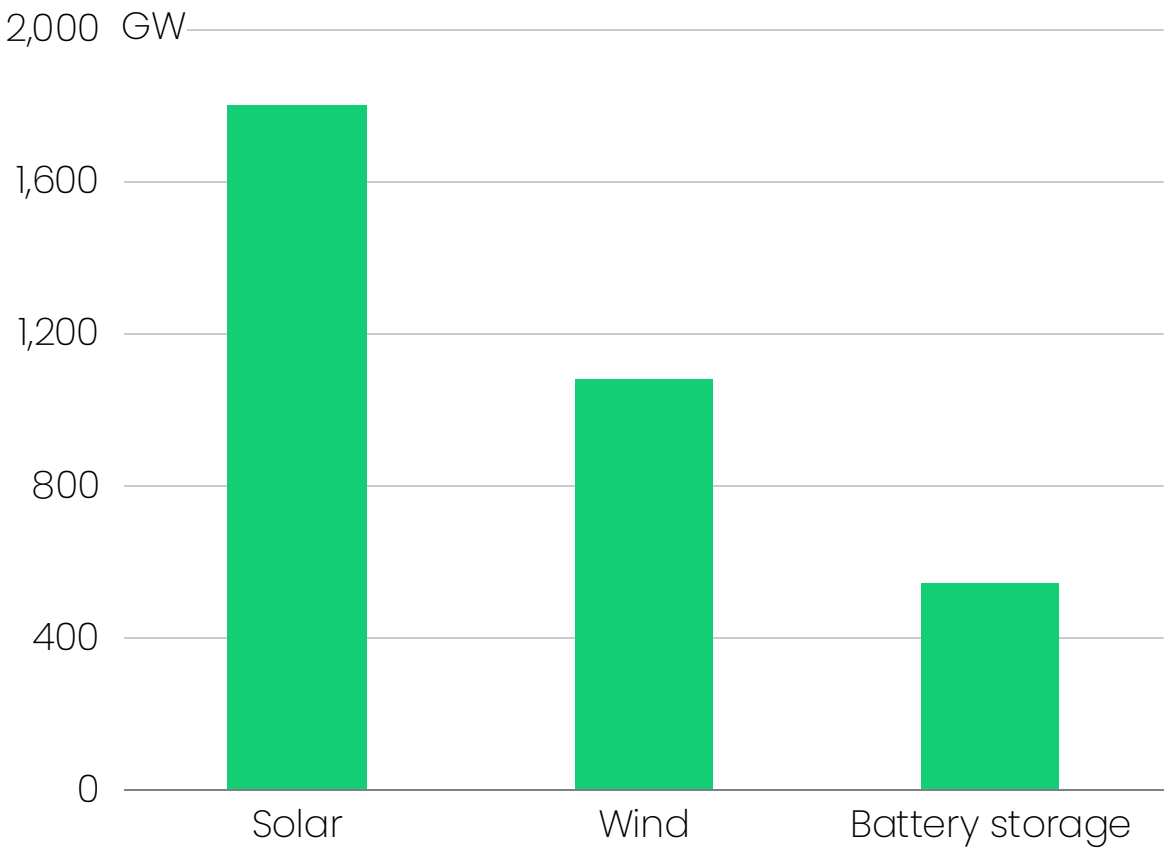
Oil and gas lobbying in the US



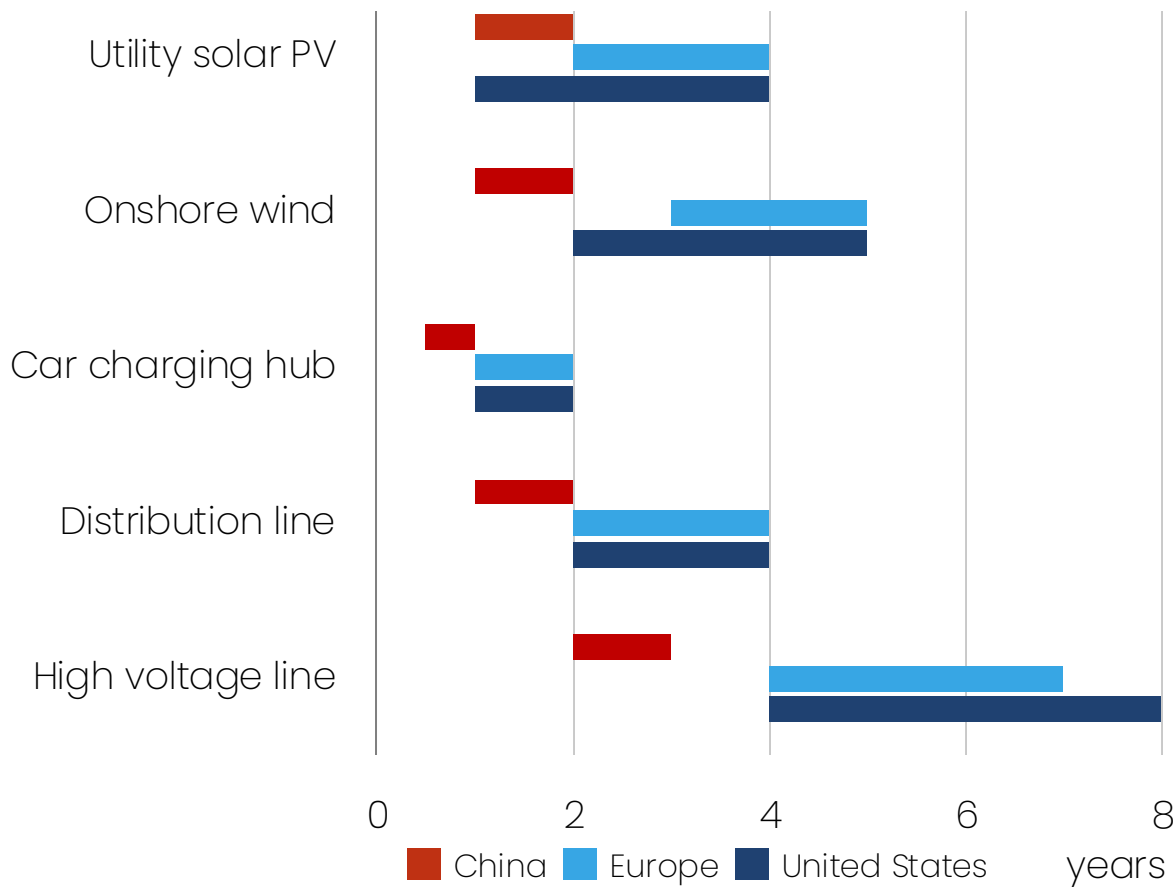
Back the builders not the blockers

Unlock the queues of electrotech that want to come online

Clean energy stuck in the connect queue



Typical deployment time

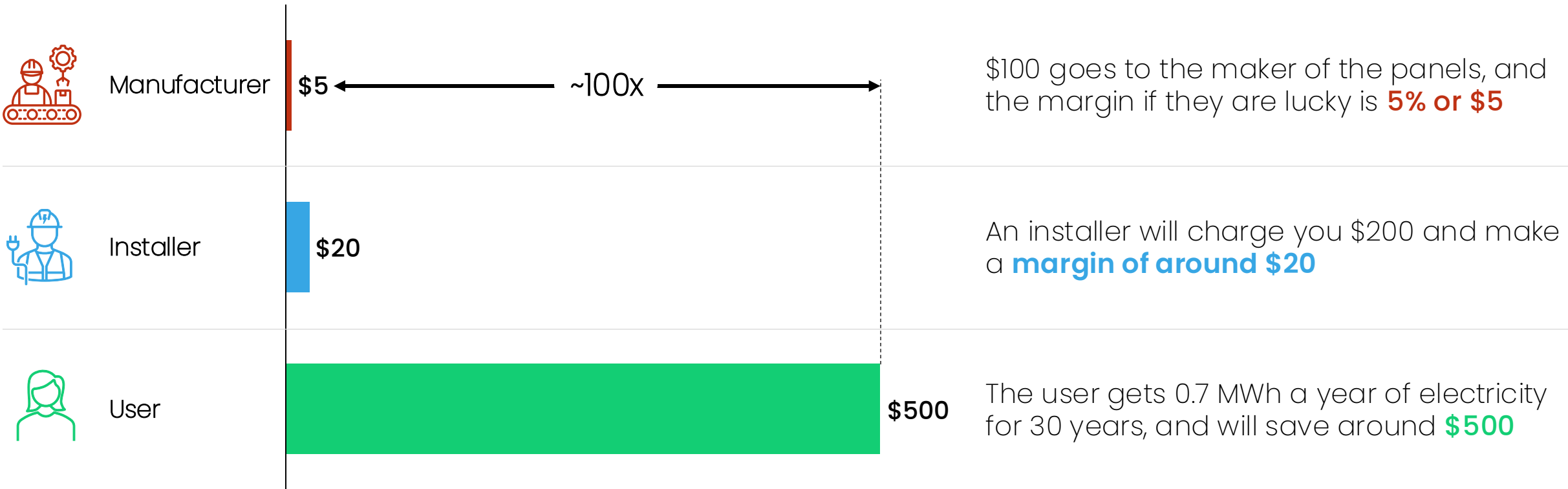


It's not all about manufacturing

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

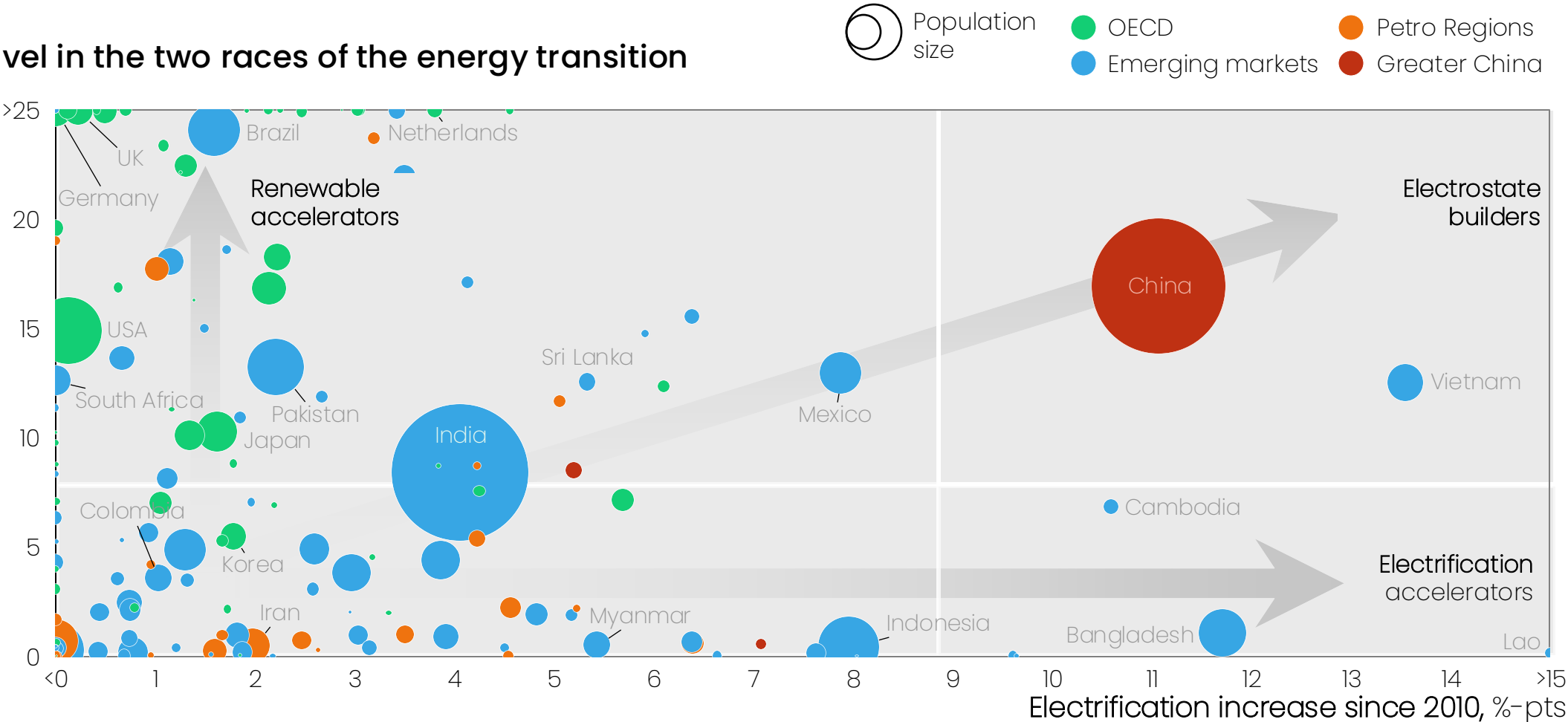


The electrification imperative

Many countries are building renewables; few an electrostate

Direction of travel in the two races of the energy transition

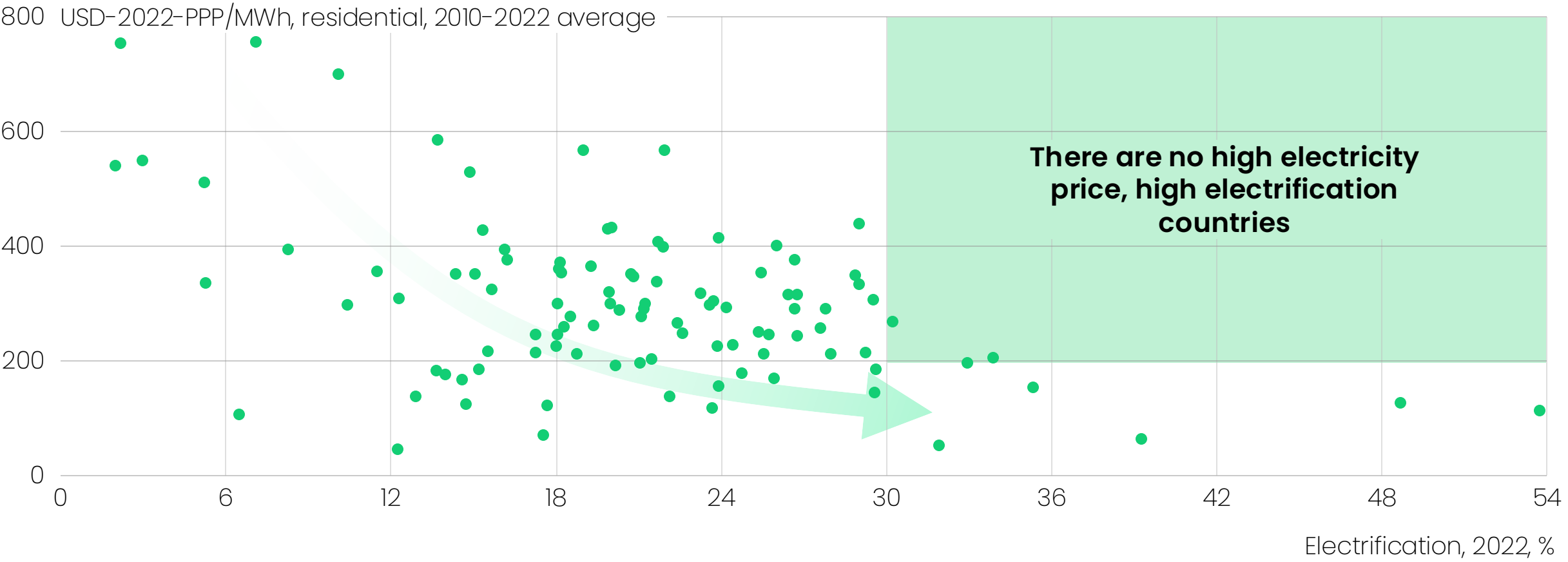
Wind & solar generation share increase since 2010, %-pt



Econ 101

Lower prices incentivise uptake

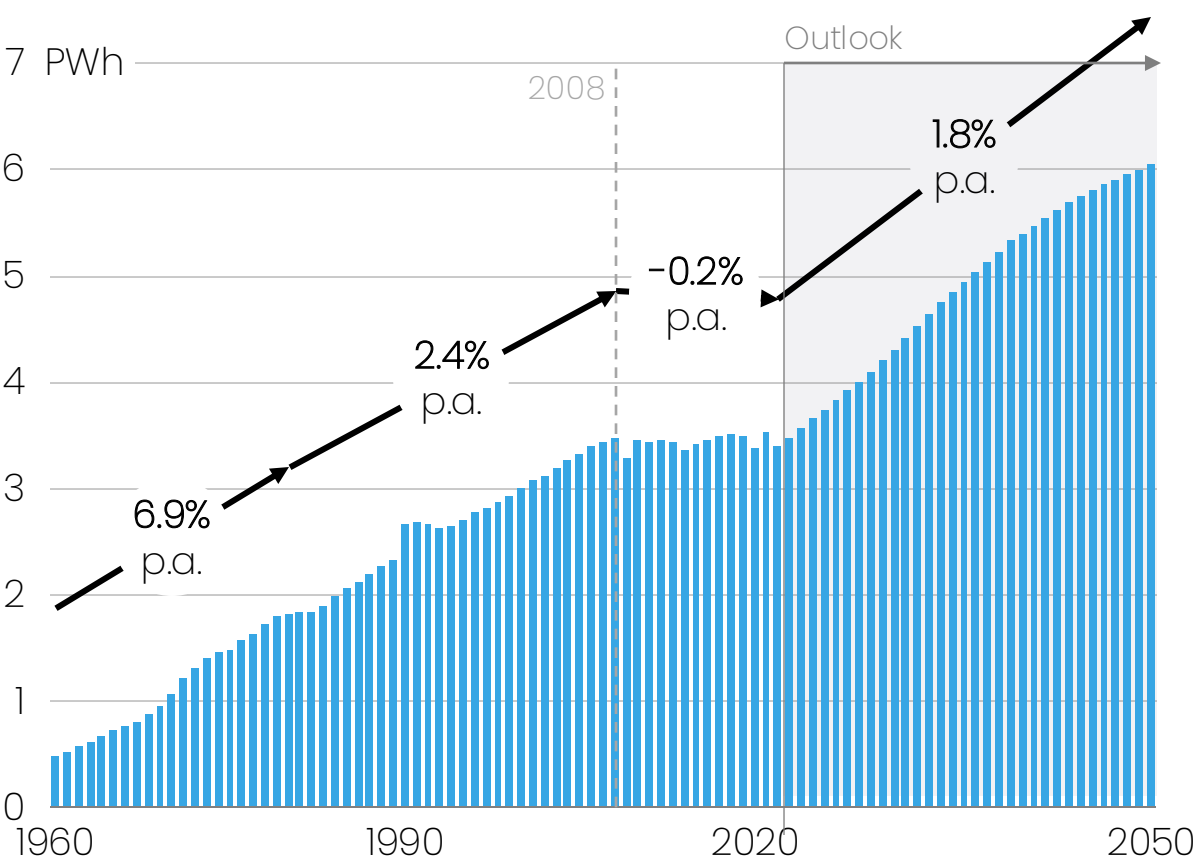
Electricity price



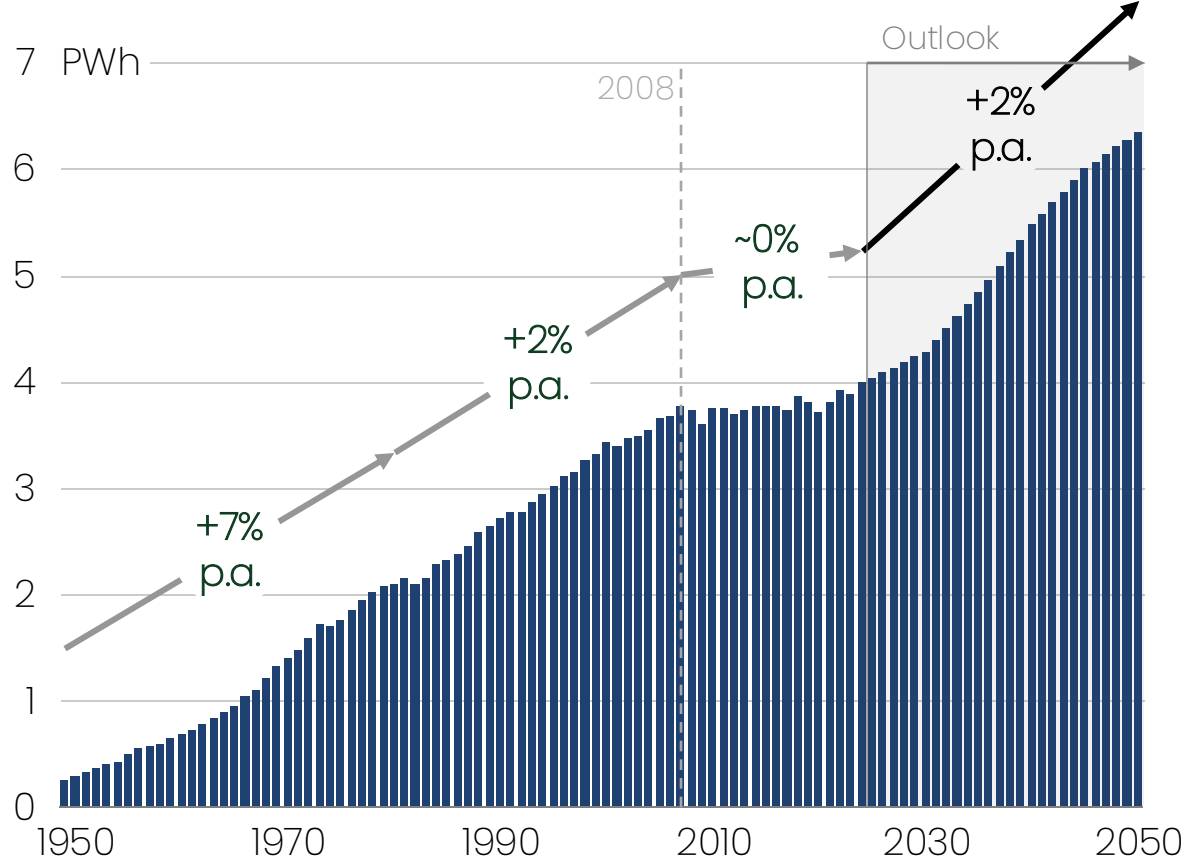
The West can get back on track with electrification

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

Europe electricity demand



US electricity demand



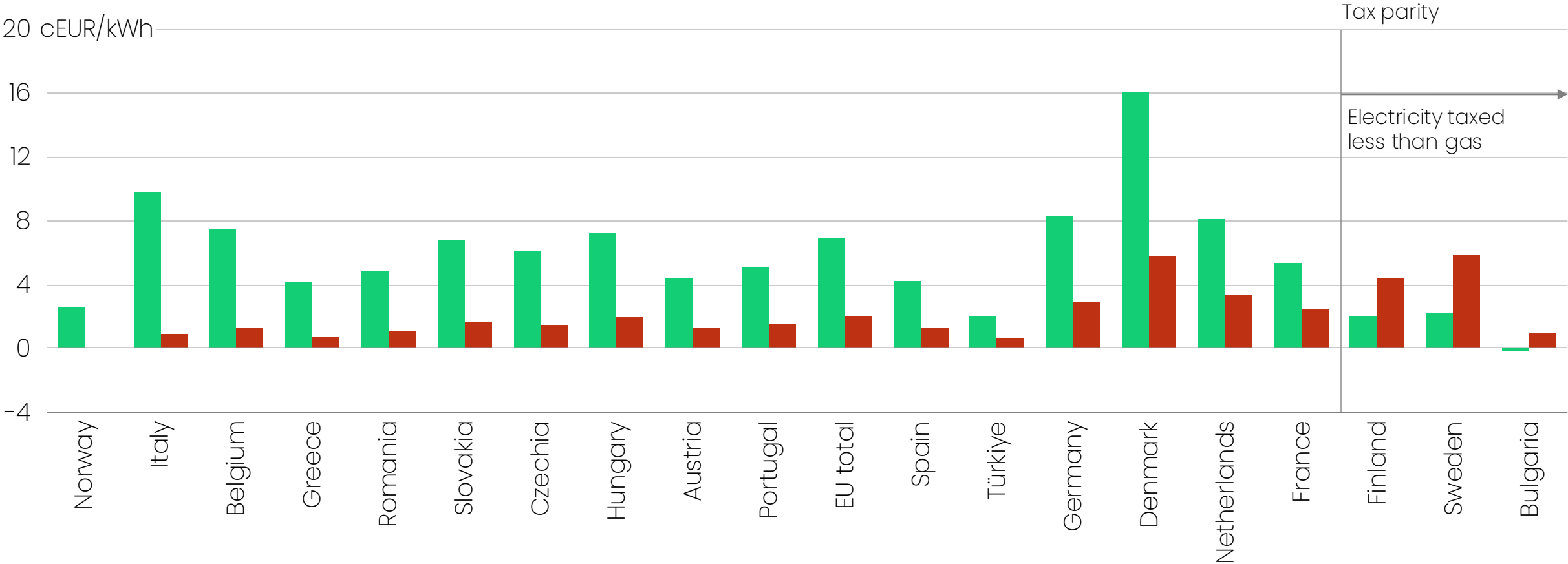


Tax what you want to phase out

High taxes on electricity will only slow down electrification



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



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 

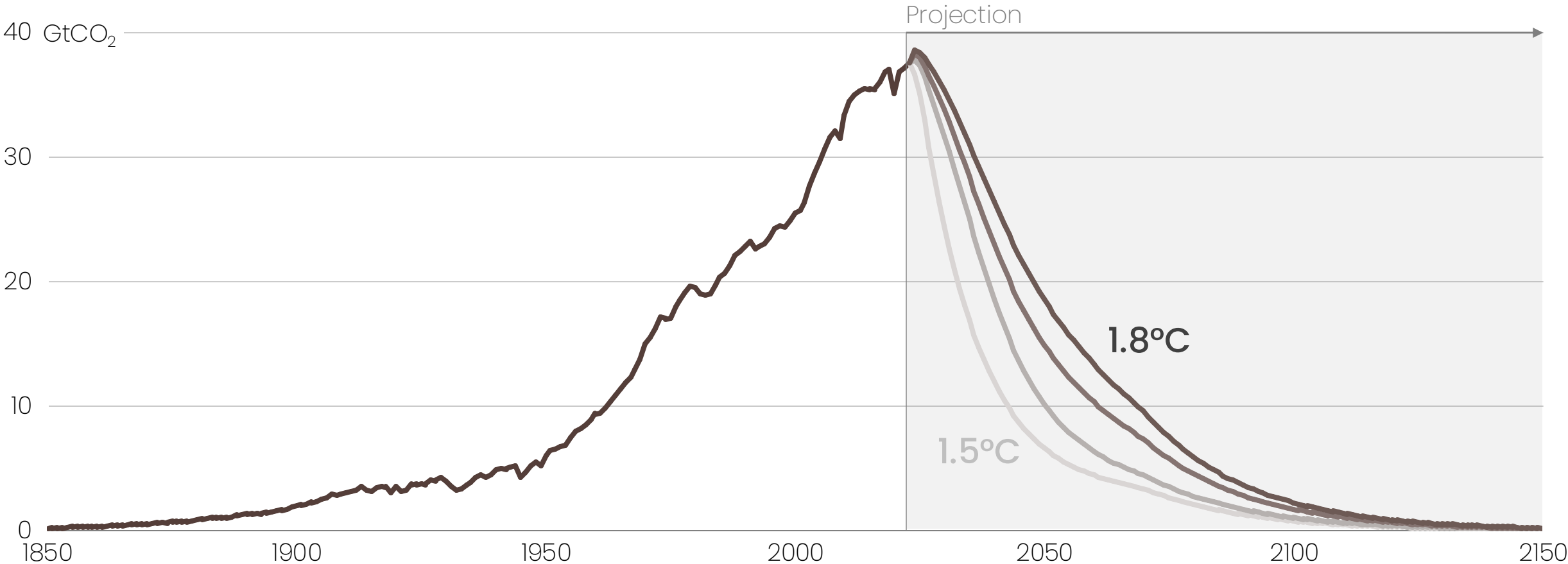


Falling emissions are a consequence of the Electrotech Revolution

The faster electrotech grows, the faster emissions will fall



Global CO₂ emissions from energy



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 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

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.

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