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First build, then break

A policy framework for accelerating zero-carbon transitions

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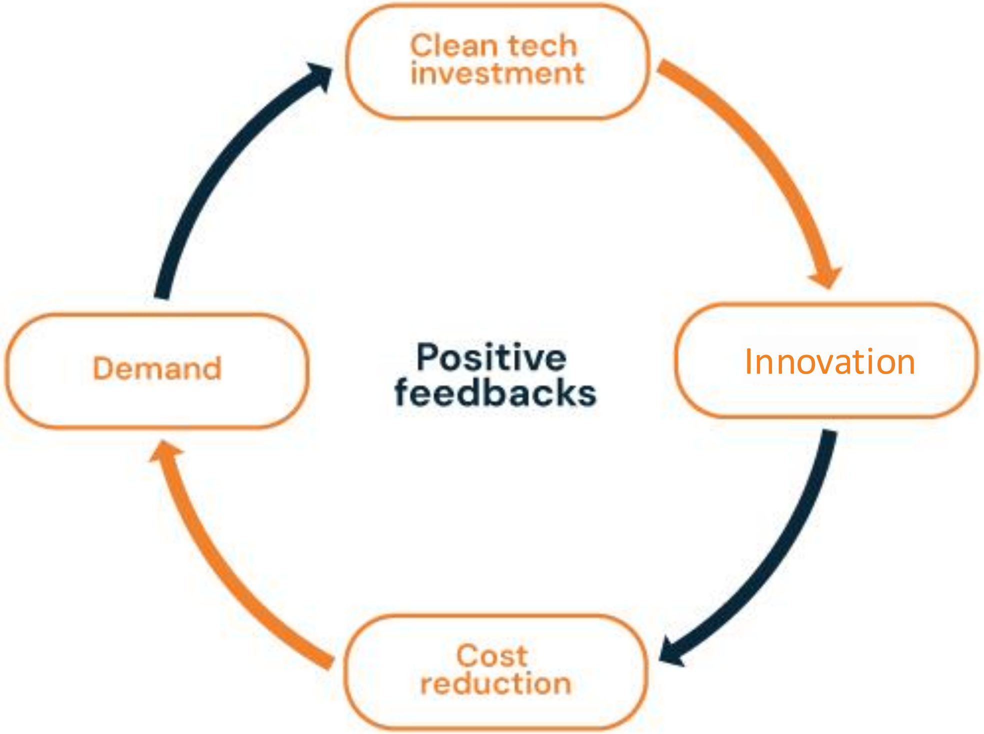
First build the new zero-carbon system, then break the old

People can only stop using an old technology when a new one is available and affordable.

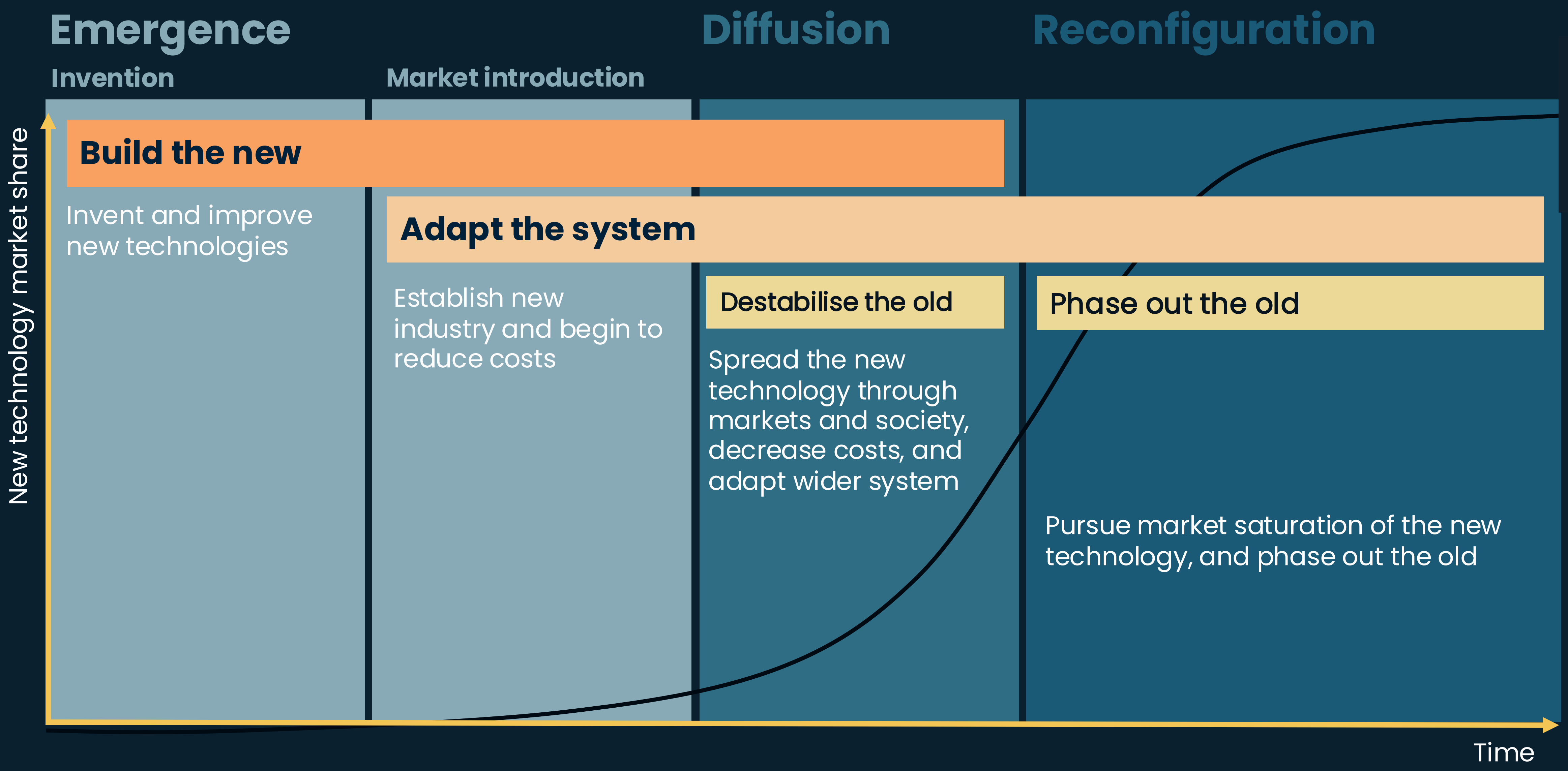
Policy makers must support innovators to invent new solutions, introduce them into the market, and scale them up, before they can phase out old systems. The fossil fuels can't be phased out until there is something ready to replace them.

Nurturing positive feedbacks is at the heart of this process.

Policies that focus on creating and deploying new solutions and systems often benefit from reinforcing feedback effects early in the transition. Positive feedbacks are self-reinforcing dynamics where initial changes—such as technology uptake or investment—make further change faster and easier. It is the disruptive growth of the new that enables the destabilisation and phase out of the old.



Transitions happen in stages, each with a different aim



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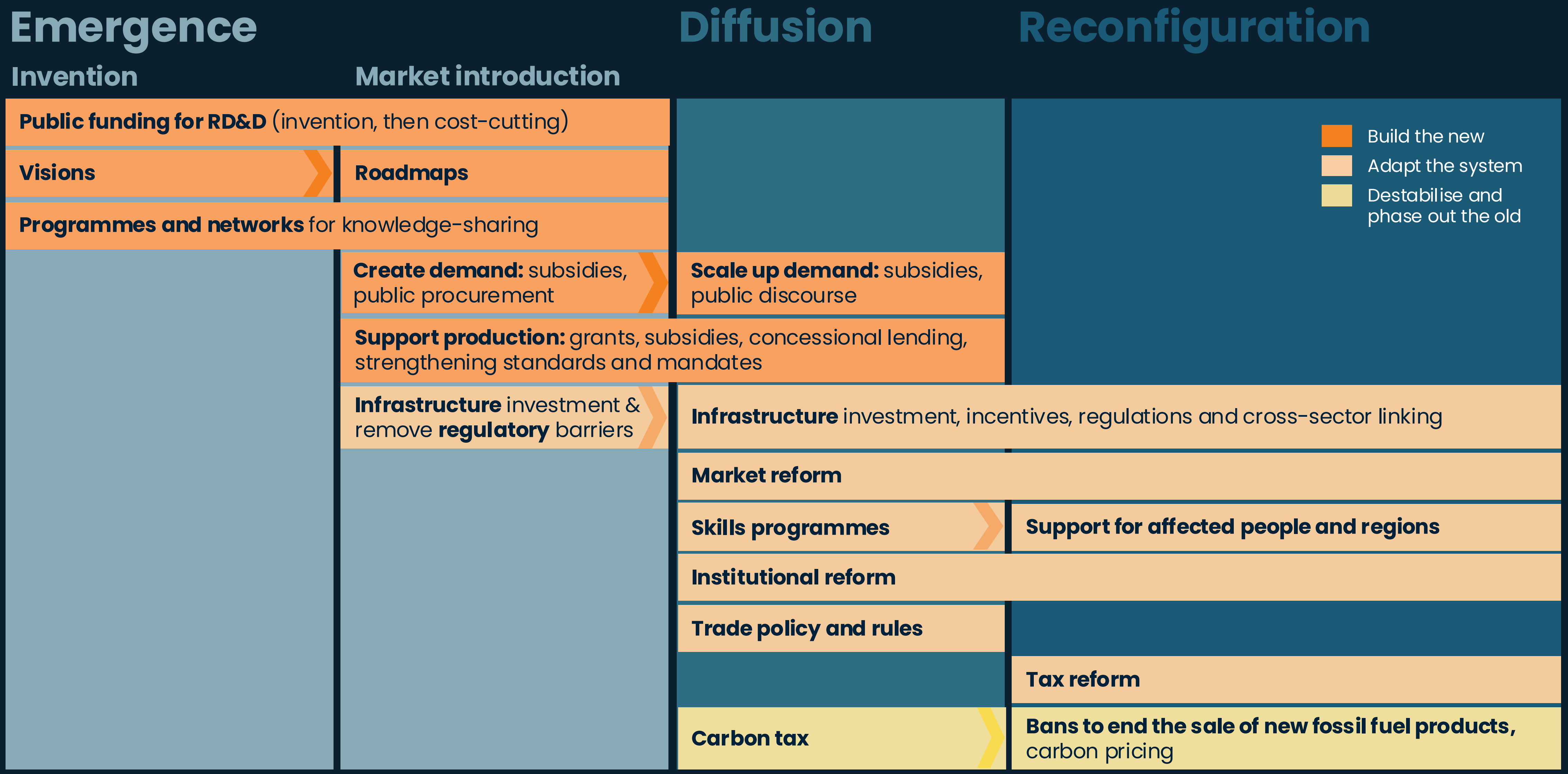
Achieving each aim requires a different set of policies



There are valuable lessons from history and international experience

Technology transitions have occurred many times in the past, and transitions to zero-carbon technologies are happening globally. Below are 18 case studies that illustrate the policy framework.

Emergence: Invention	Emergence: Market introduction	Diffusion	Reconfiguration
1: Turbojet engines*	5: Tram systems*	10: Oil to district heating*	15: Horse-and-cart to automobiles*
2: Biomass district heating*	6: Electric buses	11: Wells to pumped indoor water*	16: Propeller aircraft to jetliners*
3: Offshore wind	7: Wind power	12: Coal to natural gas*	17: Coal phase-out
4: Zero-carbon steel	8: Aviation*	13: Road transport shift to EVs	18: Zero-carbon heating district-by-district
	9: Mixed to specialised wheat farming*	14: Coal phase-out	

* Historical technology transitions, rather than recent zero-carbon ones

Invention

Invent and improve new technologies

End-of-stage boundary: viable designs and technologies have been demonstrated
Indicative market share: 0%

Policy challenges

Inventing viable solutions

High risks and failure rates among innovators.

Technological uncertainty

High uncertainty about which innovations may succeed reduces private investment.

Innovator isolation

Inventors can be isolated from one another and other stakeholders, slowing progress.

Policy solutions

Public funding for RD&D

Stimulates development of many potential solutions

Visions

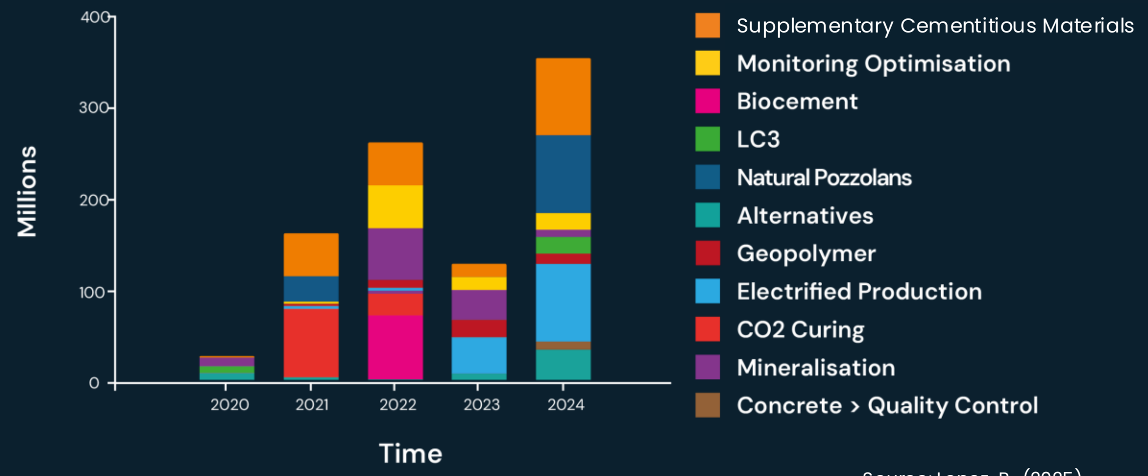
Mobilises actors and resources towards shared goals

Programmes & networks for knowledge-sharing

Reduces isolation between innovators, financiers and policymakers, accelerating progress

Example: cement

Cement and concrete innovation attracted about $370m in 2024 – and innovation is going into a range of solutions

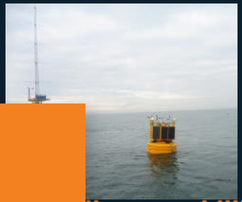


Source: Lopez, B., (2025).

- **Inventing technically viable solutions**: existing innovations are reaching demonstration stage. Industry still seeks new ones given unknowns over future viability.
- **Uncertainty**: given uncertainty over zero-carbon technologies and future revenues, the industry is prioritising material efficiency and CCUS over innovation, leaving relatively low investment in R&D, given the sector's emissions profile.
- **Isolation**: recognising the need for collaboration, the Global Cement and Concrete Association created an entrepreneur network, and North American start-ups formed an alliance to engage the public sector in supporting low-carbon cement procurement.

Invention case studies

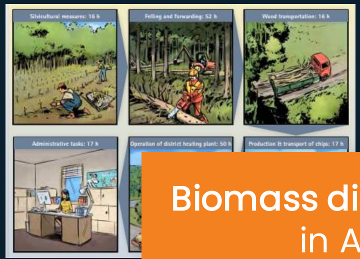
R&D enabled by network-building & knowledge-sharing on UK offshore wind decreased costs by an estimated 15% in 10 years



Offshore wind
in the UK
(2008-present)

Zero-carbon steel
in Sweden
(2016-present)

Clear vision and finance for a joint venture demonstration project kickstarted zero carbon hydrogen DRI steel in Sweden, and globally



Biomass district heating
in Austria
(1970-2013)

Network building and knowledge-sharing reduced operational challenges in biomass district heating, and paved the way for a world-leading pellet boiler export industry

Turbojet engines
in the UK & Germany
(1930 to 1945)

Publicly funded R&D nurtured turbojet engine development, and planes with 8x the thrust compared with early demonstrations

Case Study 1.

Publicly funded R&D led to turbojet engines, and faster planes in the UK and Germany

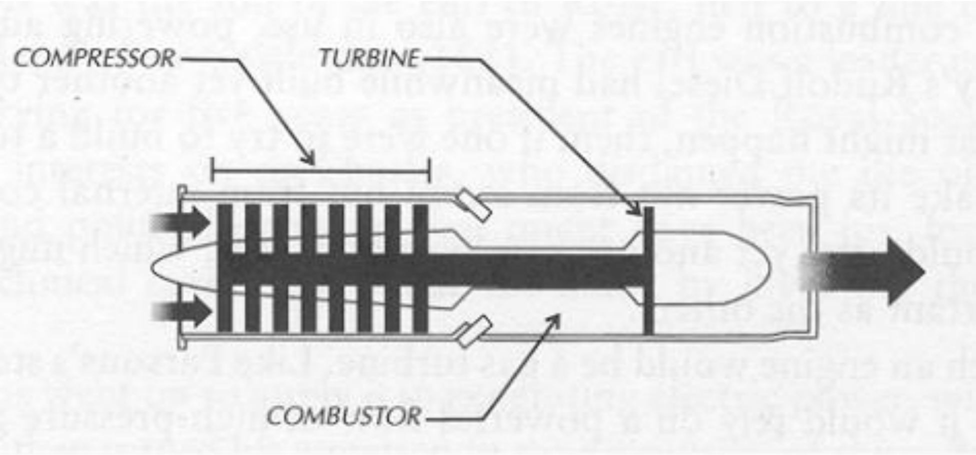
1930 - 1945

- Propeller aircraft had limited speed and altitude, but inventors of the turbojet engine struggled for investment.
- Geopolitical tensions in late 1930s increased military interest and public R&D into aero-engines, and a small public R&D contract was awarded.
- Successful demonstrations increased public and private investment, improving turbojet engine performance.
- By 1945, turbojet powered planes had up to 8 times the thrust compared with early demonstrations.

Turbojet-powered aircraft: the 1942 Me-262 (left), 1944 Gloster Meteor (middle), and 1947 F-86 Sabre (right).
Sources: AsisBiz; Gloster Meteor Centenary of Military Aviation (2014); Wikipedia (n.d.).

Schematic representation of turbojet engine.

The turbojet worked by sucking in air, compressing it, mixing it with fuel, igniting it to create hot expanded gases, then using that force to create thrust.



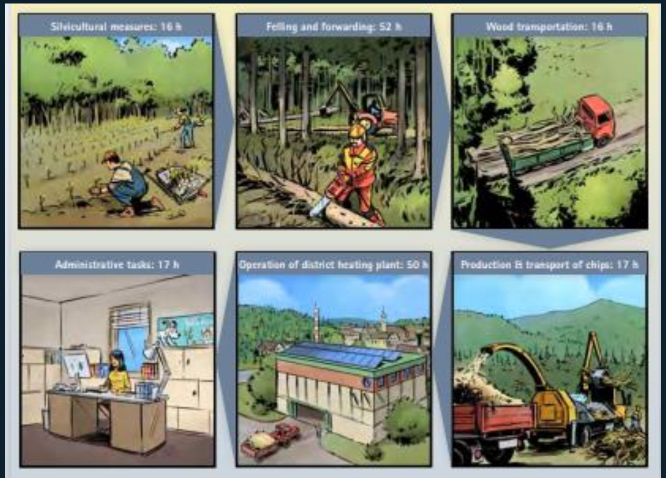
Source: Heppenheimer (1995)

Case Study 2.

Networks and knowledge-sharing reduced operational challenges in biomass district heating in Austria

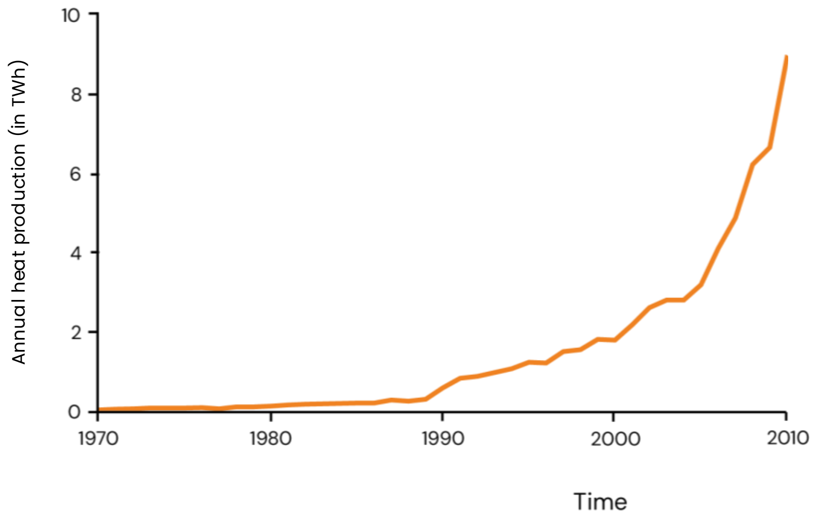
1970 - 2013

- Biomass district heating was pioneered in 1970s by rural workers to monetise surplus wood, but they were isolated and secretive about operational issues.
- Public energy agencies delivered network building and knowledge-sharing in 1980s (connecting component operators and suppliers, delivering workshops and brochures).
- Operational challenges and costs reduced, driving diffusion.
- Over decades, the success of biomass district heating in Austria stimulated complementary innovations, and related clusters and supply chains made Austrian manufacturers world-leading exporters of pellet boilers.



The chain of custody for bioenergy.
Source: Klimaactiv (2020).

Annual heat production from Austrian biomass district heating increased slowly, and then rapidly, between 1970 and 2010



Source: Statistik Austria (2015).

Case Study 3.

Networks and knowledge-sharing on R&D reduced the costs of UK offshore wind

2008 - present

- The UK had good natural conditions and expertise for offshore wind, but it was expensive and untested. In 2001, the UK government created the Carbon Trust as a publicly funded, business-led institution to enable collaborative RD&D, and to facilitate knowledge-sharing.
- In 2008, the Carbon Trust created the Offshore Wind Accelerator, which identified key industry challenges, to focus innovator attention and knowledge-sharing.
- Its 150 joint R&D projects cut the costs of a UK offshore wind project by 15% in 10 years.*
- The Offshore Wind Accelerator has expanded and been replicated internationally in Vietnam and the Philippines.

*Analysis estimated that in 2018, the levelised cost of electricity from an offshore wind plant using technologies commercialised by the program would be 15% lower than that of an equivalent site not using those technologies.

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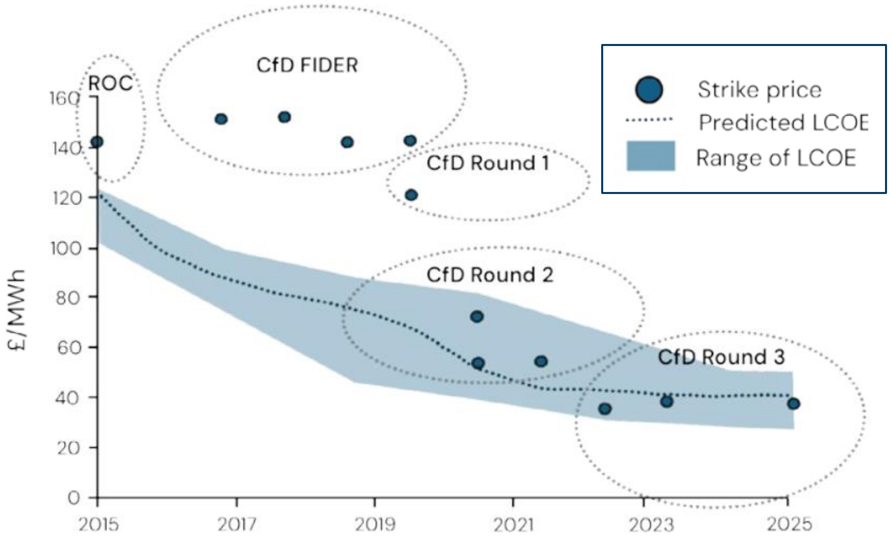
Floating LIDAR trial supported by the OWA. LiDAR is used to measure wind profiles, that are crucial for understanding how much energy a wind turbine at a proposed site could generate. Reliable wind data reduces the risks for investors, and helps projects secure financing. Floating LiDAR was an improvement over LiDAR on fixed platforms, which could not be used in deep waters. Source: ORE Catapult .

The strike price and estimated LCOE of operational offshore wind farms decreased significantly over 2015 -2025



Graph shows estimated LCOE of operational offshore wind farms from Rounds 1 and 2, and predicted average LCOE for Round 3.

Source: Jennings et al. (2020).

Case Study 4.

Vision and finance for demonstration project kickstarted zero-carbon steel in Sweden

2015 - present

- Sweden is a leader in deploying zero-carbon steel production, using using H2-DRI-EAF (Hydrogen direct reduced iron, with electric arc furnace). It had a history of steel innovation, and abundant, low-cost renewable energy.
- Policies underpinning the 2016 joint venture, HYBRIT, included: government commitment to full steel decarbonisation and priority setting, negotiation and technical support, streamlining permitting; grants ($60m for plant construction); and state-ownership (two of three key HYBRIT actors). The Swedish Energy Agency and EU respectively provided additional grants totalling $450m for construction of a subsequent full-sized production facility.
- The first demonstration plant began producing H2-DRI-EAF steel in 2021. A second is under construction.
- Germany, France, the Netherlands, Austria and Spain followed with state support for demonstration and commercial projects.

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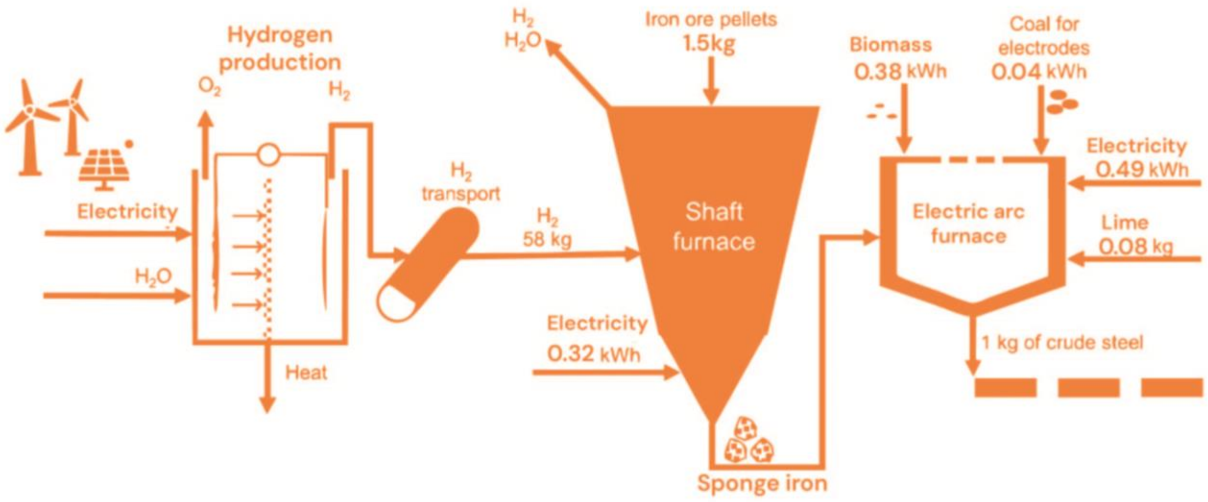
Plans for a fossil-free mini-mill in Luleå, Sweden. It will be supplied with a mix of fossil free sponge iron from the HYBRIT demonstration plant in Gällivare, and recycled scrap. Source: SSAB (2024).

A summary of H2-DRI-EAF steel production

The DRI furnace heats syngas and reacts it with iron ore pellets. DRI reactors produce 'sponge' iron (iron produced from ore, without being melted), which, like scrap, becomes molten steel in an EAF.



Source: SSAB (2024)

Market introduction

Establish the new industry and begin to reduce costs

End-of-stage boundary: market demand from early adopters
Indicative market share: 0-5%

Policy challenges

High costs, low performance

New tech costs more, underperform compared with old, and potential to outcompete is unclear.

Lack of investment

Kickstarting investment is undermined by high financing costs and uncertain demand.

System barriers

Infrastructure or regulatory change is sometimes needed for first deployment.

Policy solutions

Create demand: purchase subsidies, public procurement

Increases affordability and attractiveness to consumers.

Support production: grants, subsidies, concessional lending, mandates

Decreases upfront costs and risks, improving commercial viability. Mandates force reallocation of investment.

System adaptation: infrastructure investment, removal of regulatory barriers

These can help enable first deployment.

Example: heavy road transport

Consensus is emerging that battery-electric trucks are the most likely technology to decarbonise heavy road freight. Across the world, the sector is now in or entering Market Introduction, and faces the relevant challenges.

- **High costs and low performance**: despite rapidly falling costs, high purchase price and performance challenges, such as lower payload, remain barriers to demand.
- **Lack of investment**: truck manufacturers are increasing investment into EV technology but not at the same scale as car manufacturers. Causes include demand uncertainty given limited incentives, and customer risks including uncertainty on resale values.
- **System barriers**: investors in charging infrastructure face uncertain demand; regulatory limits on gross vehicle weights disadvantage e-trucks given extra weight of batteries.

Policies such as stable regulatory timelines for the transition, purchase subsidies and infrastructure investment, public procurement, and regulatory changes to allow higher weight limits may support progress.

Market introduction case studies

Specialised wheat farming
In the UK
(1930-1970)

Guaranteed wheat prices, capital grants and cheap loans for new machinery, and knowledge-sharing schemes, together drove rapid tractor and machinery uptake and higher wheat yields

Tram systems
in France
(1970-2000)

Public procurement, financing and technical support developed tram systems in 15 cities, and car use peaked

Aviation
in the US and Europe
(1890-1930)

Subsidies for airmail services, and safety rules and regulation, created passenger market niche and commercial aviation by 1930s

Wind power
in Uruguay
(2005-2016)

Reverse auctions for large-scale capacity, and feed-in tariffs for small-scale capacity, led to the fastest growing wind share globally between 2014 and 2016

E-buses
in India
(2015-2024)

Cities, supported by a specially created public agency, aggregated procurement contracts to decrease the cost of e-buses

Case Study 5

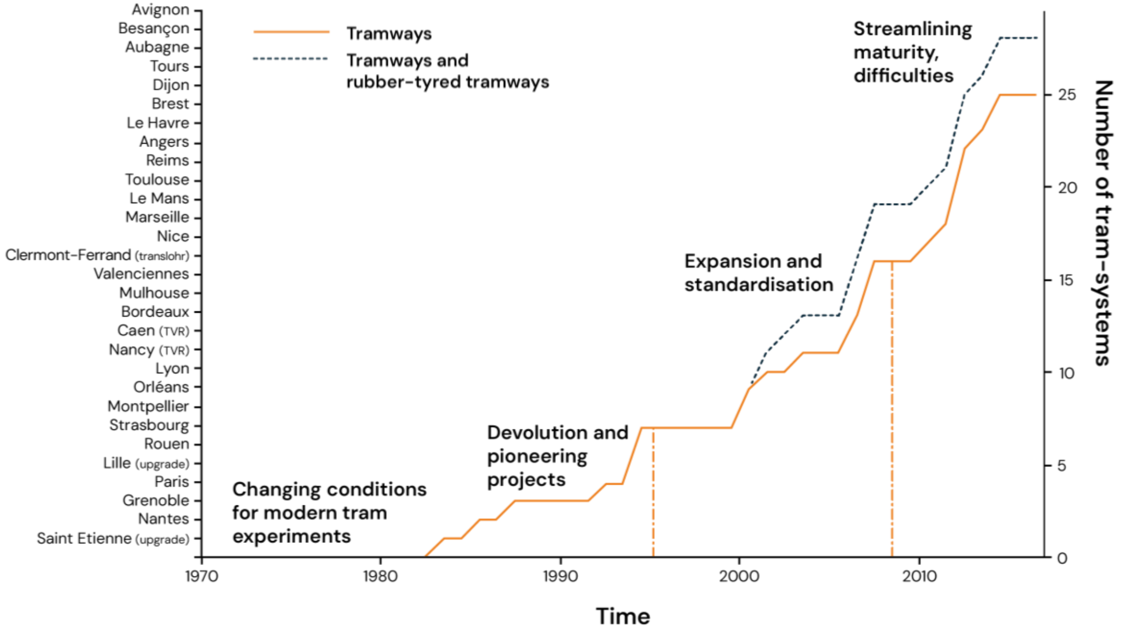
Public procurement increased the number of French tram systems, and car use peaked

1970 - 2000

- Urban congestion, accidents and the success of high-speed rail in France motivated policymakers to commission new trams.
- The first new trams were paid for by increased employment tax for transport, and central funding for 15-40% capital costs.
- Funding schemes were complemented by supply-push measures, including codifying technical knowledge and the provision of advisory support.
- Early successes were replicated, with new tram systems established in 15 of 19 major French cities.
- From the late 1990s, the use of trams increased and the use of cars decreased. Trams were associated with quality of life, access, sustainability and urban renewal.


Grenoble light-rail system. Source: Boussard (2010).

Modern tramways diffused across many French cities



Source: Turnheim & Geels (2019).

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Case Study 6

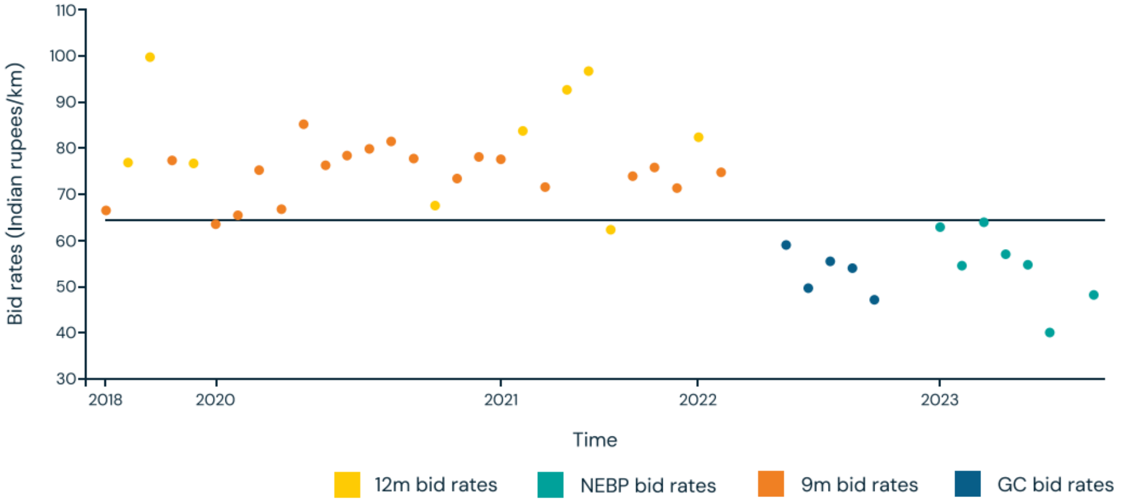
Cities aggregated procurement contracts to decrease the cost of electric buses in India

2015 - 2024

- Policy drivers included air pollution, the high costs of oil imports and insufficient public transport.
- From 2019 to 2022, a specially created public agency aggregated demand for e-buses from different cities, to reduce costs through economies of scale and greater bargaining power.
- A bulk procurement bid in 2021 aggregated demand from 5 cities. The cost of purchasing and operating these e-buses was 23-27% lower than a diesel or CNG equivalent.
- Success inspired a more ambitious e-bus procurement programme, and there were >10,000 buses on the road by November 2024.

BYD Electric bus, Hyderabad. Source: Wikipedia.

Cities achieved lower bid rates when they aggregated demand into larger tenders, compared with tendering alone



The graph compares individual city tenders (9m and 12m long buses) with aggregated tenders, 2018–2023. Grand Challenge (GC) and the National Electric Bus Programme (NEPB) were aggregated procurement efforts. Their bid rates were lower than the earlier individual city tenders.

Source: Dubedi (2024)

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Case Study 7.

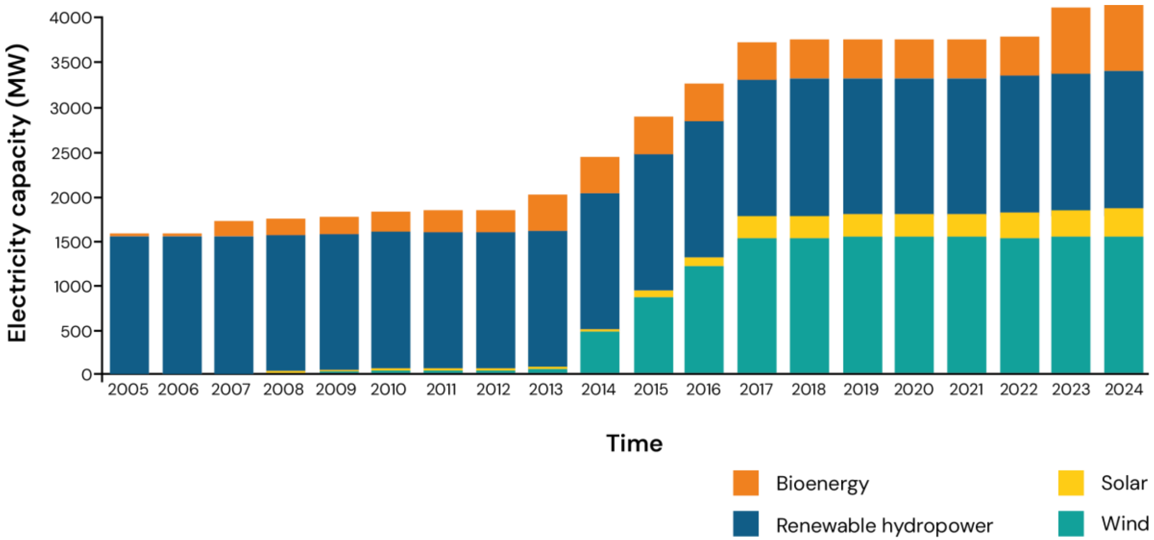
Auctions and feed-in-tariffs in Uruguay enabled successful electricity diversification into wind power

2005 - 2016

- Repeated drought in early 2000s decreased energy from hydropower, increased energy imports, and motivated energy diversification.
- Initial reform efforts were unsuccessful given country risk profile and high financing costs.
- From 2005, policymakers introduced reverse auctions for large-scale capacity. In 2012, feed-in tariffs for small-scale wind power were also introduced.
- Uruguay had the fastest growing wind share of all countries globally between 2014 and 2016. Measures improved power system stability and the country increased export revenues.
- Contracts awarding further wind deployment plateaued after 2016, likely given a lack of further policy support.


Wind farms in Northern Uruguay. Source: Wikipedia.

Cumulative renewable power capacity in Uruguay increased with the introduction of reverse auctions, before plateauing



Source: IRENA (2025).

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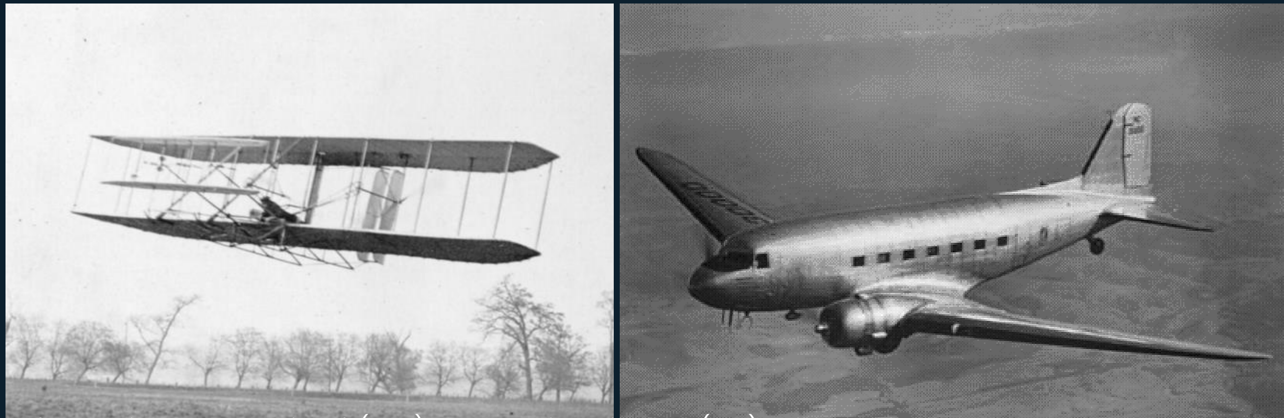
Case Study 8.

Grants and subsidies for American and European aviation created a viable market niche

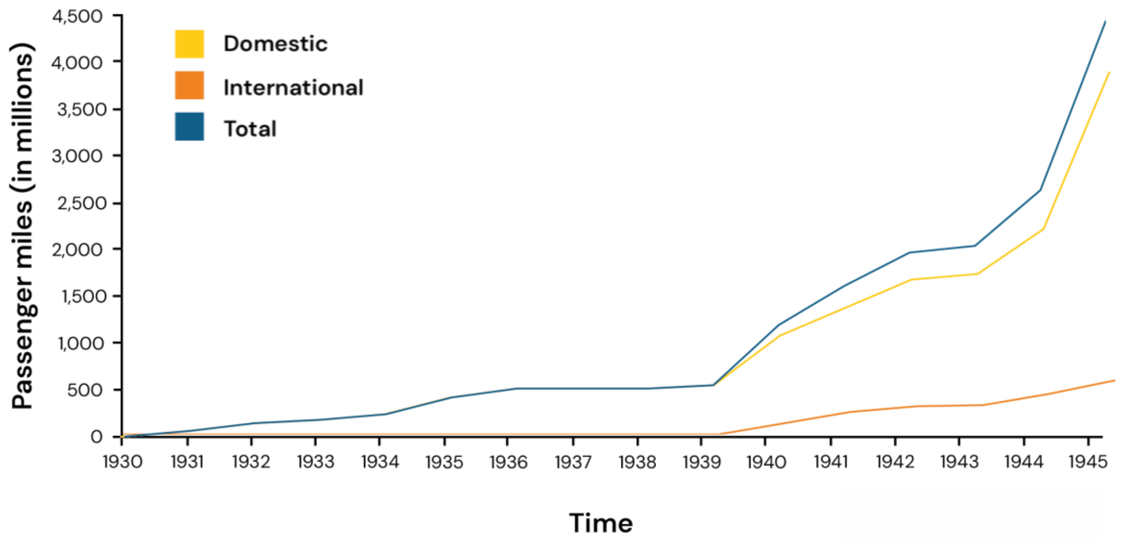
1890 - 1930

- After the second world war, airline companies failed to create a successful market niche for civil aviation.
- Policymakers subsidised flights for postal services (at the time, less than 40% of Americans had telephone connections).
- The 1926 Air Commerce Act introduced safety rules and regulations.
- By 1930s, a passenger transport niche emerged for business people and politicians. It spurred manufacturer investment and innovations.
- These innovations came together in the DC-3, which became the main design for commercial aviation. Commercial aviation expanded significantly in the late 1930s and 1940s.



Left: the Wright brothers' aircraft (1903). Source: Wright Airplanes (n.d.).
Right: the Douglas DC-3 aircraft. Source: The Aviation History Online Museum (2014).

American civil aviation expanded significantly
In the 1930s and 1940s



Constructed with data from American Air Transport Association.

Case Study 9.

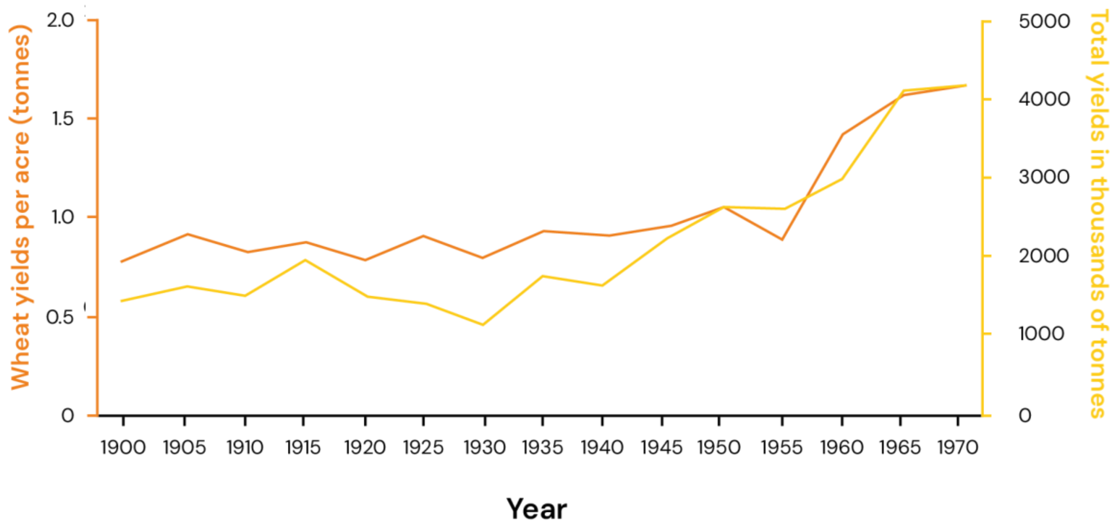
Production support accelerated UK transition to specialised farming, increasing yield and decreasing prices

1930 - 1970

- Food insecurity became a top priority during World War 2, particularly as German U-boats disrupted wheat imports. Policymakers sought a rapid shift to modern wheat agriculture practices, including the use of machinery, larger plot sizes and reduced labour.
- Policymakers introduced wide-ranging measures including:
  - Guaranteed wheat prices which provided stable, attractive income for farmers
  - Capital grants and cheap loans for new machinery such as tractors
  - Knowledge-sharing schemes including visits to demonstration farms.
- These drove rapid diffusion of modern practices, increased land under cultivation, and accelerated the transition to mass-production systems, increasing wheat yields per acre, and total wheat yields.

Trainees at the Oxford Institute of Agricultural Engineering, 6th August 1940. *Source: William Vanderson/Fox Photos/Getty Images.*

Wheat yields increased rapidly starting in the 1940s, as policymakers supported specialised farming



Constructed using data from Mitchell (2011).

Diffusion

Spread the new technology through markets and society, decrease costs, and adapt the wider system

End-of-stage boundary: critical thresholds for rapid uptake are crossed, and majority of new sales are zero-carbon.
Indicative market share: 5-50%.

Policy challenges

Cost reduction

Needed for widespread diffusion as governments are unlikely to subsidise at scale

Reallocating industry investment

Vast investments are needed to scale up new system, and likely exceed what governments can manage

System adaptation

Existing infrastructure, market structures, regulations, norms and business practices were built for the incumbent technologies

Competitiveness challenges

In trade-exposed sectors, competitiveness risks can prevent transition (when new technology is costlier than old)

Resistance from incumbents

Incumbent firms can oppose the transition politically and commercially.

Policy solutions

Scale up demand: subsidies and public discourse

Deployment subsidies, and public communications campaigns can accelerate uptake (and can be funded by taxing old technologies)

Scale up supply and reallocate investment: mandates, regulations

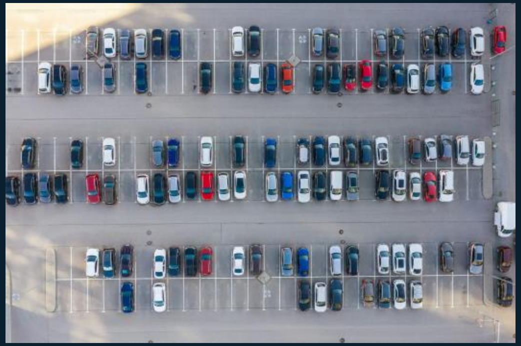
Mandates requiring increasing % sales or production of zero carbon technologies force reallocation of investment.

System adaptation: infrastructure, markets, skills, institutions, trade

Infrastructure investment, incentives and cross-sector linking; market reforms; skills programmes; institutional reforms and trade policy all adapt system to new technologies.

Example: light road transport

EVs are now competing on price and performance with incumbents in the mass market, even without subsidies in leading countries.

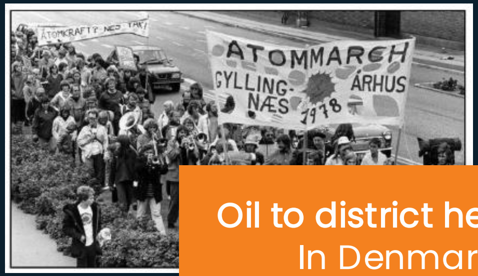


- **Cost reduction**: EV purchase prices remain significantly higher than petrol or diesel equivalents in most markets, making them less affordable despite lower operating and lifetime costs.
- **Reallocating industry investment**: although car companies are increasing investment into EV technology, models and manufacturing, many continue to introduce new petrol and diesel models into the market, and some have slowed timelines for investment and targets for EV roll-out.
- **System adaptation**: charging infrastructure and electricity grid upgrades remain a barrier to uptake in many countries.
- **Competitiveness challenges**: China's leadership in EV manufacturing presents a trade-off for many governments – to import low-cost Chinese vehicles, or protect domestic industry and accept the higher costs and slower pace of transition.
- **Resistance from incumbents**: incumbent car companies continue to spend heavily on political lobbying against policies promoting EVs, at the same time as re-orienting towards EVs.

Diffusion case studies

Cities supported public health initiatives and provided subsidies, to support the expansion of modern water works

Wells to pumped indoor water
In the Netherlands
(1870-1945)



Oil to district heating
In Denmark
(1950-1980)

Clean technology mandates, portfolio standards, energy taxes and financial support accelerated the shift from oil to district heating

Natural gas heating
in the Netherlands
(1960-1980)

Dutch policymakers drove uptake of natural gas for heating through the construction of a national gas transmission network, new institutions, a public campaign and compensation to those affected

Coal phase-out
In the UK
(2000s to present)

A small carbon floor price in the UK made coal more expensive than gas, coal generators were pushed out of the market, and coal phase-out accelerated

EV uptake
in China
(2000s to present)

Subsidies, infrastructure investment and dual credit regulation (a hybrid between a zero-emission vehicle mandate and efficiency regulation) accelerated EV uptake

Case Study 10.

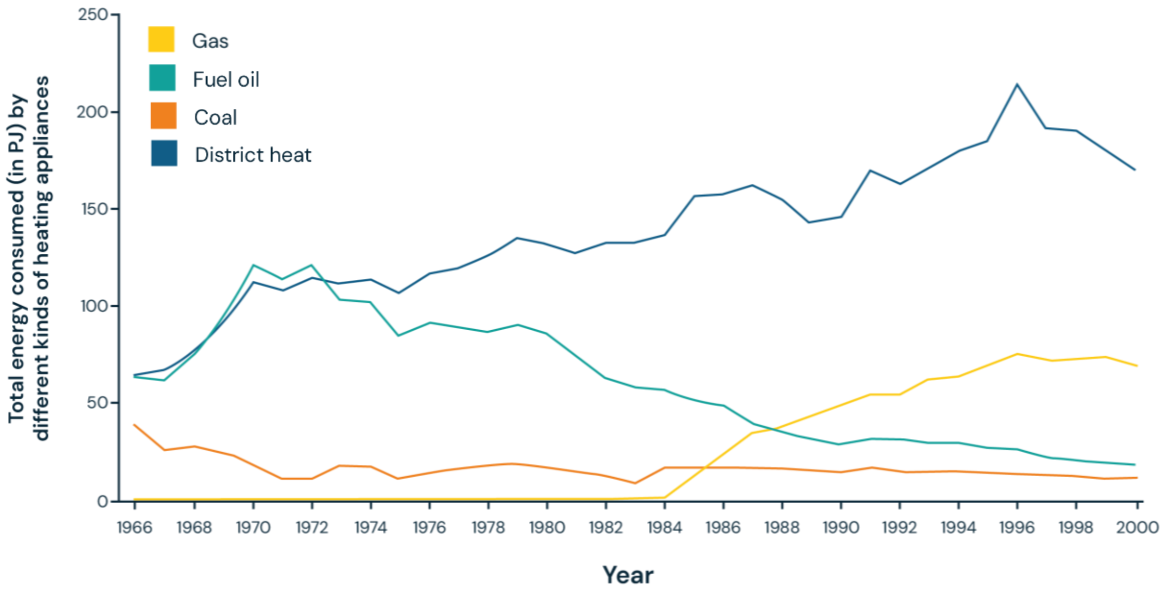
Clean technology mandates and portfolio standards accelerated the shift from oil to district heating in Denmark

1950 - 1980

- Denmark imported 99% of its primary energy during the 1973 oil crisis, leading to urgent debates on alternative heating. There was societal opposition to nuclear.
- With the 1979 oil crisis, the government introduced policies to increase district heating and drive a fuel shift away from oil to coal, natural gas, waste and biofuels.
- Regulatory measures included municipality heating plans, mandates and building codes, and financing.
- District heating increased in the 1980s, and energy taxes also decreased the use of oil-based heating.

Antinuclear protest march in 1978 *and the 'Nuclear? No Thanks' icon from the Danish anti-nuclear movement.* .
Source: Johansen & Werner, 2022.

District heating rose and fuel oil declined in Denmark, 1966 - 2000



Source data: Statistics Denmark, 2016.

Case Study 11.

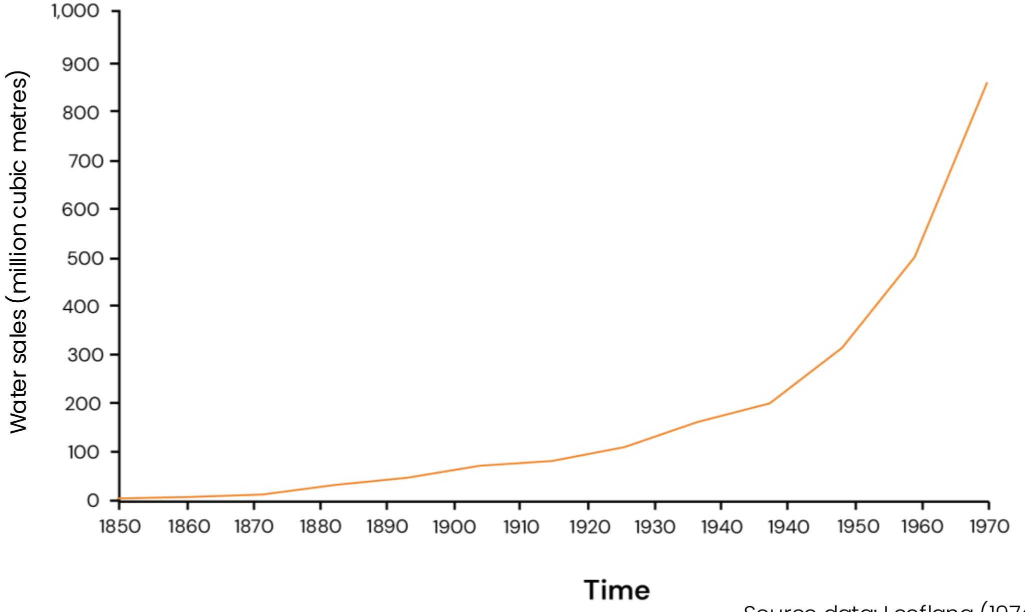
Public campaigns accelerated the shift from wells and rivers to pumped indoor water in the Netherlands

1890 - 1945

- Demands from medics, engineers, wealthy citizens and firms to lower water pollution in cities aligned with policymaker concerns about working class urban living conditions.
- City authorities supported public health initiatives to promote hygiene and the easy use of modern piped water. They joined up with health campaigns, organised by doctors and civil society.
- City authorities provided subsidies to water companies to reduce the cost of building new infrastructure.
- Modern waterworks rapidly expanded, though reaching rural areas remained challenging.

Advertisement from the Limburg water company in 1930 (left & middle), and leaflets advocating hygienic practices in the battle against tuberculosis (right). Source: Wijmer, 1992.

Water sales by modern water companies increased in the Netherlands, 1850 - 1970



Source data: Leeflang (1974).

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Case Study 12 .

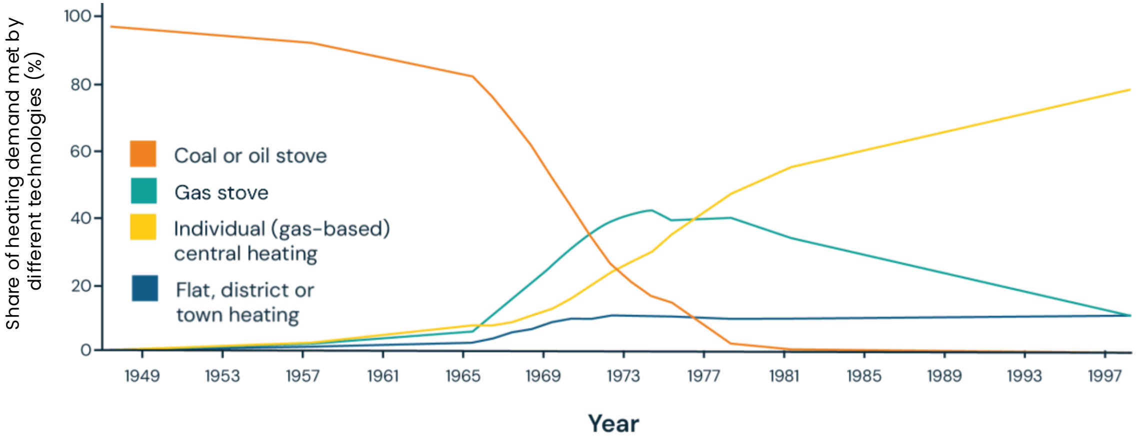
Infrastructure investment, new institutions, campaigns and compensation drove uptake of gas for heating in the Netherlands

1960 - 1980

- The government debated how to use gas more widely after an easy-to-exploit natural gas field was discovered. The government chose heating to maximise revenue.
- Government policies included:
  - **Construction of a national gas transmission network** and local distribution networks, including repurposing
  - **New institutions** for pricing, construction and transmission
  - A state-led and financed **public campaign** to change appliances from coal to natural gas
  - **Compensation to negatively affected people** and businesses in coal mining.
- These combined efforts drove a rapid transition from coal to natural gas in Dutch heating.

Sponsored conversion of kitchen appliances to natural gas.
Source: The Hague, 1964.

The shift from coal to gas in heating in the Netherlands, 1947 - 1998



Source data: Van Overbeeke (2001).

Case Study 13.

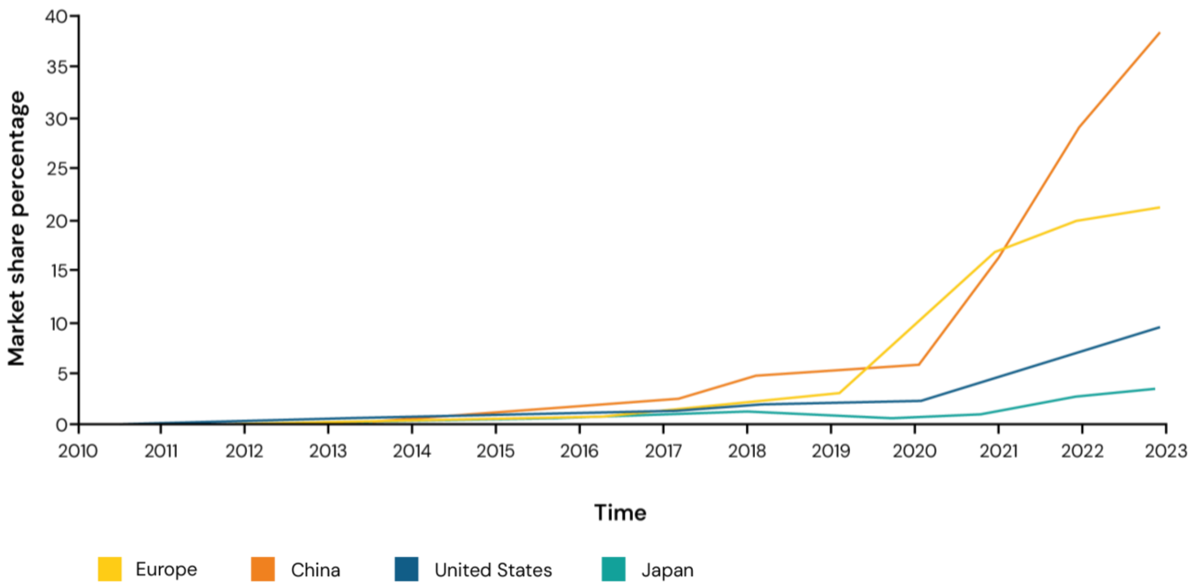
Subsidies, infrastructure investment and regulations accelerated China's road transport transition

2000s - present

- High air pollution, oil imports and industrial opportunity motivated the government to support R&D in zero emission cars from 2006. EVs looked promising.
- Demand-side subsidies, charging infrastructure investment and supply-side regulation increased EV demand and supply.
- The government introduced the 'dual credit' regulation in2018 (a hybrid between zero emission vehicle mandate and efficiency regulation, applying to imports and domestic production). Manufacturers could meet regulation targets by selling EVs, and high efficiency petrol cars.
- The dual-credit regulation forced manufacturers to reallocate investment and increase EV sales. After it was introduced in 2018, the EV share of car sales grew from around 5% in 2019, over 20% in 2022, and 33% in 2023.

Electric vehicle manufacturing plant. Source: Unsplash.

China leads the way on annual BEV sales share of market (%)



Source data: IEA (2024).

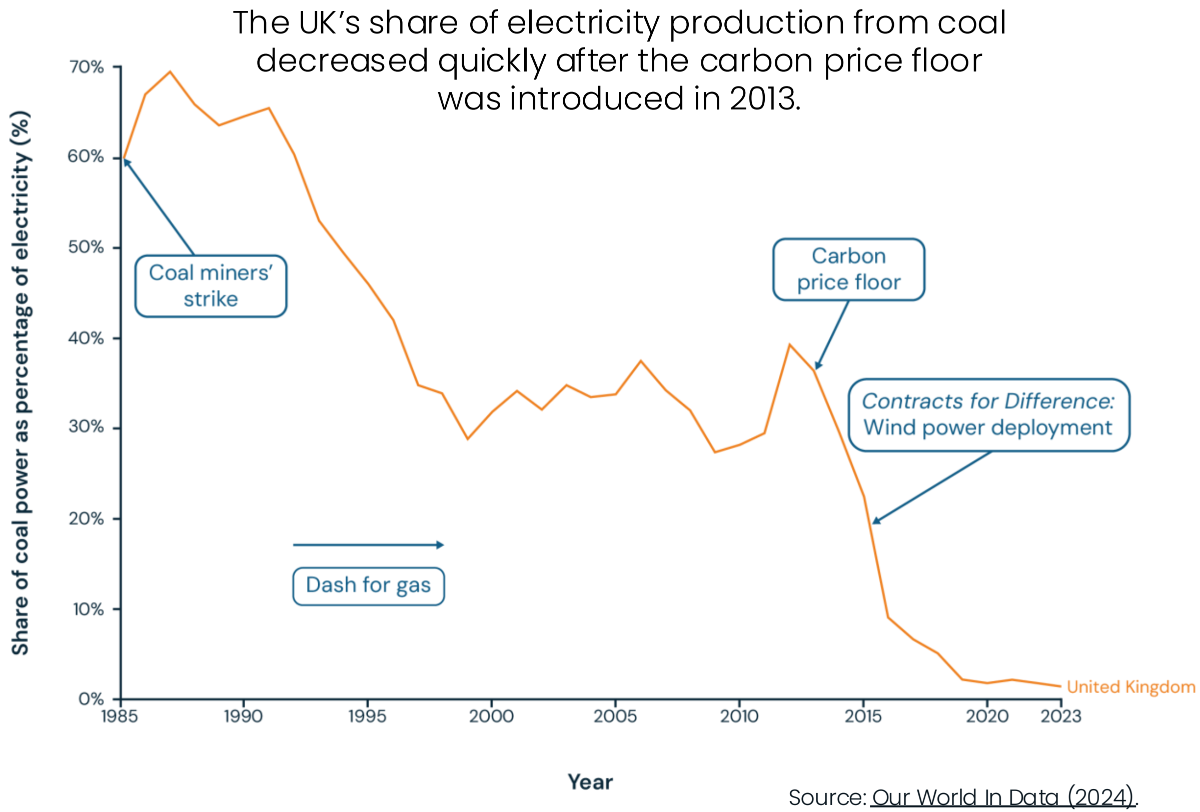
Case Study 14 .

A carbon floor price in the UK made gas cheaper than coal, accelerating UK coal phase-out

2000s - present

- In the 2010s, the economics of coal power had weakened, gas prices had decreased, and the government was pursuing decarbonisation.
- A carbon price floor was introduced (£9/tCO_2 in2013, rising to £18/tCO_2 in 2015). It made coal more expensive than gas.
- Coal generators were pushed out of the market. This accelerated as more zero marginal cost wind power came online (helped by contracts for difference), and electricity demand decreased.
- These factors meant fewer hours in which all energy sources were required, including the most expensive which were drawn on as a last resort.
- The UK electricity system's carbon intensity decreased by 9% per year during the 2010s. This was two times faster than any other industrialised country, and eight times faster than the global average in the 2010s.

Ratcliffe-on-Soar Power Station near Nottingham, whilst operating. It was the last coal fired power station in the UK, and closed in 2024. Source: Unsplash.



Source: Our World In Data (2024).

Reconfiguration

Pursue market saturation of the new technology, and phase out the old

Transition complete: new tech makes up all stocks
Indicative market share: 50-100%

Policy challenges

Completing diffusion of the new technologies

Social and geographical challenges arise to reach 100% market share (e.g. infrastructure expansion to remote locations is expensive / market design challenges to secure electricity supply with no fossil backup).

Winding down the old with minimum disruption

Feedbacks can drive rapid decline of the old technology, and this risks unstable supply. Early asset retirement imposes losses on industry or costs on consumers or taxpayers.

Managing the social, political and economic risks of decline

Risk of unemployment, social opposition to the transition and regional deprivation.

Policy solutions

Complete system adaptation: Infrastructure extension & adaptation, market & tax reforms

Stop old systems from preventing complete saturation of new technology, or overcome constraints affecting new systems.

Carbon pricing & regulations to limit and end sale of fossil fuel products

Change relative costs of technology options, and force phase out old technology.

Support for affected workers, commmunities and regions

Prevent negative socio-economic impacts of transition and lessen social opposition.

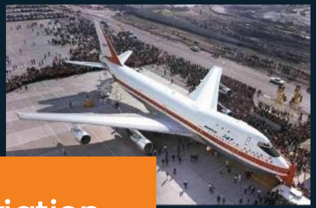
Example: clean power

Renewables have become the default source of new power capacity, accounting for 93% total capacity expansion. New wind and solar already undercut new coal and gas plants on generation cost in most countries.




- **Transforming the system to complete the diffusion of clean power tech**: eliminating final power sector emissions requires long-duration energy storage, peaking plants using hydrogen or gas with CCS and / or new technologies to regulate frequency, which may need new market structures and investment.
- **Phasing out coal and gas with minimum disruption**: if coal or gas plants become unprofitable faster than expected, and close, security of supply could be at risk. Capacity markets or strategic reserves may be needed. Countries with relatively new plants are also managing the costs of early plant retirement.
- **Adapting to the decline of coal power, managing social and political risks**: countries with coal mining industries face significant socio-economic risks from the transition.

Reconfiguration case studies



Long-haul aviation
In the US
(1945-1980)

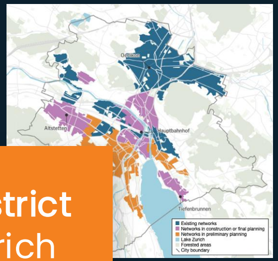
A new regulatory agency and noise regulations supported growth of civil aviation

Coal phase-out
In Germany
(2000-present)

A multi-stakeholder commission recommended policies for a just coal phase-out, improving societal acceptance and ensuring support for affected communities

Horse-and-carriage to automobiles
in the US
(1900-1992)

Public investments created an interstate highway system



District-by-district heating in Zurich
(2023-present)

The heating transition is enabled by a ban on new fossil fuel heating, subsidies for renewable heating installation, and by coupling an end to gas delivery with neighbourhood-by-neighbourhood district heating expansion, and a public information platform

Case Study 15.

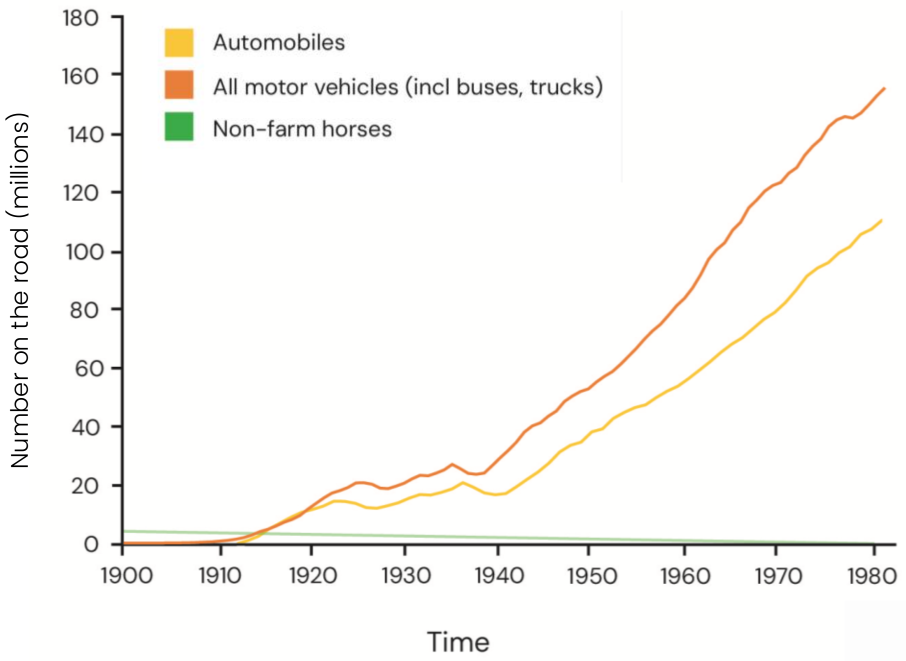
The US Government built motorways to finalise transition from horse-and-carriages to automobiles (USA)

1900 - 1992

- From the 1900s, cars became increasingly popular. By the mid 1940s, they were popular among working class families and created a new car culture, including commuting between suburban homes and down-town jobs, car holidays and motels, and drive-in entertainment. The car industry became a critical economic sector linked to the petrol, steel and construction industries.
- The US government invested in large-scale road infrastructure to connect cities. It increased federal funding of motorways to 60% in 1944, and 90% in 1956 to deliver an interstate motorway system.
- This vast infrastructure system was completed in 1992, costing $521bn in today's prices.

New holiday practices in the 1950s. Source: The History Lounge (2023).

Motor vehicles on the road increased from zero to 100 million in 60 years, in America



Source data: Nakićenović (1986) and Federal Highway Administration (2010).

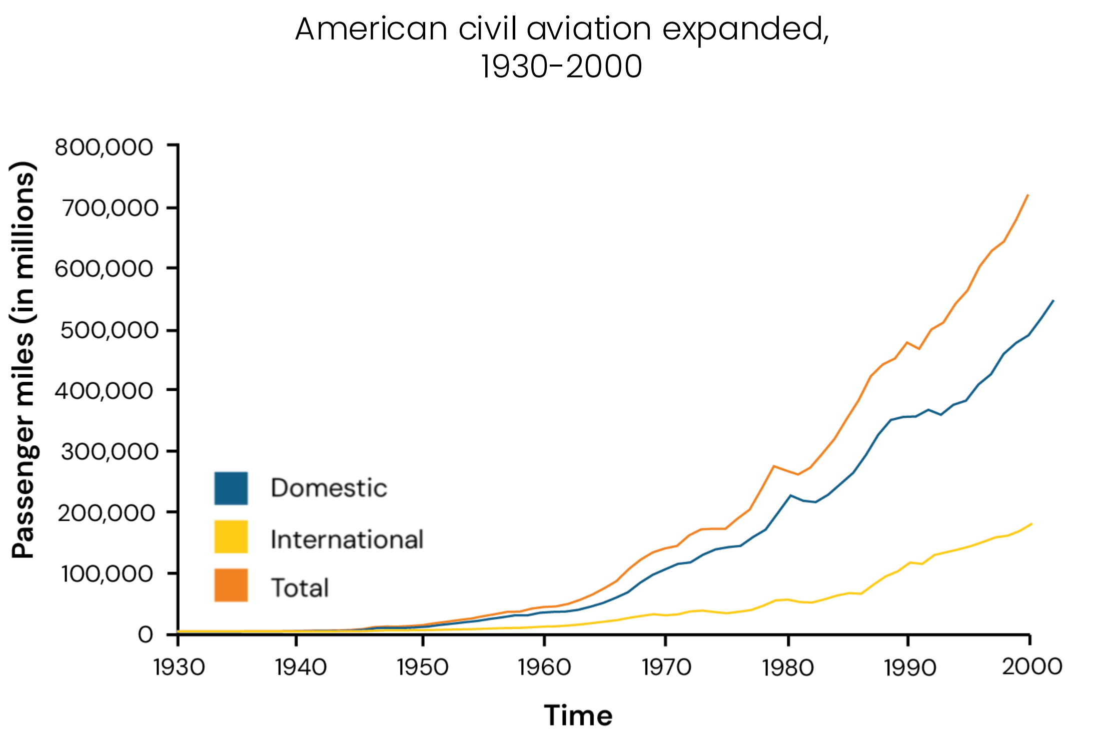
Case Study 16.

The US improved governance and regulations to enable long-haul aviation

1945 - 1980

- Aircraft using jet engines were becoming popular as they enabled longer, smoother distances. But they were noisy, crashed, raising safety concerns.
- In 1958, the US government created a new regulatory agency to update traffic control systems to prevent collisions.
- It also introduced noise regulations for airports and aircraft.
- Airports introduced sound barriers, and manufacturers reduced plane noise levels.
- Civil aviation significantly increased, though there were still some issues with social acceptance.

The Boeing 707 (1958) and Boeing 747 (1969) jetliners. Sources: Geels (2002).



Source data: American Air Transport Association.

Case Study 17.

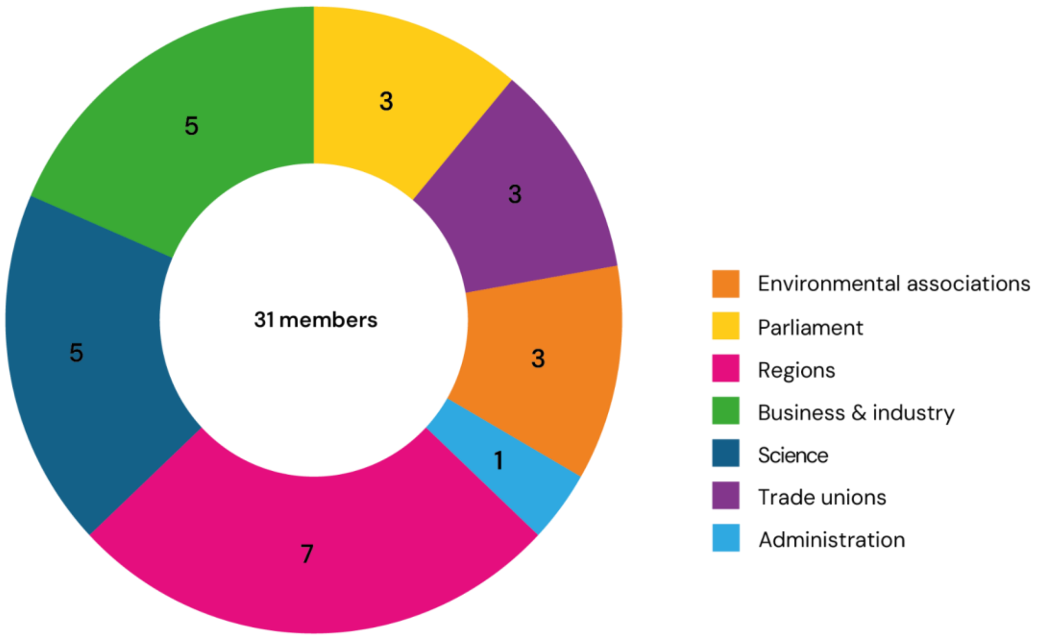
Germany's Coal Commission is increasing societal acceptance of coal phase-out

2000 - present


Opencast lignite mining at Hambach, Germany. Source: Chris Munch on Unsplash.

- The German government wanted to meet climate targets, but 20,000 people worked in lignite coal, and the industry provided up to 70% local value creation in some regions.
- In 2018, a multi-stakeholder commission was created to explore a just phase out. Its recommendations, including coal phase-out by 2038, gained broad social acceptance and were largely legislated. It included compensation for industry, and €40bn investments in regional economies over 20 years.
- This consultative approach has inspired approaches in Poland, Czechia and beyond, though it is too early to tell whether economic diversification efforts will succeed.

Germany's multi-stakeholder coal commission included representatives of diverse interests



Source: Agora Energiewende und Aurora Energy Research (2019).

s-curve economics

Case Study 18.

Zurich is replacing gas heating with heat pumps district-by-district, to avoid high costs of gas delivery for few customers

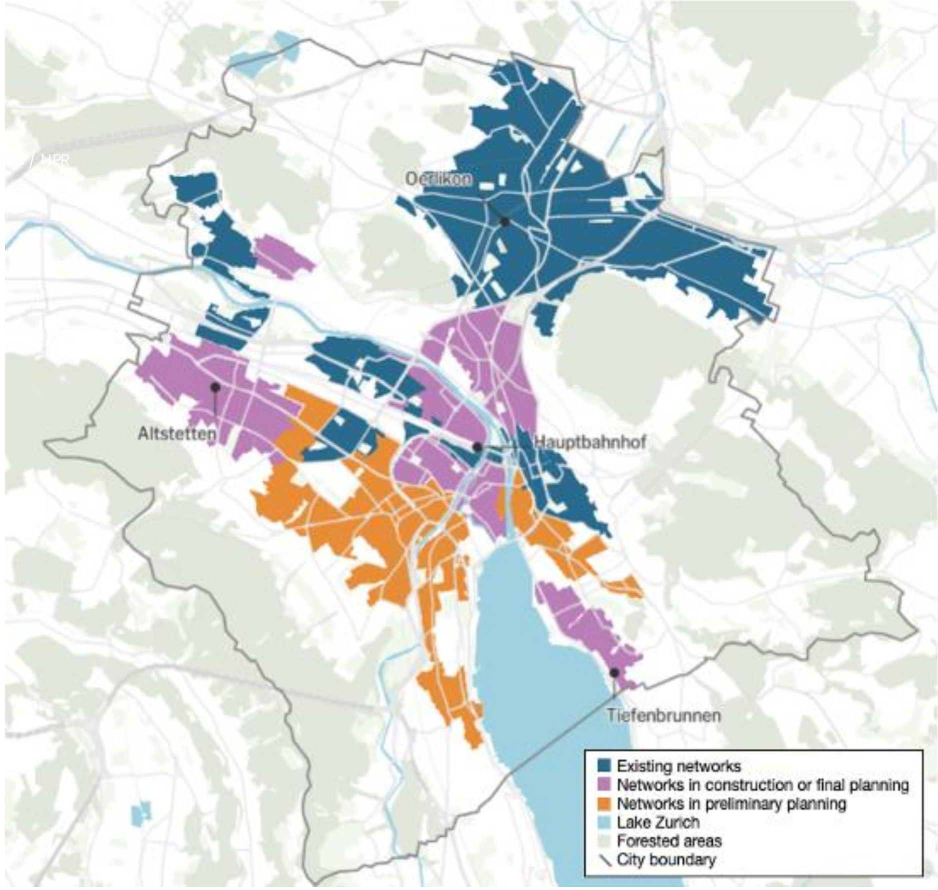
2023 - present

- In 2023, heat pumps were popular for new buildings and old building heating replacements, because of a carbon tax on heating. Faster progress was needed: building heating was still 50% of Zurich's emissions, heating systems have long life spans, and the city has a 2040 net zero target.

- The city's policy approach since 2023 includes:
  - A **ban** on new fossil fuel heating systems
  - **District heating expansion** financed by municipal bonds
  - **Subsidies** for renewable heating installation
  - A **plan to end gas delivery neighbourhood-by-neighbourhood, coupled with the expansion of district heating**
  - A **public information** platform.

- It aims to keep social acceptance high and avoid high costs of gas infrastructure being operated for a few, disparate customers. Plans are on track.

A map of Zurich, with locations for the district heating networks which exist, or are under construction or in planning



Source: City of Zurich (2022).

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We can use the pattern from history to accelerate towards the future

The transitions towards solar and wind in the power sector, and towards electric vehicles in the road transport sector, show that the patterns of historical technology transitions can be repeated in the zero-carbon transition. In both sectors, leading countries have adopted policies that map closely to the framework described in this report. Their results have exceeded expectations, thanks to the positive feedbacks that amplified their effects. The opportunity now is to take the learning from these sectors, from international experience and from history, and to use this knowledge to accelerate progress elsewhere.

First build, then break

Governments must make sure that new technologies are widely available, affordable, and attractive in each sector. This is the fastest way to enable the phase-out of the old. Efforts to phase out old technologies before new ones are established will be politically and economically costly, and risk using vast resources for little positive effect. Policymakers must focus first on invention, early deployment, infrastructure construction, and cost reduction of the new technologies.

Match policy to the stage of transition

Just as the problems faced differ at each stage of the transition, so do the policies that are likely to work. This framework enables policymakers to identify where a sector stands, and to quickly shortlist policies that might be needed. It can also be used to anticipate upcoming challenges, and to identify policies likely to be needed in the near and long-term future, as the transition of any given sector progresses.

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About S-Curve Economics

S-Curve Economics CIC is a non-profit research organisation focused on advancing the understanding of the economics and diplomacy of the energy transition. Our analysis focuses on the power, road transport, and steel sectors, and cross-cutting issues of economics, policy appraisal, and diplomacy. We are based in London. Find out more at www.scurveeconomics.org.

Sources

The text and figures from this pack summarise the report, *First build, then break: a policy framework for accelerating zero-carbon transitions*. The full text and references can be found at www.scurveeconomics.org/publications/first-build-then-break/.

Acknowledgements

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