

First build, then break. A policy framework for accelerating zero-carbon transitions

2025

Executive summary

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About this report

‘First build, then break: a policy framework for accelerating zero-carbon transitions’ builds on a previous report ‘Analytical tools for innovation and competitiveness in the low carbon transition’, which outlined key policy questions facing ministries of finance in addressing decarbonisation, low-carbon growth, and competitiveness. It proposed a set of conceptual frameworks, decision-making frameworks, and analytical tools that can support policymakers to navigate low-carbon transitions, working with structural change, path-dependency, and uncertainty.

This report brings an empirical perspective to low-carbon transition policy instruments, packages and sequences. It explains how technology transitions, including low-carbon transitions, occur in four stages: Emergence I: Invention, Emergence II: Market Introduction, Diffusion, and Reconfiguration, and how, because each stage has different aims and challenges, different policies are required. The framework is illustrated by nearly 20 case studies of policy-enabled technological change from history and present-day low-carbon transitions.

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.

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EXECUTIVE SUMMARY

The majority of governments have set goals for their economies to reach net zero emissions. Meeting these goals requires transitions from fossil fuels to zero-emission systems in each greenhouse-gas-emitting sector: power, transport, buildings, industry, and agriculture. Whether the aim is to avoid dangerous climate change or to take advantage of zero-carbon¹ technologies for reasons of cost, quality, or competitiveness, it is useful for governments to know what kinds of policies and strategies are likely to be effective in advancing these transitions. This report provides a guiding framework to inform those choices.

First build, then break

First build the new zero-carbon technology systems, then break the old polluting ones. This is the overarching principle. It is not only a political necessity, but also a practical one. People can only stop using an old technology when a new one is available and affordable. New solutions must be invented, introduced into the market, and scaled up, before old systems can be phased out. Crucially, policies that focus on developing new solutions and constructing new systems benefit from self-amplifying feedback effects, early in the transition.

A transition is not the same as decarbonisation. Emissions can be reduced by policies that make fossil fuel systems operate more efficiently, but can only be eliminated by the development of zero- or near-zero-carbon technologies and systems.

Match the policy to the stage of transition

There are distinct stages in the process of building new technologies, and the infrastructure and social systems they need, and dismantling the old systems. Each stage involves different problems, which different policies can help to address.

- During the **Emergence stage**, policymakers must first support the **Invention** of new solutions by setting out a vision for the future, directing publicly funded research and development (R&D), and connecting key stakeholders. They can then enable the **Market Introduction** of new technologies with policies that simultaneously create demand and support supply, such as public procurement, targeted subsidies for production or consumption, and concessional lending.



- **Diffusion** requires scale-up and cost reduction, which policymakers can support with subsidies and public communications campaigns, financial support for manufacturing and deployment, technology mandates and standards, and support for infrastructure, skills, and trade. Measures to put pressure on the old technology, such as taxes, can begin to play a role here too.
- Finally, the **Reconfiguration** of broader infrastructure, markets, social norms, and governance is achieved through a range of measures. Only at this stage can old technologies be phased out, with bans and taxes on their sale and use.

In sum, there is no single most appropriate policy to drive a transition, but rather a sequence of policies whose importance changes as the transition progresses.

Technology transitions happen both globally and nationally, and the process is largely the same for countries leading and following in global transitions. However, ‘follower’ countries can start at the Market Introduction stage and are typically able to move into the Diffusion stage more quickly by drawing on international experience. Although followers may progress faster, first movers may capture most of the new industry and jobs.

There are examples of effective policies to drive transitions throughout history, and in the present. Technology transitions (more properly described as ‘socio-technical transitions’) have taken place many times in the past, providing opportunities to learn what works. In the examples of transitions from horses to cars, from wells to piped water, from coal to gas, and many more, we can see how government policies have enabled and accelerated progress. Similarly, we can see which policies have been successful in driving transitions from fossil fuels to zero-carbon technologies. This report draws on case studies to illustrate which policies have worked at certain stages, and why.

A framework to identify policies needed now and in future. This report outlines the goals of policy, and common challenges, at each stage of the transition. This can help policymakers to identify which stage a given sector is at, in their country. We then identify the policies typically able to address those challenges, and we explain their rationale. We provide a series of case studies that illustrate how those policies have worked in historical technology transitions and in zero-carbon transitions over the past few years. At each stage, we suggest principles to inform policy design.

This framework can be used by policymakers to quickly identify policies needed now, foresee those likely to be needed in future, and design them effectively. It can also be used to inform strategies for the transition.

¹ The term ‘zero carbon’ is used interchangeably with ‘zero emissions’ throughout the report, and refers to zero or near-zero carbon emissions, or greenhouse gas emissions, arising from the use of a product or production process.



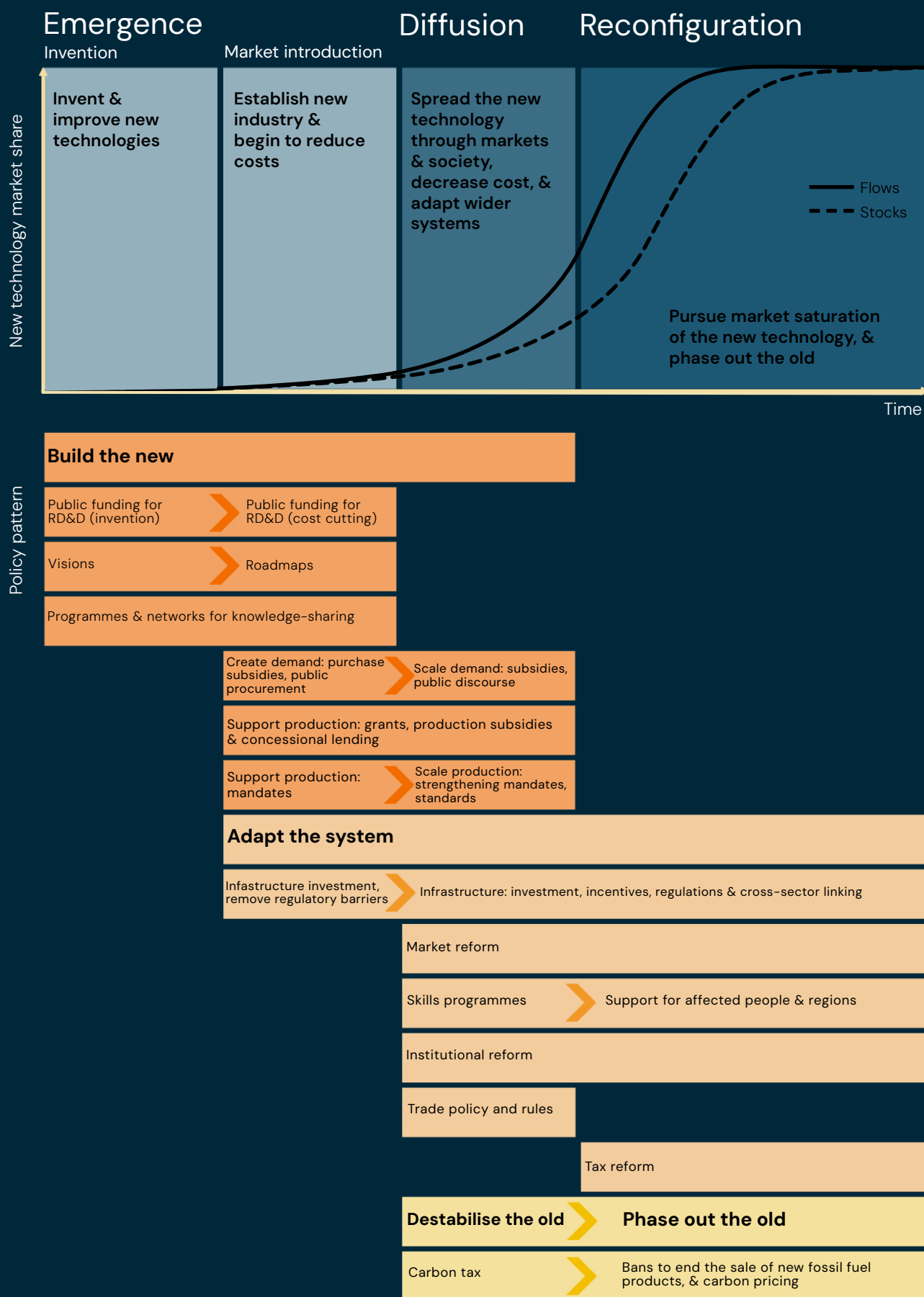


Figure i. The Accelerating Transitions Framework for policy. Note: the figure illustrates the stages of the transition in a given sector, the policy aims at each stage, and the policies likely to be effective at each stage. The market share of the new technology follows an s-curve, first growing slowly, then accelerating, before plateauing as the transition nears completion. The solid s-curve represents flows (sales or investment, such as annual car sales). The dashed s-curve represents stocks (products or assets in use, such as total car fleet). Once flows change, a shift in stocks becomes inevitable, but it has a time lag which is longer in sectors where assets have longer lifetimes. This is a generalised framework: the specifics will differ across sectors and countries. Source: authors.

1. Emergence I: Invention

At the start of the transition, policymakers must support innovators to invent and test new technologies, identify which of these might meet society's needs, and eventually consolidate around one or more viable designs. Their aim is to ensure that zero-carbon innovations which may accelerate decarbonisation are discovered, and that the most promising design options progress from research and development to pilots and demonstration projects. Once the new technologies prove viable at the demonstration stage, they are ready for market introduction.

Problems to solve include the reality that nurturing the invention of viable solutions is fundamentally difficult, time-consuming, and involves failure. The high uncertainty in this process can undermine private sector involvement, and isolation of innovators from industry, policymakers, and other researchers can slow progress.

Policies

- **Public funding for research, development and demonstration (RD&D)** can help innovators to develop technically viable, high-performance, and low-cost zero-carbon solutions. This reduces private sector reluctance to invest in high-risk solutions.
- **Policy objectives** clarify desired technology capabilities, characteristics, or outcomes, and help to align innovators and financiers around specific goals.
- **Knowledge-sharing programmes and network-building** enable innovators to exchange information, collaborate on solutions and connect to industry, investors, and policymakers, potentially enabling co-design, commercialisation, and supportive policy.

Case studies from the UK, Germany, Austria and Sweden, from the aviation, heating, power, and steel sectors, illustrate how these policies have been used effectively during this stage of the transition.

The stage ends when one or more technology options for the sector have been invented, and their designs have been tested, validated, and stabilised sufficiently to be introduced into a commercial market setting.

Principles for policymaking during the Invention stage

Principle	Explanation
Additionality in the global context	No country can or must invent every clean technology itself; it can import or adapt innovations while focusing its own invention efforts on sectors where it has strong potential to succeed.
Stable commitment	A clear vision for the future direction of technological development will only galvanise innovators and reassure investors if underpinned by stable political commitment, even as specific policy instruments evolve.
Adaptive portfolio approach	When technological uncertainty is high, supporting diverse options, evaluating progress, and adjusting support can help to avoid premature commitment to certain technologies or designs.

2. Emergence II: Market Introduction

At this stage, the goal for policymakers is to help companies to **introduce the new technologies into the market for the first time**, despite high costs and uncertainties. The aims are to achieve the first deployment of new technologies, establish new industries (which may be new to the country or new to the world, if the country is leading), and create early market demand. At this stage, the new technology remains immature and is unlikely to be able to compete successfully against incumbents. Demand-creating and supply-enabling policies can kickstart positive feedback effects such as economies of scale and learning-by-doing, which drive cost reductions and increase uptake. Small differences in the uptake of different technologies can be quickly amplified, leading some options to succeed and others to fail. Through this process, it becomes clear which of the technology options may be viable to deploy at a scale that could meet the demand of the whole sector.

Problems to solve include high costs and performance-related issues of the new technologies. New technologies are typically more expensive than existing technologies and would not survive competition without support. There is still uncertainty about which technologies and designs will have most potential and should be scaled up. This uncertainty can cause a lack of investment, and high financing costs. Regulatory barriers or lack of infrastructure can also prevent first deployment in a market context.

Policies

- **Creating demand: purchase subsidies and public procurement.** Purchase subsidies improve the new technology's affordability and attractiveness to consumers, creating demand and enabling introduction into the market.² Subsidies can be funded through taxes on the sale of fossil fuel products.³ (These have a different purpose from the carbon taxes used during Diffusion and Reconfiguration, which aim to disincentivise the use of polluting technologies – an aim that can be realised once alternatives are available.) Demand can also be created by public procurement: a government's purchasing power is often large enough to create a meaningful market niche.
- **Supporting production: grants, subsidies, concessional lending and mandates.** Grants or subsidies decrease upfront costs and risks of early production. Concessional lending similarly can reduce the cost of capital and catalyse business investment. Mandates can force an initial investment into new technologies.
- **Adapting the wider system: initial infrastructure investment and removing regulatory barriers.** For some technologies, new infrastructure or regulatory change may be needed for a technology to reach the market at all. The government can invest directly or incentivise the private sector to invest in infrastructure (with the most appropriate choice depending on the sector), and can adapt regulation to make new technologies legal and viable.

Case studies from France, India, Uruguay, the UK, and the US, from the public transport, power, aviation, and food sectors, show how these policies have been used effectively.

This stage ends when it is clear which of the technologies introduced to the market are most likely to diffuse at scale and have the potential to compete with the incumbents in the mainstream market. This is likely to be due to those technologies' cost reduction or potential for it, or their better performance than other options.

² The distributional effects of technology-specific subsidies depend on the sector and on policy design. The first beneficiaries are sometimes wealthy consumers, who can afford to buy more expensive products. This increases deployment, brings the technology down the learning curve, and helps the technology to become more affordable for all consumers. Alternatively, subsidies can be designed to exclude high-income earners, or to target low-income households or low-cost segments of a market. In other sectors, subsidies for production using the new technologies may have no direct distributional effects.

³ These are different from carbon taxes in practice and intent, because the tax level is set based on the revenue needed and is not proportionate to emissions.

Principles for policymaking during the Market Introduction stage

Principle	Explanation
Focus on zero-carbon technologies	Support the early deployment and improvement of zero-carbon technologies that have the long-term potential to eliminate emissions from the sector, rather than supporting lower-carbon technologies, even if the latter achieve emission reductions at lower cost.
Back winning technologies	Early-stage technologies are likely to face a disadvantage compared with more mature technologies. Policies can be tailored to support more than one viable option, with the strongest support given to those that emerge as most successful and suited to the long-term needs of the sector.
Match supply push with demand pull	Producers and consumers often wait for each other to move to the new technology, preventing momentum. Governments can simultaneously stimulate supply and demand to overcome this problem.



3. Diffusion

The goal at this stage is to spread the new technology rapidly through markets and society. This can be helped by crossing thresholds where the new technology begins to outperform the old in cost, performance, profitability, or desirability, making it the 'common-sense' choice for a growing share of producers and consumers. Positive feedbacks of learning-by-doing and economies of scale – where the more the technology is deployed, the more it improves and the less it costs – can drive rapid progress.

Problems to solve still include cost reduction, and improving attractiveness of the zero-carbon technology to consumers who make up the majority of the market. Widespread deployment requires industry to reallocate investment from the old to the new technology. In addition, infrastructure, market, regulatory, and other systems must be transformed at scale, so they no longer favour incumbent technologies and are adapted to the new. There can be competitiveness challenges in trade-exposed sectors, and fierce resistance from incumbents.

Policies

- **Scale up demand: subsidies and positive public discourse.** Deployment subsidies are often still important to enable new technologies to compete against incumbents, though policymakers can taper them as costs fall. Subsidies can be complemented with taxes on the old technologies, to maintain revenue neutrality, or to further shift the cost advantage towards the new technologies, or to signal the start of a transition away from incumbent industries. Public communications campaigns can advertise the benefits of zero-carbon technologies, and the policy support available to consumers.
- **Scale up supply and reallocate investment: mandates and standards.** Mandates that require a rising proportion of sales or production to have a given characteristic (such as zero emissions) can at this stage reallocate private sector investment from the old to the new technologies on a large scale, increasing economies of scale and accelerating cost reduction. Performance standards, when sufficiently stringent, can also incentivise or force a switch to the new technologies. These policy tools both support the growth of the new technologies and begin to disincentivise and destabilise the old technologies and systems.
- **Adapt the system: infrastructure, markets, skills, institutions and trade.** As the new technology grows, it will start causing friction within the existing system. Market reforms can rewire existing markets built for and favouring incumbent technologies. Skills programmes, funding, incentives and partnerships can help to develop needed capabilities. Infrastructure investment at scale may be necessary. New institutions can be created to govern markets that did not previously exist. In trade-exposed sectors where the new technologies are higher cost, international agreements on standards, tariffs, or taxes can enable the new technologies to be produced, sold, and adopted more effectively across borders.

Case studies from the heating, water, power, and passenger transport sectors in Denmark, the Netherlands, China, and the UK show effective use of these policies at this stage.

This stage ends after critical thresholds in the attractiveness of the new technologies to consumers or its profitability to producers have been crossed, and the new technology accounts for the majority of sales or new investments.

Principles for policymaking during the Diffusion stage

Principle	Explanation
Focus on positive feedbacks	Policies that grow the new technologies' market share can drive investment, innovation, cost reduction, and demand, changing the political economy and expanding future policy options. The priority is to support the growth of new industries first, enabling the decline of the old industries later.
Target tipping points	Target policies to make zero-carbon technologies lower cost and more attractive than fossil fuel technologies. This makes zero-carbon technologies the default choice for producers and consumers and locks in rapid, long-term change.
Remove barriers	Removing regulatory, administrative and societal barriers is critical to enable the rapid diffusion of zero-carbon technologies.



4: Reconfiguration

The aims for policymakers at this stage are to enable the new technology to reach a full share of the market, to phase out the old technology with a minimum of disruption, and to adapt the rest of the system. There are three different but related processes. First, the new technology must reach market saturation in new inputs into the system, such as electric vehicles (EVs) as a percentage of new car sales (this is the solid line in Figure i and represents ‘flows’); then it must reach saturation across the whole system, such as EVs as the percentage of all cars on the road (this is the dashed line in Figure i and represents ‘stocks’). The second process is that the old technology and its infrastructure must be wound down and retired. Third, the wider social and economic system must be adapted, to avoid problems arising either from the final stage of growth of the new technology or from the wind-down of the old.

Problems to solve include difficulties associated with completing the diffusion of the new technology to the last market segments or geographical areas. Winding down the old technology must be attempted without disrupting services to users. The significant political, social, and economic risks of this stage must be carefully managed to prevent backlash against the transition, or long-term adverse social and economic consequences.

Policies

- **Complete system adaptation: infrastructure extension and adaptation with public investment and regulation, market reforms, and tax reforms.** The new infrastructure must be extended to cover all users and uses, which may involve regulation requiring coverage in remote locations. Deeper market reforms can support the deployment of complementary technologies that support the functioning of systems built around the new ‘core’ technologies; for example, energy storage and flexible grid technologies will be important to power systems dominated by solar and wind. Tax reforms need to replace decreasing revenues from taxes on the old technology with new sources.
- **Carbon prices and regulations to limit and end the sale of fossil fuel products.** In the zero-carbon transition, carbon pricing can change the relative costs of technology options, pushing the most carbon-intensive technologies and assets out of the market first, but only when alternatives are in place to take over. In any transition, regulations (explicit bans on the old technology, or mandates requiring the new technologies to reach 100% of sales) are likely to be the most effective way to phase out the old technology, since banning a product or technology is stronger than merely disincentivising it.
- **Support for affected workers, communities and regions.** Regional development programmes to support workers, communities, and regions that stand to lose from the decline of the old industries may be desirable for many reasons, and may help to avoid strong social opposition to the transition. This may need to start during the Diffusion stage, but it becomes even more critical in Reconfiguration. (During the Invention and Market Introduction stages, most workers, communities, and regions are unlikely to be strongly affected by the transition.).

Case studies from the road transport, aviation, power, and heating sectors in the US, Germany, and Switzerland show the effective use of these policies at this stage.

Principles for policymaking during the Reconfiguration stage

Principle	Explanation
Create positive cross-sector links	Linking transitions across sectors at this stage can enable progress and overcome challenges. Positive cross-sector interdependencies can be created through sharing infrastructure, sharing technologies, and aligning standards and market designs.
Integrate the transition into broader strategies	To help policies for the transition and policies with other objectives to reinforce rather than undermine one another, coordination across government can integrate policies for the transition into skills, industrial, infrastructure, housing, development, trade, national security, and other strategies.
Deal deliberately with distributional issues	Effective policy must be politically embedded, not just economically rational. It may require institutional reform, broad-based coalitions, and combining technical policy with legitimacy-building measures.

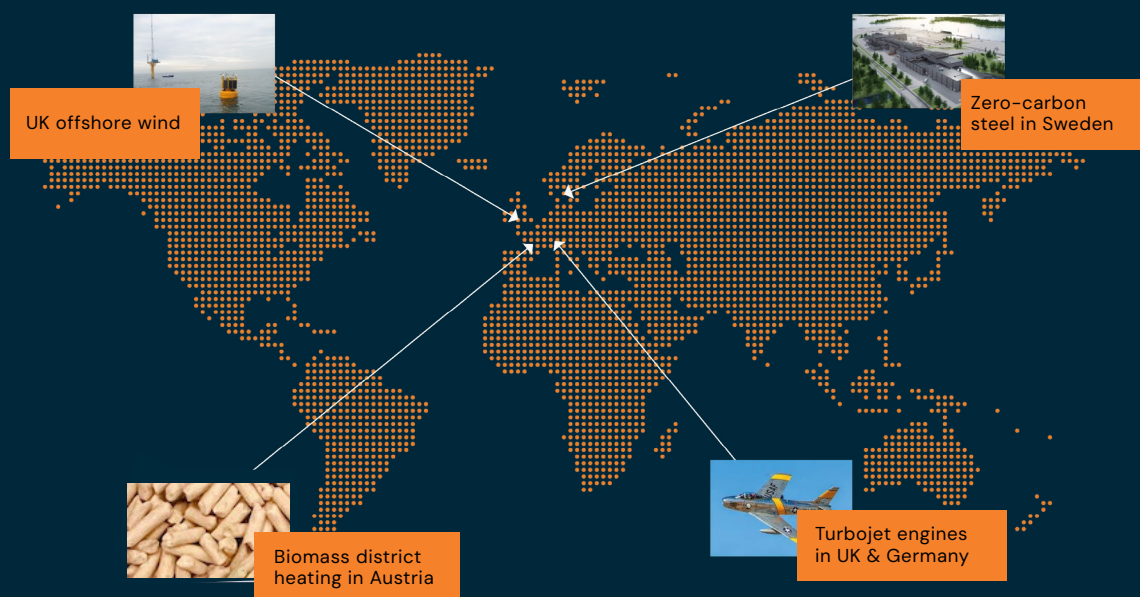


The case studies

The case studies include examples of historical technology system transitions, as well as recent and current examples of transitions to zero- or near-zero-carbon technologies. They cross time-periods, countries, and sectors. While each is unique, together they illustrate the pattern in the process of transitions and the policies that typically contribute to progress at each stage.

Key: **C:** Context and challenge. **P:** Policy solution. **R:** Result. **I:** Longer-term impact.





Invention case studies

1. Turbojet engines in UK & Germany (1930–45)

- C.** Turbojet innovators struggled for investment
- P.** Publicly funded RD&D (military interest)
- R.** Successful demonstrations drove public and private sector investment
- I.** Faster planes (up to 8x thrust of early demonstrations)

2. Biomass district heating (BMDH) in Austria (1970–2013)

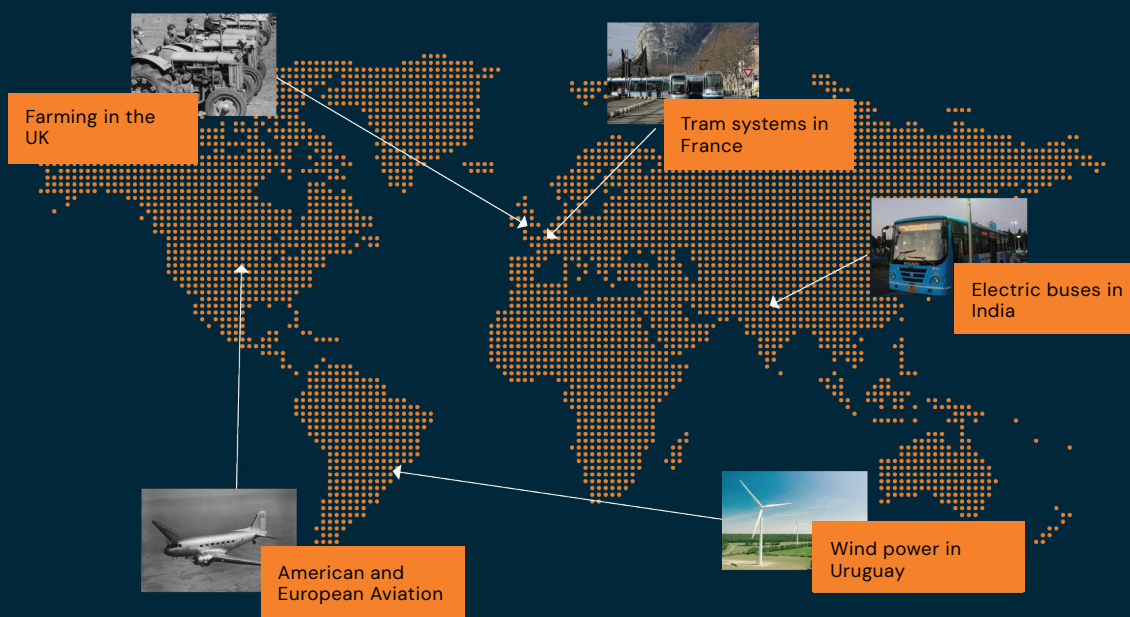
- C.** Rural innovators were isolated
- P.** Network building and knowledge sharing in 1980s by public energy agencies
- R.** Systems improved and costs reduced
- I.** Laid foundations for Austrian exporter industry of pellet boilers

3. Offshore wind in the UK (2008 to present)

- C.** Offshore wind expensive and untested
- P.** Public–private innovation accelerator was created
- R.** 150 joint R&D projects cut costs by 15% in 10 years
- I.** Accelerator was expanded and replicated internationally

4. Zero-carbon steel in Sweden (2015 to present)

- C.** History of steel innovation, cheap renewables to produce hydrogen
- P.** Government commitment to zero-carbon steel, joint venture and public finance
- R.** Successful and evolving demonstration project(s)
- I.** Other countries followed, and global transition beginning



Market Introduction case studies

5. Tram systems in France (1970–2000)

- C.** Urban congestion and accidents
- P.** Public procurement
- R.** First tram systems were replicated to 15 of 19 major French cities
- I.** From late 1990s, declining car use in many French cities

6. Electric buses in India (2015–2024)

- C.** Air pollution, oil imports, insufficient public transport
- P.** Public procurement – aggregated bus purchasing
- R.** Higher electric bus deployment at lower costs
- I.** Policy being replicated internationally

7. Wind power in Uruguay (2005–2016)

- C.** Energy insecurity and drought undermining hydropower
- P.** Reverse auctions for large-scale capacity, feed-in tariffs for small-scale
- R.** Fastest-growing wind share of all countries globally 2014–2016
- I.** Improved power system stability and increased export revenue

8. American and European aviation (1890–1930)

- C.** Post-war airline companies failing to create commercial niche
- P.** Grants and subsidies to create postal niche
- R.** Demand spurred manufacturer investment
- I.** Dominant design for commercial aviation popular by 1930s

9. From mixed to specialised wheat farming in the UK (1930–1970)

- C.** Bread/food insecurity due to war
- P.** Guaranteed prices to farmers, grants and cheap loans, knowledge sharing
- R.** Tractor and machinery diffusion, more land used for food
- I.** Long-term transition to mass-production systems



Diffusion case studies

10. From oil to district heating in Denmark (1950–1980)

- C.** 1973 oil crisis and debate on alternative heating
- P.** Plans, mandates and building codes for district heating
- R.** Diffusion of district heating in 1980s
- I.** Complementary policies and financing further lowered costs

11. From wells to pumped indoor water in the Netherlands (1870–1945)

- C.** Concerns about working-class living conditions
- P.** Public health campaigns on hygiene, and subsidies to water companies
- R.** Improved modern waterworks but challenges expanding to rural areas

12. From coal to natural gas in Dutch heating (1960–1980)

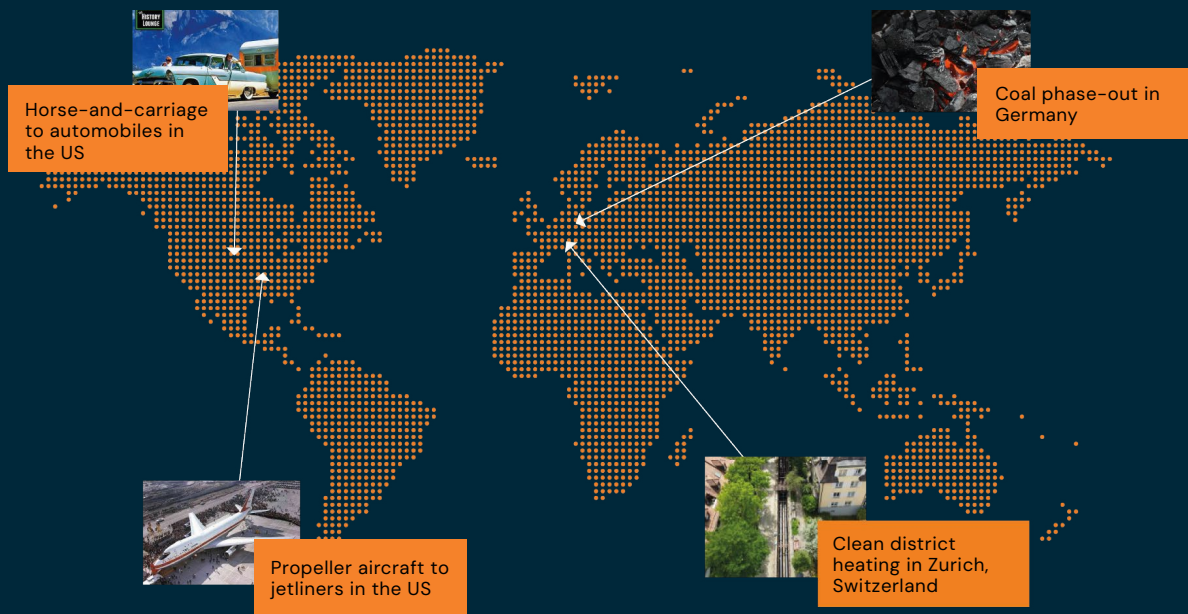
- C.** Discovery of easy-to-exploit natural gas field
- P.** New institutions for pricing, construction and transmission; campaign to change appliances; compensation to negatively affected people and businesses
- R.** Rapid transition from coal to natural gas in heating

13. Road transport shift to EVs in China (early 2000s to 2024)

- C.** High air pollution, high oil imports, R&D into zero-emission cars
- P.** Demand-side subsidies, charging infrastructure investment, supply-side regulation
- R.** Rapid EV sales growth especially after regulation introduced
- I.** China became largest car exporter in the world, made EVs cheap

14. Coal phase-out in the UK (2000s to present)

- C.** Weakened economics of coal, decreasing gas prices, climate concerns
- P.** Small carbon price floor on coal finance
- R.** Coal power made generally more expensive than gas
- I.** Coal rapidly pushed out of market



Reconfiguration case studies

15. Horse-and-carriages to automobiles in the US (1900–1992)

- C.** Increasing car popularity
- P.** Infrastructure subsidies and investments, particularly roads
- R.** Huge infrastructure system completed in 1992

16. From propeller aircraft to jetliners, US (1945–1980)

- C.** Expansion of air travel created safety and noise issues
- P.** New regulatory agency, long-range radar to improve safety, noise regulations
- R.** Ongoing social acceptance challenges for airport expansion
- I.** Funds beginning to be allocated

17. Coal phase-out in Germany (2019 to present day)

- C.** Aim to phase out coal
- P.** Coal Commission, recommended 2038 phase-out and funding for those affected
- R.** Recommendations adopted and widely accepted; coal plants being closed

18. Heat reconfiguration in Zurich, Switzerland (2023 to present)

- C.** 2040 net zero target, 50% of the city's emissions from heating buildings
- P.** Ban on new fossil fuel heating systems, district heating expansion, subsidies for renewable heating, coupled plan to end gas delivery and expand district heating, public information finance
- R.** Plans are on track, no visible opposition





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